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Influence of Weed Management Practices on Soil Microbial Activities and Corm Yield of Elephant Foot Yam (*Amorphophallus paeoniifolius*) in Alfisols of Coastal Odisha

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Field experiments were carried out 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 of coastal Odisha during kharif, 2015-16 at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India.The results of the study revealed that weed control ground cover has recorded lower weed biomass and greater weed control efficiency. Significantly highest corm yield of elephant foot yam was registered with weed control ground cover (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 the post-emergence application of glyphosate at 90 DAP (32.9 t ha^{-1}). Maximum gross returns were observed in weed control ground cover, however, the highest benefit-cost ratio was noticed due to two manual weedings at 30 and 60 DAP + spraying of glyphosate at 90 DAP. Use of weed control ground cover resulted in greater soil available N, P, K, Fe, Cu, Mn and Zn as well as microbial (fungi, bacteria and actinomycetes) counts and soil enzyme (dehydrogenase, fluorescein diacetate, acid and alkaline phosphatase) activities.The study emphasized that weed control ground cover, manual weeding at periodic intervals or manual weeding combined with the application of post-emergence herbicides not only enhanced the corm yield but also improved the soil quality parameters and microbial activities in the soil.

(***Key words:*** *Elephant foot yam, Soil microbial activities,Weed management, Yield)*

Weeds play a significant role in the reduction of crop yields and are a major constraint on 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 the quantity and quality of agricultural productivity (Rao *et al*., 2015). Often, weeds germinate and grow much earlier than the yam crop because of the slow sprouting of the corm setts. 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 an inevitable method of weed control in elephant foot yam, especially where labour is scarce or expensive or farm size is large.

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 tropical regions of Africa. In India, it is cultivated mostly in West Bengal, Kerala, Chhattisgarh, Bihar, Jharkhand, Uttar Pradesh, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Madhya Pradesh 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 tumours, 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

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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.

Elephant foot yam is susceptible to weed growth throughout the crop growth period because of less coverage of the field by the leaf canopy. 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 an early stage causes severe yield reduction and it may go up to 100% in wide-spaced crops. 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 to 200 man days ha^{-1}. Manual weeding alone is expensive, tedious and time-consuming.

At present a 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 are applied to control the weeds in the crop field have direct or indirect consequences on non-targeted organisms including soil microflora 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, the effects of herbicides on microbial growth either stimulating or depressive depend on the chemicals type, microbial species and environmental conditions (Zain *et al*., 2013). In recent years many multinational companies have released new herbicide molecules that need to be evaluated for their influence on weeds and soil microorganisms. The application of herbicides affects the 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 methods for elephant foot yam under sub-humid tropics is not available. The present investigation was undertaken to study the effect of weed management practices on yield performance of elephant foot yam and its residual effect on soil quality under sub-humid tropics in coastal Odisha.

MATERIALS AND METHODS

A field experiment was conducted during the kharif season, 2015-16 in an Alfisol (*Typic Rhodustalf*) at the Regional Centre of ICAR-Central Tuber Crops Research Institute (20° 14′ 50″ N and 85° 47′ 06″ E), Dumuduma, Bhubaneswar, Odisha, India. The experimental soil is sandy clam loam, neutral in reaction (pH - 6.61), non-saline (EC - 0.20 dS m^{-1}), low in organic carbon (0.32%) and available N (168.2 kg ha^{-1}), high in available P (26.3 kg ha^{-1}) and having medium status of available K (170.5 kg ha^{-1}) (Table 1). The soil also contains micronutrients above the critical limits but has lower 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} [applied 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 pyrithiobacsodium @ 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 pyrithiobacsodium @ 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 90DAP), T_9 - weed control ground cover (WCGC, black polythene mulch), T_{10} - four manual weedings (at 30, 60, 90 and 120 DAP) and T_{11} - control (weedy check).

Healthy whole corms of elephant foot yam (cv. Gajendra) weighing 500 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 90 cm x 90 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 consisted of perforated black coloured polythene sheet of 100 µ thickness and 1.0 m width which was used as a mulch to suppress the germination of weeds as well as to regulate the soil temperature for faster germination of elephant foot yam by breaking the dormancy of corms in sprouting. The plastic cover mulch was spread on the ridge and furrows and the ends were covered with soil. Holes were made at elephant foot yam planted space using a 4″ (10 cm) diameter GI pipe to allow the sprouts to come out. Farmyard manure (FYM) @ 10 t ha^{-1} was incorporated during last ploughing 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 at 10 days after planting. The crop was drip irrigated based on 80% of cumulative pan evaporation (CPE) in alternative days. Irrigation was stopped at 15 days prior to harvest of the crop. The crop was harvested 8 months after planting.

Fresh soil samples from individual treatments at a depth of 30 cm were collected after harvest of the crop, removed gravels, roots, etc., sieved with 0.5 mm sieve and preserved in refrigerator at 4°C and used later 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 in to 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 and 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 in to 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 counts and enzyme activities are presented in Table 1.

Table 1. *Soil physical, chemical and biological properties of the experimental site*

Soil property		Value
A. Soil physical properties		
Coarse sand (%)	:	41.3
Fine sand (%)	:	28.1
Silt (%)	:	8.70
Clay (%)	:	21.9
Soil texture	:	Sandy clay loam
Family	:	*Typic Rhodustalf*
Bulk density (Mg m^{-3})	:	1.50
B. Soil chemical and biological properties		
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
Dehydrogenase (µg TPF hr^{-1} g^{-1})	:	0.545
Fluorescein diacetate (µg g^{-1} hr^{-1})	:	1.182
Acid phosphatase (µg PNP g^{-1} h^{-1})	:	33.16
Alkaline phosphatase (µg PNP g^{-1} h^{-1})	:	25.23
Fungi (cfu g^{-1} of soil)	:	5 x 10^4
Bacteria (cfu g^{-1} of soil)	:	3 x 10^5
Actinomycetes (cfu g^{-1} of soil)	:	3 x 10^4

Weeds were removed from two locations each measuring 50 cm x 50 cm area before each manual weeding and post emergence herbicide application and at harvest from all the treatments. Weeds were separated species-wise, initially sun-dried and later oven dried at 60°C until constant weight was attained. Weed control efficiency (WCE) was calculated as follows:

$$WCE = \frac{WDC\text{-}WDT}{WDC} \times 100 \quad (1)$$

Where, WDC is the dry biomass of weeds in control plot (weedy check) and WDT is the dry biomass of weeds in treated plot.

The 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 as per the design of experiment. Treatment means were compared using least significant difference (LSD) at 5% probability (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Weed flora in elephant foot yam and weed control efficiency

Weed flora found in this experiment was not specific to the 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 [*Digitatias anguinalis* L. (Scop.)], bermuda grass [*Cynodon dactylon* (L.) Pers.], barnyard grass [*Echinochloa crusgalli* (L.) Beauv.], shaggy buttonweed [*Borreria hispida* (L.) K. Schum.], cock's comb (*Celosia argentia* L.), goat weed (*Ageratum conyzoides* L.), tropical spiderwort (*Commelina 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*, *Digitatias anguinalis* and *Cleome viscosa* dominated the other weed flora. Similar findings were reported in *Typic Rhodustalfs* of Bhubaneswar, India by 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 weedings 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 were 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). Among pre-emergence application of herbicides, pendimethalin was found more effective in weed control than metribuzin. Among post-emergence herbicides glyphosate was found very effective than tank mix of pyrithiobacsodium and propiquizafop. Maximum weed biomass was recorded in control treatment wherein no weeding was done.

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 treatments T_9 (WCGC) and T_{10} (four manual weedingsat 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 treatments 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

Discerning differences in corm yield was noticed with respect to weed management practices (Table 2). Significantly higher corm yield was registered with T_9 (WCGC) as compared to other treatments. The treatment T_9 (WCGC) recorded with 335% higher corm yield over that of 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) andT_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 for longer period might have contributed in improving the growth and development of elephant foot yam which was

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

Treatment	Weed biomass (g m^{-2})	Weed control efficiency (%)	Corm yield (t ha^{-1})	Yield response (%)
T_1-Pendimethalin @ 1000 g ha^{-1} [at 1 DAP)] + glyphosate @ 2000 g ha-1 (at 90 DAP)	7.5 (54.7)	77.3	24.4	183.7
T_2-Metribuzin @ 525 g ha^{-1} (at 1 DAP) + Glyphosate @ 2000 g ha^{-1} (at 90 DAP)	7.6 (56.3)	76.5	23.6	174.4
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)	9.8 (94.7)	60.5	20.2	134.9
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)	9.9 (96.5)	59.8	19.5	126.7
T_5-Pendimethalin @ 1000 g ha^{-1} (at 1 DAP) + two manual weedings (at 60 & 90 DAP)	6.6 (43.1)	82.0	30.3	252.3
T_6-Metribuzin @ 525 g ha^{-1} (at 1 DAP) + two manual weedings (at 60 & 90 DAP)	6.9 (46.7)	80.5	28.4	230.2
T_7-Two manual weedings (at 30 and 60 DAP) + Glyphosate @ 2000 g ha^{-1} (at 90 DAP)	5.9 (33.4)	86.0	32.9	282.6
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)	7.1 (48.8)	79.6	26.1	203.5
T_9-Weed control ground cover (WCGC)	2.9 (7.4)	96.9	37.4	334.9
T_{10}-Four manual weedings (at 30, 60, 90 and 120 DAP)	3.8 (13.2)	94.5	33.7	291.9
T_{11}-Control (weedy check)	15.5 (239.7)	-	8.6	-
CD (P=0.05)	0.3	-	2.84	-

ultimately 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 metribuzin. Among the post-emergence herbicides glyphosate was found very effective than tank mix of pyrithiobacsodium and propiquizafop. The present study also indicated that T_{10} (four manual weedingsat 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. Farmers can choose weed management options depending on financial and labour availability for weeding. 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 physico-chemical properties

Weed management practices influenced the post harvest soil pH, which varied from 6.49 to 7.01 (Table 3). The treatment T_9 resulted in higher soil pH. Application of post emergence herbicides glyphosate and tank mix of pyrithiobacsodium and propiquizafop (T_1, T_2, T_3, T_4, T_7 and T_8) also recorded greater soil pH. The treatment T_{11} (weedy check) recorded higher soil pH than hand weeding treatments. The lowest soil pH was observed in T_{10} (four manual weedingsat 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 pyrithiobacsodium and propiquizafop (T_1, T_2, T_3, T_4, T_7 and T_8) resulted in higher build up of organic carbon. Post emergence application of herbicides glyphosate treated plots resulted in higher soil organic carbon. Highest organic carbon content was observed in the treatment T_7. The greater 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 hand weeding treatments. Increased number of manual weedings decreased the soil organic carbon content. The treatment T_{10} (four manual weedings at 30, 60, 90 and 120 DAP) resulted in lower soil organic carbon, which might be due to clean cultivation as well as continuous disturbance and exposure of soil enhances the 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 residues to the soil is very negligible in this treatment. Elephant foot yam produces 3-4 leaves with petioles and pseudo stem per plant during the crop growth period, which was 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 contents were increased in all the treatments except T_{11}, T_6 and T_5 as compared to initial status, whereas, the 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, 24.6-36.5 and 161-194 kg ha^{-1}, respectively (Table 3). Maximum available N, P and K was recorded in WCGC. This might be due to prevention of weed growth and consequently nutrient uptake by the 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 stage as well as suppression of weeds at later stage. 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 available N, P and K status in the soil due to application of pre (Pendimethalin and oxyfluorfen) and post (Oxadiargyl) emergence herbicides. The treatment T_{10} also resulted in higher available nutrient status of the soil in comparison to T_5, T_6 and T_{11} owing to frequent weeding which 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.

Application of FYM and inorganic fertilizers uniformly in all the treatments resulted a significant improvement in the available N, P and K. Increase in available P content of the soil attributed by decomposition of organic manures which could have enhanced the

Table 3. *Effect of herbicides on physico-chemical properties of the soil*

Treatment	pH	Org. 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

labile P in the soil by complexing Ca, Mg and Al and solubilization of phosphate rich organic compounds through release of organic acids upon decomposition of organic matter and chelation of organic anions with Fe and Al resulting effective solubilization of inorganic phosphates in the soil (Subba Rao, 2009). Accumulation of available K in the soils seems that the crop requirements were partly met from the released K and both the applied K and released K brought out available K build up in the soil. The differential release pattern of non-exchangeable K from the soil reserve besides variation in K uptake by the crop was responsible for such differences in the available K status of the soil (Svotwa *et al*., 2007).

No significant variations were observed in respect of available Fe, Cu and Mn in the soil due to weed management practices (Table 3), however, the available Zn showed significant variations due to weeding practices. 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 available Fe, Cu, Mn and Zn status of the soil. 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 of crop growth. 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 macro and micro nutrients status of 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 plant nutrients from the soil. Both Fe and Mn contents in the post harvested soils were found greater than the critical limits of 4.0 and 2.0 mg kg^{-1}, respectively which 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 population

Weed management practices significantly influenced the soil microbial population (Table 4). Maximum counts of fungi, bacteria and actinomycetes were recorded 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 were also resulted in greater 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 of weeds. Soil microbes were significantly and

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

Treatment	Fungi ($x10^4$cfu g^{-1})	Bacteria ($x10^5$cfu g^{-1})	Actinomycetes ($x10^4$cfu g^{-1})	Dehydrogenase (µg TPF hr^{-1} g^{-1})	Fluorescein diacetate (µg g^{-1} hr^{-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	-	-	-	-

positively correlated with organic carbon content of the soil (Table 5). Immediately after herbicide application a decreasing trend of microbial population was noticed, but 15-20 days after application when the applied herbicides gets degraded and multiplication of the microbes starts. 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 of microbial counts initially but with the degradation of applied herbicides within a considerable time, the populations later even exceeded the initial count. In the present experiment, the increase of microbial populations in post emergence application of glyphosate might be due to increase of 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 of 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 glyphosate binds to soil, it becomes inactive, losing its antimicrobial properties and can be readily degraded by microorganisms to CO_2 and the microbes 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 population was 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 making the environment 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 population with the increased available nutrient status of the soil play a significant role in organic matter decomposition as well as transformation of nutrients. Soil microbial population was significantly and positively

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

Microbes/enzyme	pH	Org. 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 ** denotes that the correlation is significant at 5 and 1% level, respectively

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 ** denotes that the correlation is significant at 5 and 1% level, respectively

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 weedingsat 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 (Tables 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 were 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 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 weedingsat 30, 60, 90 and 120 DAP). This might be ascribed to lower organic carbon content and microbial activity in the soil.

The results in Table 7 showed that dehydrogenase activity and FDA had highly significant relationship with corm yield of elephant foot yam (r = 0.87** and 0.82**, respectively). Among the soil microbes, actinomycetes had significant relationship with corm yield of elephant foot yam (r = 0.85**) rather than other microbes. Application of organic amendments along with recommended doses of NPK fertilizers at balanced proportion not only helps to augment the crop yields but also enhances the microbial activities. Organic amendments and associated plant residues may supply additional sources of labile C and P to soil, which can stimulate microbial growth and biochemical activity. Alkaline phosphomonoesterase showed significantly higher relationship with corm yield (r = 0.96**) rather than acid phosphomonoesterase (r = 0.93**). Weed biomass had significantly negative relationship with the soil microbes and enzyme activities, indicating that the higher weed dry matter suppress the microbial activities and causes significant reduction of crop yields.

Weed management practices significantly influenced the corm yield of elephant foot yam and soil health. Use

Table 7. *Correlation coefficients (r) between soil micro-flora and enzyme activities with corm yield of elephant foot yam*

Parameter	Fungi	Bacteria	Actinomycetes	DHA	FDA	Acid phosphatase	Alkaline phosphatase
Corm yield	0.81**	0.81**	0.85**	0.87**	0.82**	0.93**	0.96**
Weed dry matter	-0.65*	-0.68*	-0.74**	-0.67*	-0.66*	-0.76**	-0.81**

* and** Significant at 5 and 1.0 per cent level, respectively

of weed control ground cover resulted in higher corm yields of elephant foot yam because of greater weed control efficiency by suppression of weed growth. It also resulted in greater 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 was also equally effective to produce higher corm yields, but recorded lower soil organic carbon, available nutrients and microbial activities. Thus, weed control ground cover is considered as 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) combined with spraying of 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 combined with application of post emergence herbicide *i.e*., glyphosate at 90 DAP can be a cost effective weed management option. However, to prevent herbicide resistant weeds, alternative herbicides should be rotated along with cultural management of weeds in elephant foot yam.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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