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Soil Enzyme Activities and Yield of Elephant Foot Yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] as Influenced by Weed Management Practices in Alfisols

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Abstract

A field experiment was conducted during 2015-16 at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India, to study the effect of various weed management practices on soil quality, microbial activities, and yield performance of elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] in an Alfisol. The results revealed that weed control ground cover resulted in lower weed biomass and greater weed control efficiency. Significantly higher corm yield was obtained with weed control ground cover treatment (37.4 t ha^{-1}),with an increase of 335% over control, followed by four manual weedings at 30, 60, 90 and 120 days after planting (DAP) (33.7 t ha^{-1}) and two manual weedings at 30 and 60 DAP along with post-emergence application of glyphosate at 90 DAP (32.9 t ha^{-1}). Use of weed control ground cover resulted in higher post-harvest soil available N, P, K, Fe, Cu, Mn and Zn, microbial population (fungi, bacteria and actinomycetes) and soil enzyme (dehydrogenase, fluorescein diacetate, acid and alkaline phosphatase) activities. Two manual weedings at 30 and 60 DAP along with application of glyphosate at 90 DAP resulted in higher soil organic carbon.

Key words: Elephant foot yam, weed management, yield, soil microbial activities

Introduction

Elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] is an edible tuber crop grown in tropical and subtropical regions, particularly in South-east Asia. It is commercially cultivated in India, Sri Lanka, China, Malaysia, Thailand, Indonesia and the Philippines and in tropical regions of Africa. In India, it is cultivated mostly in West Bengal, Kerala, Karnataka, Andhra Pradesh, Maharashtra, Chhattisgarh, Bihar, Jharkhand and Odisha. Because of its higher yield potential, culinary properties, medicinal utility and therapeutic values, it is referred to as 'King of tuber crops'. The corm of elephant foot yam is mainly used as a vegetable in the preparation of various delicious cuisines and is a major ingredient in indigenous Ayurvedic prescriptions (Misra et al., 2002; Srinivas and Ramanathan, 2005). It is restorative, carminative, stomachic and tonic. Fresh corm acts as an acrid stimulant and expectorant (Ghani, 1988). The corm is useful in the treatment of piles, acute rheumatism, enlarged spleen, abdominal tumors, boils, asthma (Yusuf et al., 1994), abdominal pain, dyspepsia and elephantiasis (Kirtikar and Basu, 1994). The fermented juice of petioles is used to treat diarrhoea, whereas seeds are used to treat rheumatic swelling (Chatterjee and Pakrashi, 2001). The major sugars identified from the corms are glucose, galactose and rhamnose, while flavonoids, phenols, coumarins, terpenoids, sterols, tannins, steroids and alkaloids have also been reported (Nataraj et al., 2009; Yadu and Ajoy, 2010). The corm is reported to have analgesic (Shilpi et al., 2005), antibacterial, antifungal, cytotoxic (Angayarkanni et al., 2007), central nervous system depressant (Dey et al., 2009), anti-inflammatory (Dey et al., 2010) and antioxidant (Angayarkanni et al., 2007) properties.

Weeds play a significant role in reducing the yield of crops and are potentially a major constraint in crop production, if not controlled. In humid and sub-humid tropics, weeds are the major pests, where adequate rainfall, temperature and humidity favour their growth (Melifonwu, 1994). They compete with crops for natural and applied resources besides being responsible for reducing quantity and quality of agricultural productivity (Rao et al., 2015). Elephant foot yam is susceptible to weed growth throughout the crop growth period because of less coverage of field by the leaf canopy. Often, weeds germinate and grow much early than the crop because of slow sprouting of the corm setts. Further elephant foot yam is planted at wider spacing because of the canopy orientation (erect single pseudostem with umbrella shaped canopy spread). Weed infestation at early stage causes severe yield reduction and it may go up to 100% in wide spaced crops (Nicholas, 2018). Weeds in elephant foot yam compete for water, nutrient, light and space both below and above ground, inhibit the growth and development of the crop. Weeding alone requires more than 30% of total labour i.e. 150-200 man days ha^{-1}. Manual weeding alone is expensive, tedious and time consuming (Nedunchezhiyan et al., 2013). Application of herbicides for weed control as pre-emergence or post emergence can reduce the dependency on manual weeding and it reduces the cost per weeding. Herbicides are likely to become inevitable method of weed control in elephant foot yam especially, where labour is scarce or expensive or farm size is large.

At present very few herbicides are available for weed control and most of these herbicides provide only a narrow spectrum weed control (Patel et al., 2006). Moreover, herbicides applied to control weeds in the crop field have direct or indirect consequences on non-targeted organisms, including soil micro flora, which are responsible for numerous biological processes essential for crop production. It has been reported that some of the microorganisms were able to degrade the herbicide, while some others were adversely affected depending on the type of herbicide used (Sebiomo et al., 2011). Therefore, effects of herbicides on microbial growth, either stimulating or depressive, depend on the type of chemical, microbial species and environmental conditions (Zain et al., 2013). In recent years many multinational companies have released new herbicide molecules. However, there is a need to study the influence of these molecules on weeds and soil microorganisms. Application of herbicides affects microbial community in the soil and reduces the important soil biological functions (Riaz et al., 2007) and also cause qualitative and quantitative changes in soil microbial populations (Latha and Gopal, 2010). However, information on suitable weed control method for elephant foot yam under sub-humid tropics is not available. Keeping in view of the above facts, the present investigation was undertaken to study the effect of weed management practices on elephant foot yam yield and soil quality under sub-humid tropics.

Materials and Methods

A field experiment was conducted during 2015 in an Alfisol at the Regional Centre of ICAR-Central Tuber Crops Research Institute (20º 14' 50" N and 85º 47' 06" E), Dumduma, Bhubaneswar, Odisha, India. The experimental soil is sandy clay loam (Typic Rhodustalf), neutral, non saline, low in organic carbon and available N and having medium status of available K (Table 1). The soil also contains micro nutrients above the critical limits and low status of microbial counts and enzyme activities. The experiment was laid out with three replications in a randomized block design. The treatments consisted of T_1 - Pendimethalin @ 1000 g ha^{-1} [at 1 day after planting (DAP)] + Glyphosate @ 2000 g ha^{-1} (at 90 DAP), T_2 - Metribuzin @ 525 g ha^{-1} (at 1 DAP) + Glyphosate @ 2000 g ha^{-1} (at 90 DAP), T_3 - Pendimethalin @ 1000 g ha^{-1} (at 1 DAP) + tank mix of Pyrithiobac sodium @ 62.5 g ha^{-1} and Propiquizafop @ 62.5 g ha^{-1} (at 90 DAP), T_4 - Metribuzin @ 525 g ha^{-1} (at 1 DAP) + tank mix of Pyrithiobac sodium @ 62.5 g ha^{-1} and Propiquizafop @ 62.5 g ha^{-1} (at 90 DAP), T_5- Pendimethalin @ 1000 g ha^{-1} (at 1 DAP) + two manual weedings (at 60 and 90 DAP), T_6- Metribuzin @ 525 g ha^{-1} (at 1 DAP) + two manual weedings (at 60 and 90 DAP), T_7- two manual weedings (at 30 and 60 DAP) + Glyphosate @ 2000 g ha^{-1} (at 90 DAP), T_8- two manual weedings (at 30 and 60 DAP) + tank mix of Pyrithiobac sodium @ 62.5 g ha^{-1} and Propiquizafop @ 62.5 g ha^{-1} (at 90 DAP), T_9- Weed control ground cover (WCGC), T_{10}- four manual weedings (at 30, 60, 90 and 120 DAP) and T_{11}- Control.

Table 1. Physico-chemical properties of the experimental site

	Particulars	Value
1.	Mechanical analysis	
	Coarse sand (%)	41.3
	Fine sand (%)	28.1
	Silt (%)	8.7
	Clay (%)	21.9
	Soil texture	Sandy clay loam
	Family	Typic Rhodustalf
	Bulk density (Mg m^{-3})	1.5
2.	Bio-chemical analysis	
	Soil pH	6.61
	Electrical conductivity (dS m^{-1})	0.20
	Organic carbon (%)	0.32
	Available N (kg ha^{-1})	168.2
	Available P (kg ha^{-1})	26.3
	Available K (kg ha^{-1})	170.5
	Available Fe (mg kg^{-1})	5.72
	Available Cu (mg kg^{-1})	1.27
	Available Mn (mg kg^{-1})	19.86
	Available Zn (mg kg^{-1})	1.28
3.	Enzyme activities	
	Dehydrogenase (µg TPF h^{-1} g^{-1})	0.545
	Fluorescein diacetate (µg g^{-1} h^{-1})	1.182
	Acid phosphatase (µg PNP g^{-1} h^{-1})	33.16
	Alkaline phosphatase (µg PNP g^{-1} h^{-1})	25.23
4.	Microbial Population	
	Fungi (cfu g^{-1} of soil)	5×10^4
	Bacteria (cfu g^{-1} of soil)	3×10^5
	Actinomycetes (cfu g^{-1} of soil)	3×10^4

Elephant foot yam (cv Gajendra) healthy whole corms weighing 400 g treated with cow dung slurry (10 kg of fresh cow dung dissolved in 10 L of water and mixed with 50 g *Trichoderma*) one day before, were planted at a spacing of 90x90 cm on the ridges. The pre emergence herbicides Pendimethalin and Metribuzin were applied one day after planting of the corms. Post-emergence herbicides glyphosate and tank mix of Pyrithiobac Sodium and Propiquizafop were applied directly on weeds. Herbicides were sprayed carefully without drift on elephant foot yam plants by manually operated knapsack sprayer with a flat-fan nozzle attached to a hood using a spray volume of 500 litres water per ha. Weed control ground cover was spread on the ridge and furrows and the ends were covered with soils. Holes were made at elephant foot yam planted space using a 4 inch (10 cm) diameter GI pipe. Farmyard manure (FYM) @ 10 t ha^{-1} was incorporated in the last plough uniformly in all the treatments. The recommended dose of water soluble fertilizer @ 120-60-120 kg ha^{-1} of N-P_2O_5-K_2O was split into 40 equal doses and applied through drip irrigation at 4 days interval (Nedunchezhiyan et al., 2017a). The first dose was started 10 days after planting. The crop was drip irrigated based on 80% of cumulative pan evaporation (CPE) in alternate days. Irrigation was stopped at 15 days prior to harvest of the crop. The crop was harvested 8 months after planting.

Fresh soil samples after removal of gravels, roots, etc. were preserved in refrigerator at 4°C and used for estimation of microbial variables. Nutrient Agar, Potato Dextrose Agar and Starch Casein Agar media were used for isolation of bacteria, fungi and actinomycetes, respectively. After the serial dilution, 1.0 ml of required dilution (10^{-4} for fungi and actinomycetes and 10^{-5} for bacteria) was inoculated into respective petriplates. The soil sample was spread over the media via a flame sterilized bent glass rod and all the plates were incubated in the dark at 37°C. After the microbial colonies are readily visible (2-7 days for bacteria & fungi and 7-14 days for actinomycetes), the number of colonies on each plate were counted and calculated. The number of cfu g^{-1} dry soil was estimated by taking the soil dilution factor and soil moisture content into account. Dehydrogenase activity (DHA) in the soils was determined by the method as described by Casida et al. (1977). The fluorescein diacetate hydrolysis assay (FDA) was determined by the method outlined by Green et al. (2006). Acid phosphomonoesterase (AcP) and Alkaline phosphomonoesterase (AlP) activities were determined by the method as described by Tabatabai and Bremner (1969). Initial soil microbial population and enzyme activities are presented in Table 1.

Weeds were removed from two locations each measuring 50x50 cm area before each manual weeding and post-emergence herbicide application in manual weeding and post emergence herbicide treatments and at harvest from all the treatments. Weeds were separated species-wise, initially sun-dried and later oven dried at 70°C until constant weight was attained. Weed control efficiency (WCE) was calculated as follows:

$$WCE = \frac{WDC - WDT}{WDC} \times 100$$

WDC = Dry biomass of weeds in control plot (weedy check)

WDT = Dry biomass of weeds in treated plot

Data on weeds (x) were subjected to square root transformation (x + 1) before statistical analysis. Data were analyzed using SAS 11.0 version. Analysis of variance (ANOVA) was carried out appropriate to the design of experiment. Treatment means were compared using least significant difference (LSD) at 5% probabilities (Gomez and Gomez, 1984).

Results and Discussion

Climate

The rainfall received during the cropping period was 970.3 mm. The average monthly maximum temperature ranged between 29.2°-39.0°C, whereas the average monthly minimum temperature between 15.7°-27.0°C. The average humidity was 75%. In general the climate of the region was warm and humid in summer and cool and dry in winter. The crop was irrigated through drip system during dry spells at 80% of CPE and a total of 303.1 mm water was applied through drip irrigation.

Weed flora and weed control efficiency

Weed flora found in this experiment was not specific to elephant foot yam crop. But it was specific to the location, soil type and climate of the experimental site. The major weed species observed in the elephant foot yam fields were Purple nutsedge (*Cyperus rotundus* L.), Crowfoot grass [*Dactyloctenium aegypticum* (L.) Willd], large crabgrass [*Digitatia sanguinalis* L. (Scop.)]. Bermuda grass [*Cynodon dactylon* (L.) Pers.]. Barnyard grass [*Echinochloa crusgalli* (L.) Beauv .]. Shaggy buttonweed [*Borreria hispido* (L.) K. Schum.], Cock's comb (*Celosia argentia* L.), Goat weed (*Ageratum conyzoides* L.). Tropical spiderwort (*Commelino benghalensis* L.). Tick weed (Cleome viscose L.), Sensitive plant (Mimosa pudica L.), Stonebreaker (*Phyllanthus niruri* L.) etc. These species appeared as soon as elephant foot yam was planted. *Celosia argentia*, *Digitatia sanguinalis* and *Cleome viscosa* dominated the other weed flora. Similar findings were reported in Typic Rhodustalf of Bhubaneswar, India (Nedunchezhiyan et al., 2017b).

Significant reduction in weed biomass was noticed in all the weed management treatments as compared to weedy check (Table 2). The treatment T_9 (WCGC) resulted in significantly lower weed biomass. This was due to suppression of weed germination and emergence by WCGC owing to complete cover of the ground. The next best treatment was T_{10} (four manual weeding at 30, 60, 90 and 120 DAP). The treatment T_7 [two manual weedings (at 30 and 60 DAP) + glyphosate (at 90 DAP)] also resulted in lower weed biomass. The treatments T_1, T_2, T_3 and T_4 resulted in relatively higher weed biomass. It indicated that in long duration crop like elephant foot yam, pre and post-emergence herbicide combinations alone was not sufficient for weed control. Pre and post emergence herbicides were effective up to 20-30 days only (Balusamy and Pothiraj, 1989; Nedunchezhiyan et al., 2017c). Among pre-emergence application of herbicides, Pendimethalin was found more effective in weed control than Metribuzine. Among post-emergence herbicides, glyphosate was found very effective than tank mix of Pyrithiobac Sodium and Propiquizafop. Maximum weed biomass was recorded in control treatment, wherein no weeding was done.

Table 2. Effect of weed control practices on weed biomass and yield of elephant foot yam

Treatment	Weed biomass ($g\ m^{-2}$)	Corm yield ($t\ ha^{-1}$)	Weed control efficiency (%)
T_1	7.5 (54.7)	24.4	77.3
T_2	7.6 (56.3)	23.6	76.5
T_3	9.8 (94.7)	20.2	60.5
T_4	9.9 (96.5)	19.5	59.8
T_5	6.6 (43.1)	30.3	82.0
T_6	6.9 (46.7)	28.4	80.5
T_7	5.9 (33.4)	32.9	86.0
T_8	7.1 (48.8)	26.1	79.6
T_9	2.9 (7.4)	37.4	96.9
T_{10}	3.8 (13.2)	33.7	94.5
T_{11}	15.5 (239.7)	8.6	-
CD ($P = 0.05$)	0.3	2.84	-

Marked variation in WCE was noticed with respect to weed management practices. The WCE of different weed management practices ranged 59.8 - 96.9% (Table 2). The treatment T_9 (WCGC) and T_{10} (four manual weedings at 30, 60, 90 and 120 DAP) resulted in higher WCE of 96.9 and 94.5%, respectively because of lower weed biomass. Better weed control efficiency with polythene mulching was reported by Nalayini et al. (2009) and Nedunchezhiyan et al. (2017b). The treatment T_7, T_5 and T_6 resulted in more than 80% WCE in the descending order. This indicated that inclusion of pre-emergence or post-emergence herbicides in combination with two manual weedings reduced the weed stress and these treatments can be an alternative to the treatments T_9 and T_{10}.

Yield performance of elephant foot yam

Significant difference in corm yield was noticed with respect to weed management practices (Table 2). Significantly higher corm yield was obtained in T_9 (WCGC) as compared to the other treatments. The treatment T_9 (WCGC) resulted in 335% higher corm yield than control, which was due to lower weed biomass production and higher weed control efficiency (96.9%). The next best treatment was T_{10} (four manual weedings at 30, 60, 90 and 120 DAP) followed by T_7 [two manual weedings (at 30 and 60 DAP) + glyphosate (at 90 DAP)]. The treatment T_{10} (four manual weedings at 30, 60, 90 and 120 DAP) and T_7 [two manual weedings (at 30 and 60 DAP) + glyphosate (at 90 DAP)] resulted in 292 and 283% higher yield over control and 10 and 12% lower than T_9 (WCGC), respectively. Higher corm yield in these treatments indicated lesser interference of weeds (Table 2). Keeping weed free relatively for longer period might have improved the growth and development of elephant foot yam, which ultimately was reflected in corm yield (Table 2). Negative linear relationship between weed biomass and yield was reported in sweet potato (Nedunchezhiyan et al., 1998) and cassava (Nedunchezhiyan et al., 2017b). Among the pre-emergence herbicides, pendimethalin was found more effective in weed control than metribuzine. Among the post-emergence herbicides glyphosate was found very effective than tank mix of pyrithiobac sodium and propiquizafop. The present study also indicated that T_{10} (four manual weedings at 30, 60, 90 and 120 DAP) and T_7 [two manual weedings (at 30 and 60 DAP) + glyphosate (at 90 DAP)] were alternative to T_9 (WCGC) for weed management in elephant foot yam. Depending on financial and labour availability, farmers can choose weed management options. The treatment weedy check (T_{11}) resulted in lower corm yield (77% reduction) owing to season long crop-weed competition, which was indicated by lower WCE (Table 2). Similar observation in cassava was reported by Nedunchezhiyan et al. (2017b).

Soil fertility

Weed management practices influenced the post-harvest soil pH and it ranged from 6.49 to 7.01 (Table 3). The treatment T_9 resulted in higher soil pH, which was ascribed to degradation of weed biomass enrich the basic cations and that might have contributed to rise the soil reaction. Application of post-emergence herbicides glyphosate and tank mix of Pyrithiobac Sodium and Propiquizafop (T_1, T_2, T_3, T_4, T_7 and T_8) also resulted in greater soil pH. The treatment T_{11} (weedy check) had higher soil pH than the hand weeding treatments. Hand weeding resulted in lower soil pH as the removal of weeds along with adhering top soil particles led to loss of Ca &

Table 3. Effect of herbicides on chemical properties of the soil

Treatment	pH	Organic C (%)	Available Nutrients (kg ha^{-1})			Available micronutrients (mg kg^{-1})			
			N	P	K	Fe	Cu	Mn	Zn
T_1	6.90	0.37	193.3	36.3	192.4	5.87	1.33	19.65	1.31
T_2	6.83	0.38	188.1	34.2	186.2	5.75	1.28	19.81	1.28
T_3	6.69	0.34	180.1	32.6	181.7	5.70	1.26	19.04	1.24
T_4	6.67	0.36	174.5	29.7	176.2	5.68	1.24	19.06	1.27
T_5	6.54	0.33	168.1	27.2	169.2	5.64	1.22	19.01	1.22
T_6	6.50	0.33	164.8	24.9	162.9	5.63	1.23	19.08	1.16
T_7	6.79	0.38	187.7	33.2	184.4	5.82	1.34	19.45	1.29
T_8	6.71	0.35	176.9	30.2	183.8	5.70	1.31	19.85	1.22
T_9	6.96	0.33	199.2	36.5	194.2	5.93	1.35	20.80	1.34
T_{10}	6.49	0.29	182.0	33.8	185.4	5.67	1.25	19.66	1.26
T_{11}	6.63	0.34	154.9	24.6	160.9	5.29	1.18	18.63	1.08
CD ($P = 0.05$)	0.03	0.03	20.0	3.2	15.4	NS	NS	NS	0.16

Mg compounds. The lowest soil pH was observed in T_{10} (four manual weedings at 30, 60, 90 and 120 DAP). Marked variation in organic carbon content in soil was noticed with respect to weed management practices. Application of post-emergence herbicides, glyphosate and tank mix of Pyrithiobac sodium and Propiquizafop (T_1, T_2, T_3, T_4, T_7 and T_8) resulted in higher organic carbon. Post-emergence application of herbicide glyphosate treated plots resulted in higher soil organic carbon. The highest organic carbon content was observed in the treatment T_7. The higher soil organic carbon in post-emergence herbicide applied treatments might be owing to *in situ* drying and decomposition of weeds. Nedunchezhiyan et al., (2017c) also reported similar findings in cassava. Organic amendments and associated plant residues may supply additional sources of labile C to the soil (Carpenter-Boggs et al., 2000). The treatment T_{11} (weedy check) recorded higher soil organic carbon than the hand weeding treatments. Increasing number of manual weedings decreased soil organic carbon content. The treatment T_{10} (four manual weedings at 30, 60, 90 and 120 DAP) resulted in lower soil organic carbon. This might be due to clean cultivation. Continuous disturbance and exposure of soil 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). The return of weed residue to the soil is very negligible in this treatment. Elephant foot yam produces 3-4 leaves with petioles (pseudostem) per plant during crop growth period, which were intact with corm after drying till harvest of the corm. Hence, crop residues were not available before harvesting of elephant foot yam.

The post-harvest soil available N and K content increased in all the treatments, except T_{11}, T_6 and T_5 compared to initial status. Whereas, the post-harvest soil available P content increased in all the treatments, except T_{11} and T_6 than the initial status (Table 3). The available N, P and K in the post-harvest soils, irrespective of the treatments ranged from 155 - 199, 34.7 - 36.5 and 161 - 194 kg ha^{-1}, respectively (Table 3). Maximum available N, P and K was recorded in the treatment T_9 (WCGC). This might be due to prevention of weed growth and consequently nutrient uptake by weeds. The treatments T_1, T_2, T_3, T_4, T_7 and T_8 also resulted in higher nutrient status of the soil as compared to T_5 T_6, and T_{11}. Application of pre and post- emergence herbicides in T_1, T_2, T_3 and T_4 prevented emergence of weeds at early stages and suppression of weeds at later stage. Application of post-emergence herbicides in T_7 and T_8 killed the weeds at later stage. The slow *in situ* decaying of the dead weeds re-assimilates the N, P and K to the soil. Sharma et al. (2015) also reported increased post-harvest soil available N, P and K with application of pre (Pendimethalin and Oxyfluorfen) and post (Oxadiargyl) emergence herbicides. The treatment T_{10} also resulted in higher post-harvest soil nutrient status compared to T_5, T_6 and T_{11} owing to frequent weeding that prevented the weed growth and uptake of N, P and K by the weeds. The treatment weedy check (T_{11}) showed lower available N, P and K status in the post-harvest soil, which might be due to robust growth of weeds (Table 2) that removed large quantities of N, P and K from the soil and resulted in lower corm yield.

The post harvest soil available Fe, Cu, and Mn in weed management treatments were not statistically significant (Table 3), whereas, the available Zn was statistically significant. Maximum available Fe, Cu, Mn and Zn was noticed in T_9 (WCGC). This might be due to prevention of uptake of Fe, Cu, Mn and Zn by weeds, inherent capacity of the soil to supply and addition through FYM. The treatments T_1, T_2, and T_7 also resulted in higher soil available Fe, Cu, Mn and Zn status. Application of pre and post-emergence herbicides in the treatments T_1 and T_2 prevented the emergence of weeds at early stage and killed the weeds at later stage. Application of post-emergence herbicides in T_7 killed the weeds at later stage. The slow *in situ* decaying of the dead weeds contributed in the build up of Fe, Cu, Mn and Zn in the soil. The treatment weedy check (T_{11}) resulted in lower available Fe, Cu, Mn and Zn status in the soil due to robust growth of weeds that might have removed large quantities of Fe, Cu, Mn and Zn from the soil. Both Fe and Mn contents in the post-harvest soils greater than the critical limits of 4.0 and 2.0 mg kg^{-1}, respectively is due to the nature of parent materials on which the soils formed and other soil forming factors. The available Cu content in the soils of the present study was also higher than the critical limit of 0.2 mg kg^{-1}.

Soil microbial populations

Weed management practices significantly influenced the post-harvest soil microbial populations (Table 4). Maximum fungi, bacteria and actinomycetes were found

Table 4. Effect of weed control practices on microbial population and soil enzyme activities

Treat-ment	Fungi ($x10^4$cfu g^{-1})	Bacteria ($x10^5$cfu g^{-1})	Actinomycetes ($x10^4$ cfu g^{-1})	Dehydroge-nase(µg TPF hr^{-1} g^{-1})	Fluorescein diacetate (µg g^{-1} h^{-1})	Acid phosphatase (µg PNP g^{-1} h^{-1})	Alkaline phosphatase (µg PNP g^{-1} h^{-1})
T_1	26	22	20	0.689	1.564	49.36	35.74
T_2	27	24	19	0.667	1.496	47.50	34.69
T_3	22	21	18	0.656	1.426	44.93	34.05
T_4	23	20	18	0.649	1.488	42.57	32.63
T_5	23	21	17	0.632	1.548	38.24	32.59
T_6	22	20	17	0.784	1.456	36.95	29.41
T_7	28	24	21	0.856	1.682	65.37	47.34
T_8	22	20	19	0.749	1.458	49.72	37.80
T_9	29	26	22	0.884	1.896	66.12	49.72
T_{10}	19	17	14	0.613	1.236	34.57	27.12
T_{11}	20	19	16	0.642	1.464	39.87	32.84
CD (P = 0.05)	0.2	0.1	0.1				

in the treatment T_9 (WCGC) due to favourable micro climate induced by WCGC apart from higher organic carbon content in the soil. The treatments T_7, T_1 and T_2, where glyphosate was applied as post-emergence herbicide also resulted in higher microbial counts of fungi, bacteria and actinomycetes. Higher microbial populations in these treatments might be due to greater organic carbon content in the soil contributed by decaying weeds. Soil microbial population was significantly and positively correlated with organic carbon content of the soil (Table 5). Immediately after herbicide application a decreasing trend in microbial population was noticed, but 15-20 days after application, the applied herbicides get degraded and soil microbes start multiplication. It can also be due to increased supply of nutrients to the microorganisms and control of weeds by herbicide application or due to the proto-cooperative influence of various microorganisms in the rhizosphere (Jeevan et al., 2016; Lokose, 2017). Ghosh et al. (2012) found that for all the cases of herbicidal treatments, total bacteria recovered from initial loss and exceeded the initial counts. Bera and Ghosh (2013) reported that herbicide treatments resulted in decrease in microbial counts initially, but with the degradation of applied herbicides within a considerable time, the population even exceeded later than the initial count. In the present experiment, the increase in microbial populations in post-emergence application of glyphosate might be due to increase in organic carbon by slow decomposition of dead weeds *in situ* and release of essential nutrients from weeds, which acts as substrate for multiplication of microbes. Haney et al. (2000 and 2016) reported an increase in soil microbial biomass, respiration as well as carbon and nitrogen mineralization after glyphosate application. There were strong linear relationships between mineralized C and soil microbial C and N. When

Table 5. Correlation coefficients (r) between microbial activities and chemical properties of the soil

Microbes/enzyme	pH	Organic C	Available N	Available P	Available K
Fungi	0.847^{**}	0.625^{*}	0.742^{**}	0.608^{*}	0.595^{*}
Bacteria	0.828^{**}	0.561^{*}	0.671^{*}	0.536	0.521
Actinomycetes	0.885^{**}	0.648^{*}	0.682^{*}	0.544	0.588^{*}
Dehydrogenase	0.503	0.231	0.430	0.252	0.309
FDA	0.735^{**}	0.374	0.496	0.340	0.353
Acid phosphatase	0.830^{**}	0.494	0.700^{**}	0.594^{*}	0.628^{*}
Alkaline phosphatase	0.774^{**}	0.413	0.607^{*}	0.490	0.531

* and ** Significant at 5 and 1 per cent level, respectively 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 (Nedunchezhiyan et al., 2017c). The death of bean plants treated with glyphosate was linked to a strong colonization of roots by soil borne fungal species that were able to use the herbicides as a nutrient source (Krzysko-Lupicka and Orlik, 1997). However, application of glyphosate in short duration crops like maize and soybean decreased the bacterial diversity at harvest (Barriuso et al., 2012).

The microbial populations were positively and significantly correlated with organic carbon (Table 5). Incorporation of organic manure (FYM) uniformly in all the treatments and decomposition of weeds due to application of post-emergence herbicides may be ascribed to greater build up of organic matter congenial for microbial growth. Organic amendments and associated plant residues may supply additional sources of labile C and P to the soil, which can stimulate microbial growth and biochemical activity (Carpenter-Boggs et al., 2000). Increased microbial populations with the increased available nutrient status of the soil play significant role in organic matter decomposition as well as transformation of nutrients. Soil microbial populations were significantly and positively correlated with soil available N, P and K (Table 5). Increasing the number of manual weedings reduced the fungi, bacteria and actinomycetes population. Lower counts of fungi, bacteria and actinomycetes were noticed in T_{10} (four manual weedings at 30, 60, 90 and 120 DAP), which might be due to lower organic carbon content in the soil.

Soil enzyme activities

Dehydrogenase enzyme activity is commonly used as an indicator of biological activity in soil. This enzyme is considered to exist as an integral part of intact cells but does not accumulate extracellularly in the soil and it is known to oxidize soil organic matter by transferring protons and electrons from substrates to acceptors. The fluorescein diacetate hydrolysis assay measures the enzyme activity of microbial population and can provide an estimate of overall microbial activity in a sample. Due to relative importance of phosphatase in soil organic P mineralization and plant nutrient, their assay in soil assumes more importance. The enzymes are classified as acid and alkaline phosphatases, because they show optimum activities in their respective pH ranges. Alkaline phosphatase is contributed both by plant roots and soil-inhabiting microbes. These enzymes play key biochemical functions in the overall process of organic matter decomposition in the soil system (Sinsabaugh et al., 1991).

The treatment T_9 (WCGC) resulted in maximum dehydrogenase, fluorescein diacetate, acid and alkaline phosphatase activities in the soil (Table 4), followed by T_7 [two manual weedings (at 30 and 60 DAP) + glyphosate (at 90 DAP)]. Higher soil enzyme activities in these treatments may be due to higher organic carbon content and microbial activity in the soil. The soil enzyme activities were significantly and positively correlated with microbial activity and positively correlated with organic carbon (Table 5 and 6). The increased soil enzyme activities (dehydrogenase, fluorescein diacetate and phosphatase) may be ascribed to greater availability of substrates that support such activities (Kremer and Jianmei Li, 2003). Organic matter is the store house of various groups of microbes and hence improvement in organic matter had significant role in accumulation of micro-flora and various groups of enzymes involved in different bio-chemical processes in the soil. Soil enzyme activities also positively correlated with soil available N, P and K (Table 5). Soil phosphatase activity was closely related to soil organic matter content, supporting previous reports that elevated organic matter levels promote soil phosphatase activity (Frankenberger and

Table 6. Correlation coefficients (r) between soil micro-flora and enzyme activities

Soil microbes	Dehydrogenase	FDA	Acid phosphatase	Alkaline phosphatase
Total fungi	0.670*	0.853**	0.853**	0.817**
Total bacteria	0.676*	0.882**	0.847**	0.835**
Total actinomycetes	0.754**	0.869**	0.920**	0.892**

* and ** Significant at 5 and 1 per cent level, respectively

Dick, 1983; Jordan et al., 1995). The lowest dehydrogenase, fluorescein diacetate, acid and alkaline phosphatase activities in the soils were noticed in T_{10} (four manual weedings at 30, 60, 90 and 120 DAP). This might be ascribed to lower organic carbon content and microbial activity in the soil.

Conclusions

Weed management practices significantly influenced the corm yield of elephant foot yam and soil health. Adoption of weed control ground cover resulted in greater elephant foot yam corm yield because of greater weed control efficiency by suppression of weed growth. Weed control ground cover with polythene mulching is cost effective as it can be re-used for 3 cropping seasons, substantially reduced the investment rendered on costly herbicides as well as minimizes the labour cost for weeding operations. It also resulted in build up of available N, P, K, Fe, Cu, Mn and Zn status, microbial populations and soil enzyme activities. Four manual weedings at 30, 60, 90 and 120 DAP is also equally effective to produce higher corm yields, but recorded lower soil organic carbon, available nutrients, microbial population and soil enzyme activities. Thus, weed control ground cover is considered a good weed management option in elephant foot yam, where weeds are major threat for crop production and drip fertigation facilities are available. Two manual weedings (at 30 and 60 DAP) + glyphosate (at 90 DAP) resulted in moderately higher corm yield as well as organic C, available nutrients and soil enzyme activities. When labour is scarce, two manual weedings (at 30 and 60 DAP) + application of post-emergence herbicide i.e. glyphosate at 90 DAP can be a weed management option. However, to prevent herbicide resistant weeds, alternative herbicides should be rotated along with cultural management in elephant foot yam.

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