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Weed management strategies in elephant foot yam (*Amorphophallus paeoniifolius*) under different agro environments in India

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ABSTRACT

In elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson], weeds are the major constraints cause yield reduction up to 100% due to its very slow initial sprouting, establishment and plant growth. Information on proper weed management in elephant foot yam in India is limited as its commercial cultivation started very recently. For arriving at suitable and better weed control, field experiments were conducted for 3 growing seasons (2019 to 2021) at ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala with 8 treatments in 6 different agro-climatic zones of India. The treatments included a combination of pre emergence (PE) and post emergence (POE) herbicides, PE followed by hand weeding (HW), intercropping followed by POE, HW with POE, POE alone, and weed control ground cover cloth mulch (WCGCC), three HW, and a weedy check were included for comparison. Weed flora was dominated by broad-leaf weeds, *Digera arvensis* (L.), *Commelina benghalensis* (L.); grasses, *Pennisetum pedicellatum* Trin., *Cynodon dactylon* (L.) pers.; and the sedge, *Cyperus rotundus* (L.), in most of the locations. Pooled analysis of data collected over different locations indicated that the lower mean weed biomass (21.24 g/m) and higher mean corm yield (35.13 t/ha), higher mean net income (₹0.326 million/ha) were recorded with weed control ground cover mulch and higher mean B:C ratio (2.39) by application of post emergence herbicide at 30, 60 and 90 days after planting (DAP).

Keywords: Corm yield, Elephant foot yam, Herbicide, Net return, Weeding

Elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] is a tuberous vegetable grown in tropical and subtropical areas. This crop became a cash crop due to its higher productivity and popularity as a vegetable in different cuisines, and therapeutic importance (Chandrasekara and Kumar 2016). This crop is cultivated approximately in 40,000 ha with a production of 1.0 million metric tonnes in India (NHB 2022). Weeds are potentially major constraints and play a significant role in producing yield and quality produce in elephant foot yam, and other tuber crops as they compete for various resources and reduce the quality (Suresh *et al.* 2020b). Weeds often germinate and grow earlier than the elephant foot yam due to slow sprouting (30–90 days for bud development, sprouting and unfolding of canopy based on soil micro climate) of seeds (corms and corm setts) (Sunitha *et al.* 2018). Planting at wider spacing (90 cm × 90 cm), coupled with characteristic plant morphology (erect single pseudostem with a leaf), allows weed infestation throughout the cropping season. But initial 1 and 5 months after planting is critical period of crop-weed competition, as crop growth and corm bulking observed during this period. The weed infestation during the critical periods may cause higher yield loss up to 100% (Suresh *et al.* 2020a).

Manual weeding consumes more than 30% of the total labour (approx. 150–200 man days/ha) (Nedunchezhiyan *et al.* 2018). Due to higher labour price and non availability of manual labour the alternative mechanisms like application of herbicides is more efficient (Suresh *et al.* 2020a). Residues of some applied herbicides in the field and in the harvested produce may harm the soil microbial population and consumers. Hence alternative techniques, namely preventive methods, cultural, biological, and mechanical methods

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will reduce the weed menace (Das *et al.* 2012, Awasthy *et al.* 2014, Verma *et al.* 2015, Suja *et al.* 2021). Apart from individual weed management techniques, integrated weed management (IWM) has the potential to reduce weed population to below critical levels, has less impact on environment. This study was carried out at various agro-climatic conditions of India to find out the most effective weed management option in this crop.

MATERIALS AND METHODS

Field experiments were conducted for 3 growing seasons during 2019 to 2021, at 6 locations [BCKV, Kalyani (Lower Gangetic plains zone); ICAR-RC, Lembucherra, Tripura (Eastern Himalayan zone); Dr YSRHU, Kovvur, Andhra Pradesh (East Coast plains and hills zone); NAU, Navsari, Gujarat (Gujarat plains and hills zone); TNAU, Coimbatore, Tamil Nadu (Southern plateau and hills zone); BAU, Ranchi, Jharkhand (Eastern plateau and hills zone)] of India representing different agro-climatic zones (Khanna 1989).

The experiment was laid out in randomized block design (RBD) with 3 replications and 8 treatments, viz. T_1, pendimethalin 1.0 kg active ingredient (ai)/ha (PE-pre emergence) + followed by (*fb*) glyphosate 0.86 kg acid equivalent (ae)/ha (POE- post emergence) at 45 and 90 DAP (days after planting); T_2, pendimethalin 1.0 kg ai/ha (PE) + *fb* hand weeding 45 and 90 DAP; T_3, raising green manure cowpea in interspaces along with planting and incorporation 45–60 DAP + *fb* glyphosate 0.86 kg ae/ha (POE) at 90 DAP; T_4, hand weeding 45 DAP + *fb* glyphosate 0.86 kg ae/ha (POE) at 90 DAP; T_5, glyphosate 0.86 kg ae/ha (POE) at 30, 60 and 90 DAP; T_6, perforated weed control ground cover cloth (120 gsm) mulching (weed mat); T_7, Hand weeding at 30, 60, 90 and 120 DAP; and T_8, unweeded control.

The gross plot size was 4.5 m × 4.5 m, and plant to plant spacing of 90 cm × 90 cm was followed, to accommodate 25 plants in each plot (Sunitha *et al.* 2020a). All other crop management practices were followed as per ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala PoP (package of practices) (Mohan *et al.* 2000) except weed management practices to raise the crop. Healthy cut corm pieces of variety Gajendra, weighing approx. 500 g, were treated with cow dung slurry mixed in fungicide one day prior to planting and shade dried for curing of cut portions. Pre-emergence herbicide was sprayed with knapsack sprayer on wet soil surface before planting the seed corm for higher efficiency. Post emergence herbicide glyphosate was applied on weeds, care was taken for avoiding drift. Weed control porus ground cover cloth (weed mat) is a polypropylene woven fabric (120 g/m^2), which allows air and water to pass through to the soil, but suppresses weed growth. Weed mat mulching was done immediately after planting, leaving the planted zone for easy shoot emergence.

From each net plot, five representative plants were selected for different observations. Plant height, pseudo stem girth, canopy spread and leaf area (Ravi *et al.* 2011) were recorded. Weed data i.e. weed species, density and dry weight, weed index (WI) (Gill and Kumar 1969) and weed control efficiency (WCE) (Patil and Patil 1993) were recorded. Corm yield per ha, and economics were calculated. Data were analysed in SAS statistical software (Version 9.4, SAS Institute, Inc., Cary, NC, USA). Treatment means were compared using least significant difference (LSD) at ≤0.05 probabilities.

RESULTS AND DISCUSSION

There was a strong effect of location, treatment, and interaction of them on weed parameters, crop growth parameters, yield, and economics. Data were combined over years and pooled analysis was carried out. The interaction effect of year, location, and weed control treatment for all these attributes was not significant, hence only significant and prominent factors are described. Broad leaf weeds, viz. *Digera arvensis* (L.), *Commelina benghalensis* (L.), grasses, viz. *Pennisetum pedicellatum* Trin., *Cynodon dactylon* (L.)

Table 1 The mean values of dry weight of weeds (g/m^2) for different treatments at study locations (pooled over years)

Treatment	Location						Mean
	LCR	KVR	CBE	KLN	NVSR	RAN	
T_1	14.89^{nop}	150.69^{bc}	11.36^{nop}	82.10^{fgh}	4.00^{op}	20.02^{nop}	47.17^{b}
T_2	17.49^{nop}	133.74^{cd}	13.22^{nop}	69.47^{ghi}	3.28^{p}	19.28^{nop}	$42.75b^{c}$
T_3	16.63^{nop}	49.14^{ijklm}	16.52^{nop}	62.83^{ghij}	4.12^{op}	19.75^{nop}	28.17^{de}
T_4	22.72^{mnop}	114.29^{de}	15.20^{nop}	86.31^{fg}	3.42^{p}	22.37^{mnop}	44.05^{b}
T_5	13.88^{nop}	100.67^{ef}	12.47^{nop}	49.18^{ijklm}	1.73^{p}	17.80^{nop}	32.62^{cd}
T_6	18.63^{nop}	35.15^{klmn}	10.42^{nop}	37.37^{jklmn}	0.70^{p}	25.151^{mnop}	21.24^{e}
T_7	14.12^{nop}	163.28^{b}	21.04^{nop}	64.06^{ghij}	4.34^{op}	6.78^{op}	45.60^{b}
T_8	58.40^{ijkl}	500.51^{a}	50.48^{ijkl}	138.77^{bcd}	12.67^{nop}	30.88^{lmno}	131.95^{a}
Mean	22.10^{c}	155.93^{a}	18.84^{c}	73.76^{b}	4.28^{d}	20.26^{c}	

[a] Values followed by the same letter are not significantly different, P = 0.05. Treatment details are given under Materials and Methods.

LCR = Lembucherra, Tripura; KVR = Kovvur, Andhra Pradesh; CBE = Coimbatore, Tamil Nadu; KLN = Kalyani, West Bengal; NVSR = Navsari, Gujarat; RAN= Ranchi, Jharkhand.

Table 2 The mean values of corm yield per hectare (t/ha) for different treatments at study locations (pooled over years)

Treatment	Location						Mean
	LCR	KVR	CBE	KLN	NVSR	RAN	
T_1	22.52^{nopq}	23.08^{mnopq}	44.06^{bcde}	42.35^{cdef}	19.44^{qr}	32.89^{jk}	30.72^{cd}
T_2	20.80^{pqr}	25.04^{lmnop}	41.34^{defg}	39.28^{efgh}	19.69^{qr}	42.44^{cdef}	31.43^{bc}
T_3	21.44^{opqr}	33.06^{ijk}	37.95^{fghi}	41.42^{defg}	20.74^{pqr}	39.39^{efgh}	32.33^{bc}
T_4	20.63^{pqr}	21.94^{opqr}	35.96^{hij}	38.86^{fgh}	17.34^{rs}	38.28^{fgh}	28.84^{d}
T_5	22.56^{nopq}	24.93^{lmnop}	40.34^{defgh}	46.64^{abc}	27.76^{lm}	47.79^{ab}	35.00^{a}
T_6	21.67^{opqr}	33.26^{ijk}	44.84^{bcd}	46.46^{bc}	27.44^{lmn}	37.08^{ghij}	35.13^{a}
T_7	23.04^{mnopq}	26.04^{lmno}	37.57^{fghij}	41.13^{defg}	19.60^{qr}	51.54^{a}	33.15^{ab}
T_8	8.49^{t}	13.08st	25.19^{lmnop}	29.52^{kl}	11.99^{t}	25.60^{lmnop}	18.98^{e}
Mean	20.14^{d}	25.06^{c}	38.41^{b}	40.71^{a}	20.50^{d}	39.38^{ab}	

[a] Values followed by the same letter are not significantly different, P = 0.05. Treatment details are given under Materials and Methods.

LCR = Lembucherra, Tripura; KVR = Kovvur, Andhra Pradesh; CBE = Coimbatore, Tamil Nadu; KLN = Kalyani, West Bengal; NVSR = Navsari, Gujarat; RAN= Ranchi, Jharkhand.

pers.; and the sedge *Cyperus rotundus* (L.) were the dominant weed species in most of the experimented locations. All weed control treatments had significantly lowered weeds than the un-weeded control plot. Lower weed density and weed biomass were recorded by T_6 (weed mat) treatment. The weed density and weed dry biomass were significantly higher in the weedy check (T_8) (Table 1). Out of the six locations, at majority of the locations (Kovvur, Coimbatore, Kalyani, Navsari) lower weed biomass was recorded in T_6 treatment, where weed mat was used. This was on par with T_5 [application of post emergence herbicide (glyphosate) at 30, 60 and 90 DAP] at majority of the locations (Lembucherra, Kalyani, Navsari, Ranchi); T_2 (pre-emergence herbicide applied at 1 DAP followed by post emergence herbicide applied at 45 and 90 DAP) at Coimbatore. Lower weed biomass was observed in T_6 treatment, it was acted as effective mulch by completely covering the ground and prevented weed growth. Similar effects of weed mat has been reported by Sekhar *et al.* (2017), Nedunchezhiyan *et al.* (2017), Nedunchezhiyan *et al.* (2018), Suresh *et al.* (2020a) and Suresh *et al.* (2020b) in elephant foot yam and Suja *et al.* (2021) in cassava.

Weed control efficiency (WCE) of treatments ranged between 64.25–83.90% (Fig 1). Higher WCE of 83.90% was observed in T_6 (weed mat) followed by 78.65% with T_3 (green manure *in situ* in inter spaces and soil incorporation, followed by glyphosate at 90 DAP). Weed index (WI) ranged from -5.97 to 42.75 (Fig 1). Higher weed index was observed in T_8 (weedy check) and the effective weed control treatment with lower weed index was recorded in T_6 (weed mat). Better WCE with weed mat was reported by George and Sindhu (2017), Nedunzhiyan *et al.* (2017), Nedunzhiyan *et al.* (2018), Suresh *et al.* (2020b) in elephant foot yam, and Nedunzhiyan *et al.* (2017) in cassava.

Weed management methods significantly influenced the growth of the plant, viz. height, pseudostem girth, canopy spread and leaf area. Leaf area index (LAI) was measured at 3 and 5 months after planting (Fig 2). At 3 MAP, the highest LAI was recorded in treatment T_5 (0.55), T_7 (0.53), which was at par with treatment T_6 (0.53) and T_3 (0.51). Significantly poor LAI was observed in weedy check (0.37). At 5 MAP, the highest LAI was recorded in treatment T_5 (0.81) which was at par with treatment T_7 (0.80). Higher LAI was observed in treatments namely three sprays of post emergence herbicide, hand weeding thrice and weed mat due to less weed competition and active growth of the plants. The linear relationship between LAI during active growth stage and the yield was observed in different crops by Guillaume *et al.* (2012), Brogi *et al.* (2020).

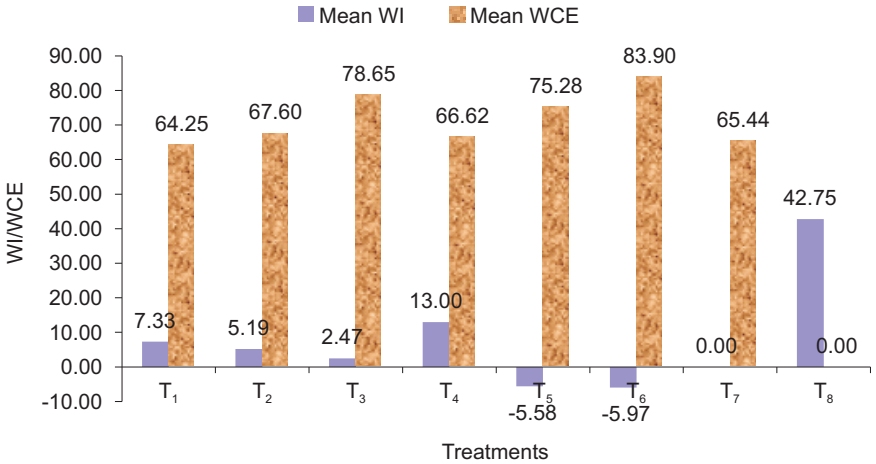

Fig 1 Means of weed index (WI) and weed control efficiency (WCE) of different treatments over locations and years.

Elephant foot yam corm yield per plant and per hectare significantly differed for weed management methods over locations, treatments, years and for treatment × location interaction. Overall mean for corm yield per

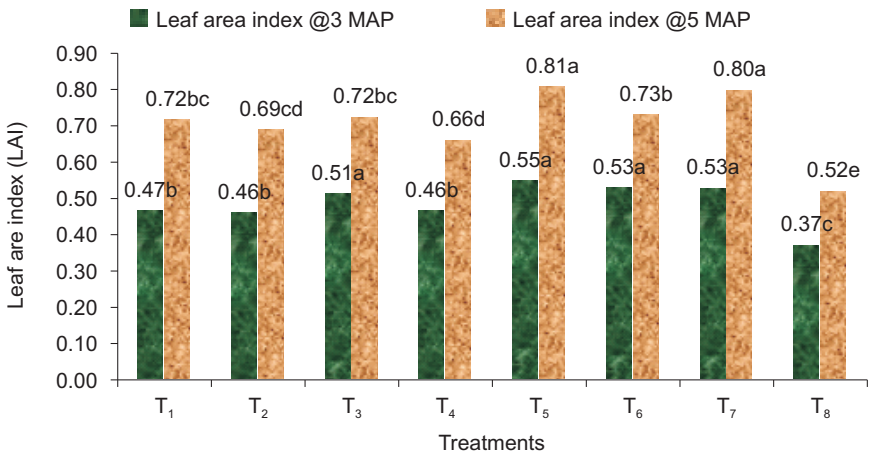

Fig 2 Means of leaf area index (LAI) of different treatments over locations and years.

hectare was significantly higher in T_6 (35.13 t/ha) i.e. 85.08% over unweeded control (T_8), and was statistically on par with T_5 (35.00 t/ha) treatment (application of 3 sprays of post emergence herbicide at 30, 60 and 90 DAP) (35.00 t/ha), which was 84.41% higher than the un-weeded control. Among the 6 locations, majority of the locations (Kovvur, Coimbatore, Kalyani, Navsari) recorded higher yields in weed mat plots (T_6), which was on par with treatment 3 sprays of glyphosate at 30, 60 and 90 DAP (T_5) of 2 locations (Kalyani, Navsari). Hand weeded thrice plot (T_7) recorded significantly higher corm yield per hectare at 2 locations (Lembucherra and Ranchi) and was on par with treatment T_5 (3 sprays of glyphosate at 30, 60 and 90 DAP) (Table 2). Effective weed control and higher growth attributed to more corm yield. Poor crop growth, low yields was recorded due to severe crop weed competition during critical period in weedy check at all locations. Suja *et al.* (2021) reported significant beneficial effects of weed mat in cassava, and Sekhar *et al.* (2017), Nedunchezhiyan *et al.* (2017), Nedunchezhiyan *et al.* (2018), Suresh *et al.* (2020a), Suresh *et al.* (2020b) in corm yield of elephant foot yam. The positive effects of weed mat in terms of soil moisture conservation, weed control and increased activity of soil microbes was reported by Nedunchezhiyan *et al.* (2018) and Suresh *et al.* (2019). Mulching with weed mat observed excellent water productivity, reduced requirement of irrigation water up to 50% and corm yield of elephant foot yam was increased by 8–12% and energy use efficiency was increased by 24–28% as compared to 100% irrigation (Sunitha *et al.* 2020b).

Greater corm bulking efficiency (corm yield per plant/weight of corm planted) was observed under T_6, weed mat plots (5.69); which was followed by T_5, three sprays of post emergence herbicides (5.67), T_7, hand weeded thrice plots (5.37) (Fig 3). Corm bulking efficiency largely depends upon the size and nature of planting material (whole seed corm or cut pieces), planted spacing and the cultivation practices (Ravi *et al.* 2011). In the current experiments, seed material (cut corms of 500 g) were planted uniformly, hence the differences observed in bulking across various treatments could be attributed to the crop-weed competition during corm bulking period.

Interaction of location × treatments showed significant variation in net returns (Table 3). Significantly higher mean net income was observed in treatment weed mat (T_6) (₹3.26 lakh/ha). Poor net come was recorded by uncontrolled plots (T_8) (0.85 lakh ₹/ha). Among the locations, the higher net income (4.53 lakh ₹/ha) was recorded at Lembucherra in treatment T_1, pre-emergence herbicide (pendimethalin applied at 1 DAP) followed by post emergence herbicide (glyphosate) applied at 45 and 90 DAP, and in T_5 (post emergence herbicide alone 3 sprays) (4.50 lakh ₹/ha). This is due to the lower cost of weed management with herbicides compared to higher labour wages per hand weeding. At Kalyani and Navsari, treatment (T_5) post emergence herbicide alone applied at 30, 60 and 90 DAP recorded significantly higher net incomes (3.99, 3.15 lakh ₹/ha respectively) and at Kalyani it was at par with T_6 (3.89 lakh ₹/ha). Significantly higher mean B:C ratio was observed in treatment T_6, weed mat (2.39) (Table 3). Poor B:C ratio was recorded by uncontrolled plots (T_8) (1.21). At Kalyani, Navsari and Ranchi higher B:C ratio was recorded by treatment T_5 (post emergence herbicide 3 sprays). At Lembucherra, T_1 (pre emergence followed by post emergence herbicide) recorded higher B:C ratio and was at par with T_5. This might be due to the reason that the cost of weed management with herbicides is lower than other methods.

Weeds are a major constraint in elephant foot yam, may

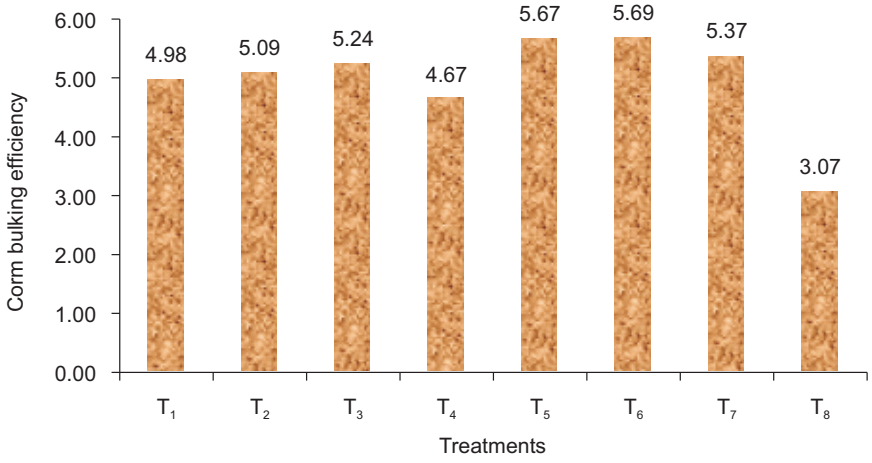

Fig 3 Means of corm bulking efficiency of different treatments over locations and years.

Table 3 The mean values of net income (lakhs ₹/ha), B:C ratio for different treatments at study locations (pooled over years0

Treatment	Locations						Mean
	LCR	KVR	CBE	KLN	NVSR	RAN	
T_1	4.53^{a} (4.36^{a})	0.94^{stu} (1.82^{jklmno})	3.40^{efg} (2.14^{fgh})	3.43^{defg} ($1.91^{hijklmn}$)	1.56^{pqr} (1.07^{stu})	1.45^{qrs} (1.42^{qr})	2.55^{c} (2.12^{b})
T_2	4.05^{abc} (3.44^{bc})	1.13^{rst} (1.94^{hijklm})	3.14^{ghij} (2.06^{fghi})	3.05^{ghijk} (1.72^{mnop})	1.45^{qrs} (0.97^{tu})	2.83^{hijkl} (1.81^{jklmno})	2.61^{bc} (1.99^{d})
T_3	4.09^{ab} (3.60^{b})	1.80^{opq} (2.45^{e})	2.79^{ijkl} (1.93^{hijklm})	3.36^{efgh} (1.97^{ghijk})	1.80^{opq} (1.06^{stu})	2.39^{lmn} (1.68^{nop})	2.70^{bc} (2.11^{b})
T_4	3.89^{bcde} (3.38^{bc})	0.85^{tu} (1.74^{klmnop})	2.69^{jkl} (2.00^{ghij})	3.10^{ghijk} ($1.84^{ijklmno}$)	1.13^{rst} (0.87^{u})	2.28^{lmno} (1.66^{op})	2.32^{d} (1.92^{d})
T_5	4.50^{a} (4.29^{a})	1.19^{rst} (2.02^{ghij})	2.98^{ghijk} (1.95^{ghijkl})	3.99^{abcd} (2.27^{ef})	3.15^{ghij} (1.73^{lmnop})	3.72^{bcdef} (2.09^{fgh})	3.26^{a} (2.39^{a})
T_6	3.22^{fghij} (3.23^{cd})	1.60^{pqr} (2.17^{fg})	3.52^{cdefg} (2.26^{ef})	3.89^{bcde} (2.10^{fgh})	2.51^{klm} (1.21^{rs})	1.94^{nopq} (1.55^{pq})	2.77^{bc} (2.09^{bc})
T_7	4.04^{abc} (3.13^{d})	1.17^{rst} (1.98^{ghij})	2.78^{ijkl} ($1.95^{ghijklm}$)	3.26^{fghi} ($1.84^{ijklmno}$)	1.55^{qr} (1.00^{stu})	4.00^{abc} (2.08^{fgh})	2.80^{b} (2.00^{cd})
T_8	0.77^{tu} (1.82^{jklmno})	0.11^{v} (1.12^{st})	1.47^{qrs} (1.40^{qr})	2.11^{mnop} (1.39^{qr})	0.16^{v} (0.39^{v})	0.49^{uv} (1.15^{st})	0.85^{e} (1.21^{e})
Mean	3.63^{a} (3.41^{a})	1.00^{f} (1.90^{b})	2.85^{c} (1.96^{b})	3.27^{b} (1.88^{b})	1.66^{e} (1.04^{d})	2.39^{d} (1.68^{c})	

[a] Values followed by the same letter are not significantly different, P = 0.05. [()]Values in the parenthesis are B:C ratio. Treatment details are given under Materials and Methods.

LCR = Lembucherra, Tripura; KVR = Kovvur, Andhra Pradesh; CBE = Coimbatore, Tamil Nadu; KLN = Lalyani, West Bengal; NVSR = Navsari, Gujarat; RAN= Ranchi, Jharkhand

causes up to 100% yield loss. Means of the treatments at different locations pooled over years indicated that weed mat produced the highest tuber yield, recorded 45.97% higher yield over control and it was on par with treatments three sprays of post emergence herbicide glyphosate, and hand weeded thrice plots by hand weeding. Higher cost of material and labour needed for laying this mulch makes weed mat next best in terms of net income over chemical weeding. Proper handling and repeated usage of it over years can help in reducing the costs involved, thus the net income and B:C ratio. It can be concluded that mulching with weed mat, herbicides and hand weeding are the suitable options available for effective weed management in elephant foot yam. Among the three methods, weed mat mulching is a safe and sustainable alternative to chemical and manual methods of weed control in elephant foot yam due to no risk bearing chemical residue like herbicides, and needs less labour over hand weeding, conserve soil moisture, control weed growth. The approximate mandays for hand weeding from 150–200/ha could be reduced to 50/ha by following weed mat mulch, and 15–20 labour for chemical application per hectare by knapsack sprayer. This could reduce the dependence on labour and save time, and money.

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