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Appraisal of the Weed Seedbank in Low-grown Tea (*Camellia sinensis* [(L) O. Kuntze]) Soil under different Weed Management Techniques

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ABSTRACT

A field experiment was conducted at the Low country Regional Centre, Tea Research Institute, Sri Lanka during the period of 1994 - 1995 to investigate the density of weed seedbank in soil in relation to different weed management methods during first year of planting of tea. Manual (hand) weeding at 2, 6, 12 and 18 week intervals and herbicides such as Glyphosate, 2, 4-D, Glufosinate Ammonium, Paraquat and Oxyfluorfen and some combinations of them at varied intervals were imposed on mulched plots. One slash weeding, every 6 weeks and Paraquat + Oxyfluorfen combination were imposed on unmulched plots. Weed seedbanks were determined using both 'seed germination' and "Malone's seed extraction" methods before and 12 months after planting (MAP) of tea. There were no significant differences ($p=0.05$) in seed density between plots before and after planting tea. However, weed seed density at both 0-5 and 5-15 cm depths was significantly different between treatments, 12 MAP. The highest weed seed density (4168 m^{-2}) at 0-5 cm depth from mulched plots hand weeded every 6 weeks was significantly ($p=0.05$) greater than that of plots hand weeded every two weeks and plots were treated with Glyphosate and the combination of Oxyfluorfen + Paraquat. The greatest seed density of 5520 m^{-2} at 5-15 cm depth was from unmulched plots, slash weeded every 6 weeks and this was significantly ($p=0.05$) greater than that of all treatments except for plots hand weeded every 18 weeks. All hand weeding except for weeding every two weeks and, slash weeding every six weeks treatments had thus significantly greater seed densities at the total depth of 0-15 cm compared to all chemical weeding treatments 12 MAP. Whereas, the seed density was not significantly ($p=0.05$) affected by any treatment 12 MAP when compared with before planting tea. Mean weed species number significantly increased 12 MAP (23.2±0.66) when compared with that of before imposition of manual weeding treatments (16±2.45) and herbicide treatments 12 MAP (17.8±1.52). Whereas, there was no significant difference in species number between chemically treated plots before (14±1.26) and 12 MAP. Majority of seeds found in all treatments, particularly of plots weeded every 6 weeks was of

desirable herbs on tea. Mulching alone is found to be unimportant in view of weed seed bank in the soil. An integrated approach, where the hand weeding at intervals of <12 weeks is practised and a herbicide particularly a combination of Oxyfluorfen and Paraquat is applied at tender phase of weed growth was found to be effective in the mitigation of weed seed bank in tea soil.

Key words: Chemical weeding, Manual weeding, Mulching, Weed management in tea, Weed seedbank

INTRODUCTION

Weed management in tea plantations is a critically important operation, particularly during early period of tea establishment (Somaratne, 1988) as weeds interfere with tea and interrupt the major field operations such as plucking, fertilizer application and pruning. Weed competition becomes more adverse if weeding was delayed for more than three months (Prematilake *et al.*, 1999). Among the possible causes for profuse weed growth in tea fields, presence of a 'weed seed stock' which is termed 'weed seedbank' in soil has a major attribution because, it could continuously release viable seeds for germination followed by weed growth. Weed seedbank has been referred to as reserves of seed present in the soil and on its surface (Roberts, 1981). Seedbanks in cultivated soils are derived from seeds produced *in situ* and those that have been introduced from elsewhere (Froud-Williams *et al.*, 1983).

Quantitative appraisal of weed seeds in soil under different agronomic conditions is particularly important in planning and providing a basis for advice on control measures (Wilson and Cussans, 1975). Furthermore, investigations on species composition provide a basis for estimating the future weed infestation (Ball and Miller, 1989) and helps in planning of control strategies (Roberts, 1981).

Although it is more costly and laborious, the manual weeding is still practised as a major operation in young tea at present, because any herbicide-based system cannot be adhered to throughout as young tea is more vulnerable for herbicide toxicity. Hence, it is more appropriate to use an integrated weed management system, where manual and cultural methods are practised together with a suitable herbicide. Understanding of the size and behavior of weed seed bank in soil will help in planning economical control stratergies. The objectives of the present study are therefore to assess the density of weed seed bank in the soil and its composition in relation to different weed management techniques practised in newly planted tea at low elevation in Sri Lanka.

MATERIALS AND METHODS

A field experiment was conducted at the Low country Regional Centre of the Tea Research Institute, Ratnapura, Sri Lanka to estimate the weed seed bank of soils of newly planted tea under different weed management techniques, during the period of June 1994 to June 1995. The elevation of the experimental site is about 60 m amsl (the latitude: 6° 41' N and longitude 80° 24' E) and the soil type is an Ultisol sandy loam. The annual rainfall is 2500-3000mm and the mean ambient temperature is 28 °C.

An old tea block with some vacancies, which were infested with weeds was selected for the investigation. Following uprooting of old tea a thorough land preparation was done in order to remove all roots and boulders, and also to keep the field weed free. Drains were also cut. Field was then planted with Mana grass (*Cymbopogon confertiflorus*) for soil rehabilitation at spacing of 0.6 - 0.9 m x 0.15 m, for a period of 24 months. Wetamara (*Gliricidia sepium*) was planted at a spacing of 2.4 m x 3.0 m as shade trees. Mana grass was cut every six months and thatched *in situ*, and finally it was cut from the base and thatched in May 1994. Planting holes (45 cm deep) were dug along the contours at a spacing of 1.2 m x 0.6 m and 8-month old poly bagged tea plants (variety KEN 16/3) were planted in holes on 15th June 1994. Forty plots each consisting of 30 tea plants were thus demarcated, leaving two rows of tea plants in the periphery of each plot as guard rows. All plots were properly hand weeded prior to allocation of treatments.

Treatment combinations

There were two component studies on weed management during early establishment of tea in Low country. In the first investigation, all present weed management methods were evaluated and findings were published elsewhere (Prematilake *et al.*, 2004). The second investigation was undertaken on weed seedbank in soil before and after imposition of above weed management methods. Therefore, treatment combinations were same in both investigations.

Thus, four hand pulling treatments to mulched plots at different intervals (T1-T4) and one slash weeding treatment (T5) to unmulched plots at 6-week intervals were imposed as manual weeding practices. Another four herbicide combinations to mulched (T6-T9) plots and one herbicide combination to unmulched plots were also imposed (T10) as given below.

Treatment combinations

T1 Mulching + Hand weeding at 2 weeks interval
T2 Mulching + Hand weeding at 6 weeks interval
T3 Mulching + Hand weeding at 12 weeks interval

T4 Mulching + Hand weeding at 18 weeks interval

T5 No mulching + Slash weeding at 6 weeks interval

T6 Mulching + Glyphosate (36%)@ 0.99 kg a.i ha^{-1} + kaolin@ 3.42 kg ha^{-1}

T7 Mulching + 2, 4 - D (73%) @ 0.73 kg a. i. ha^{-1} + Paraquat (20%) @ 0.15-0.22 kg a.i. ha^{-1}

T8 Mulching + Glufosinate Ammonium (15%) @ 0.2 kg a.i.ha^{-1}

T9 Mulching + Oxyfluorfen (24%) @ 0.29 kg a.i. ha^{-1} + Paraquat @ 0.15-0.22 kg a.i. ha^{-1}

T10 No mulching + Oxyfluorfen (24%) @ 0.29 kg a.i. ha^{-1} + Paraquat @ 0.15-0.22 kg a.i. ha^{-1}

The experimental design was RCBD with four replications.

Tea inter-row spaces of plots for T1-T4 and T6-T9 were laid with fresh Mana (*Cymbopogon confertiflorus*) grass @ 37 tonnes ha^{-1} soon after planting tea and repeated twice in October and March 1995 (Table 1).

In unmulched plots (T5), the weeds found within tea inter-row spaces were retained as a live ground cover, slashed and removed at six week interval. For chemically treated plots, all herbicide solutions were applied at 550 L ha^{-1} along the tea inter-rows using a knapsack sprayer fixed with a Poli-Jet nozzle (Orifice size 042) and a spray guard. Herbicide treatments applied to mulched plots included split applications of Round up (glyphosate, 36%) (T6), split applications of Fernoxone (powdered formulation) (2, 4-D, 73%) alone and 2, 4-D + Gramoxone (Paraquat 20%) combination (T7), split applications of Basta (Glufosinate Ammonium, 15%) alone (T8). Goal-2E (Oxyfluorfen, 24%) was first applied directly to the bare soil soon after planting tea on T10 plots but on T9 plots prior to mulching. Another, two applications of oxyfluorfen in mixture with paraquat were applied in November 1994 and April 1995. Other herbicides were applied when weeds were 10-15 cm tall (Table 1). Weeds were hand pulled prior to application of fertilizer mixture (T-200 at 1500 kg ha^{-1} yr^{-1}) at two-month intervals in plots.

Weed seedbank determination

The weed seed density in soil was assessed following the 'Germination method' as described by Brenchley and Warrington (1930) and Roberts (1970) and was supported by additional seed extraction (Malone, 1967). A total of 15 soil samples were obtained randomly from the depth of 0-5 and 5-15 cm before planting tea (from an area of 218 cm^2) within and between tea rows in each plot, using a metal pipe (4.3 cm diameter) and stored in polythene bags at a mean temperature of 30°C until processing within a week period. Samples from the same depth in each plot were bulked to make a composite sample of 800 g and each was placed on a tray to a depth of 15 cm. Five trays filled

Table 1. Calendar of herbicide application, hand pulling mulching and sampling on chemical treated plots during the first year of establishment of tea in the field (15th June 1994-15th June 1995)

Month	June-July 94		Aug 94		Sep 94			Oct 94			
WAP	0	3	6	7	9	10	12	15	16	18	19
T6	M		-	Gly			Gly			w	M
T7	M	D	w			P	w		P	w	M
T8	M	w			GA			GA		w	M
T9	O/ M		w			P			P	w	M
T10	O					P			P	w	

Month	Nov 94		Dec 94			Jan 94		Feb 95		
WAP	22	23	25	26	28	29	31	32	34	36
T6	Gly			w		Gly		w		w
T7		P	D		w		P		D+P	w
T8			GA			GA				w
T9		O+P					P			w
T10		O+P					P			w

Month	Mar 95		Apr 95		May 95			June 95		
WAP	37	39	42	44	45	46	48	50	51	52
T6	M	Gly	w			Gly		w		s
T7	M				w		D	w		s
T8	M		w	GA			w			s
T9	M			O+P						s
T10				O+P						s

M : Mulching O : Oxyfluorfen D : 2,4-D
Gly : Glyphosate P : Paraquat GA : Glufosinate Ammonium
w : Hand pulling s : Soil sampling for seed bank assessments

with sterilized sand were used as the control. All trays were then placed in a screen house and protected from contamination by foreign air-borne weed seeds. Soil was kept moist as necessary, facilitating weed seed germination and frequently re-arranged to avoid differential light effects. Same procedure was followed for sampling and bulking of soils, 12 MAP of tea. To estimate the weed seed density, emerged seedlings of weed species were counted, identified and removed from trays weekly over a period of seven months, until further emergence ceased in both sample sets. Soil was disturbed at six week interval to facilitate germination of buried seeds. Seed and rhizome count was thus assessed in terms of the number of seedlings emerged. Subsequently, the balance of seeds in soil was isolated using Malone's seed extraction method in order to determine the actual number of viable seeds present. In this method seeds were recovered by

floating organic soil fraction on a dense liquid solution. One hundred grams of soil sample was mixed in a solution of 5, 10 and 25 g of sodium bicarbonate, sodium hexametaphosphate, and magnesium sulphate, respectively and 200 ml tap water. For dispersion of soil and floatation, soil was agitated in the solution for two minutes. Floating debris was then decanted and sieved for retention of even smallest seeds. This process was repeated three times. Debris on the sieve was washed with tap water to remove foam and small soil particles. All material collected in sieve were dried and removed for identification. Viability of extracted seeds was simply checked by pressing seeds with a forcep.

Statistical analysis

Count data (Seed No.) were first log transformed and they were subjected to analysis of variance (ANOVA) using SAS package. Mean separation was done using Least Significant Difference (LSD) and Standard Error (*se*) at p=0.05 probability level. The original values were used for interpretation of results. Weed species (seeds) numbers present at 0-5 cm depth, were listed with the Mean value and Standard Error (se).

RESULTS AND DISCUSSION

Weed seed density and composition prior to imposition of treatments

There was no significant difference in seed density among these plots at both depth (0-5 and 5-15 cm) (Table 2). However, the slight variation in seed density would be due to the spread of forty plots over a large area, 860 m^2, where soil fertility level and degree of infestation of weeds before planting grasses might have been varied. Vacancies in former old tea field were normally infested with many weeds. Furthermore, dispersal of weed seeds on plots through dissemination from surrounding fields at varying degree is quite possible, even if the entire land block was covered by the grass for two years. As Boli and Watkinson (1993) also pointed out, the variation in seed density in soil is attributed to the *in situ* weed density, proximity to source, soil conditions, burial depth, cropping regime, fertilizer and organic manures *etc.*

However, the present densities (max. 5114 m^{-2}) at the total depth of 0-15 cm was remarkably lower when compared with 13000-27000 seeds m^{-2} in old tea fields as reported by Eden (1949). Such a lower figure might be attributed to the previous ground cover with establishment of Mana (*C. confertiflorus*) for 24 month period followed by the weed free situation maintained until time of imposition of treatments. Seed density per unit depth at 0-5 cm in plots to be imposed with different treatments, except in one treatment, was greater than that at 5-15 cm depth (Table 2). Number of weed species was also varied within a range of 11-21 (15.89±3.37) in all plots except for plots to be treated with hand pulling every 18 weeks, where only 7 species were reported (Table 4 a).

Table 2. Mean density of the soil weed seed bank before planting of tea and imposition of treatments in 1994

Treatment combination	Mean seed density (No./m²)*									
	Seed No. at 0-5 cm depth				Seed No. at 5-15 cm depth				Total seed No. 0-15 depth	
	Emerged	Extracted	Total	Original	Emerged	Extracted	Total	Original	Log	Original
T1	3.03	2.00	3.05	1346	3.18	2.05	3.20	1976	3.46	3322
T2	3.17	nd	3.17	2026	3.19	2.10	3.21	1791	3.53	3817
T3	3.34	2.41	3.43	2903	3.01	2.58	3.25	2199	3.66	5102
T4	2.57	2.00	2.46	852	3.13	nd	3.13	2371	3.44	3223
T5	3.06	1.88	3.08	2223	3.43	nd	3.43	2891	3.65	5114
T6	3.10	2.68	3.27	1890	3.14	2.17	3.21	2297	3.57	4187
T7	3.10	nd	3.10	1667	3.09	2.54	3.20	1618	3.48	3285
T8	2.60	1.80	2.61	2322	3.29	2.17	3.32	2557	3.64	4879
T9	3.01	nd	3.01	1235	3.07	2.21	3.10	1816	3.36	3051
T10	2.34	2.10	2.36	1223	2.89	2.17	2.94	1235	3.30	2458
LSD at (0.05)			(ns)				(ns)		(ns)	

* Mean value among 4 replicates ns: not significant at 0.05 level nd: not detected

A majority of weed seeds buried at 0-5 cm depth in all plots was of broad-leaved species such as *Stemodia verticillata, Peperomia pellucida, Molligo pentaphylla, Oldenlandia corymbosa* and *Lindernia cordifolia* (Table 4 a). Such herbs are considered to be desirable for tea as they do cover the ground conserving soil and moisture. They are also known as 'soft herbs' (Anon, 2003) as they are tiny annual species with a very short life span of 4-6 weeks, having less interference with tea (Prematilake *et al*, 2008). Furthermore, seeds and rhizomes of sedges such as *C. rotundus* and *Bulbostylis barbata* were abundant in almost all treatments.

Broad leaved species such as *Borreria latifolia, Desmodium heterophyllum, Oxalis barrelieri* and *Croton hirtus* were very common though occurred in moderate numbers in many plots. Seeds of *Mitrocapan villosum, Cleomi viscose, Euphobia prostate* and cormes of *Caladium hortulanum* were also present in majority of plots in small numbers (Table 4a). Seeds of grasses were infrequent.

Effect of various treatments on the size and composition of the weed seed bank, 12 MAP

Effect of manual weeding treatments

There was a significant difference in total seed density between treatments both at 0-5 cm and 5-15 cm depth, 12 MAP *i.e.* in 1995 (Table 3). The greatest number of seeds at 0-5cm depth was present in mulched plots weeded every six weeks (4168). The seed density reported from hand weeding at two-week intervals (weed free treatment) was significantly less (p=0.05) than that of all other manual weeding treatments, but comparable to that of Glyphosate and Oxyfluorfen+ Paraquat treatments.

At 5-15 cm depth, the highest seed density of 5519 m^{-2} was recorded in unmulched plots slash weeded every 6 weeks and this was significantly greater (p=0.05) than that of all treatments except for hand weeding every 18 weeks. Weed seed density of other three hand weeded and all chemically weeded treatments were thus comparable. As a

Table 3. Mean weed seed density of the soil seed bank at 0-15 cm depth as affected by different treatments 12 MAP, in 1995

Treatment combination	Mean seed density (No./m^2)*									
	Seed No. at 0-5 cm depth				Seed No. at 5-15 cm depth				Total seed No. 0-15 depth	
	Emerged	Extracted	Total	Original	Emerged	Extracted	Total	Original	Log	Original
T1	2.46	3.00	3.11	1601	2.998	2.08	3.048	1481	3.40	3082
T2	3.52	2.59	3.57	4168	3.113	2.81	3.290	2163	3.76	6331
T3	3.46	2.52	3.51	3293	3.212	1.89	3.233	2033	3.70	5327
T4	3.51	2.52	3.55	3723	3.303	2.51	3.368	2653	3.80	6375
T5	3.38	1.76	3.39	2709	3.690	2.46	3.715	5519	3.90	8228
T6	2.98	2.54	3.12	1430	3.005	2.53	3.130	1506	3.44	2936
T7	3.24	2.30	3.29	2514	3.008	2.38	3.100	1314	3.54	3828
T8	3.26	2.10	3.29	2284	3.260	1.74	3.273	2276	3.59	4560
T9	2.90	2.29	3.00	1241	2.968	1.82	2.998	1026	3.34	2267
T10	3.00	2.19	3.07	1296	3.120	2.29	3.180	1621	3.44	2926
LSD at (0.05)			0.31				0.39		0.23	

* Mean value among 4 replicates

Table 4a. Mean number of weed seedlings emerged from soil weed seed bank at 0-5 cm depth before the imposition of treatments in June 1994 (No./ m^2)

Species/Treatment	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Stemodia verticillata	148±59*	321±82	432±102	25±12.5	202±80	99±49	136±46	222±88	136±25	111±29
Peperomia pellucida	136±53	210±32	nd	49±15	772±354	222±71	333±82	37±19	173±52	185±53
Molligo pentaphylla	130±28	161±42	395±135	247±63	296±37	111±36	191±62	741±214	222±38	185±60
Oldenlandia corymbosa	111±36	49±14	99±49	nd	37±19	49±13	130±44	nd	nd	62±31
Lindernia cordifolia	62±15	99±35	nd	37±19	62±31	74±30	74±24	62±31	25±12.5	12±6
Borreria latifolia	43±13	49±14	124±26	nd	nd	12±06	19±8.5	25±12	37±19	62±19
B. leavis	nd	247±123	383±162	nd	nd	nd	nd	nd	nd	nd
B. hispida	nd	nd	nd	nd	nd	nd	nd	nd	nd	37±19
B. ocymoides	49±14	25±12.2	nd	nd	nd	99±31	nd	nd	111±36	nd
Desmodium heterophyllum	37±	37±12	nd	nd	74±37	86±29	161±59	37±05	nd	62±23
Oxalis barrelieri	nd	111±18	nd	nd	198±92	99±31	93±26	74±37	nd	25±12
Mitrocapan villosum	nd	nd	86±25	nd	124±62	nd	68±12	93±46	nd	74±37
Caladium bicolor	56±18	nd	136±31	nd	37±19	nd	37±19	nd	37±19	nd
Croton hirtus	nd	25±12.5	173±49	12±06	56±26	12±06	19±8.5	nd	12±06	nd
Euphobia prostrata	149±66	nd	37±19	nd	nd	25±12	nd	nd	nd	nd
E.thymifolia	148±74	nd	37±19	25±6	nd	nd	nd	nd	nd	nd
Cleomi viscosa	19±9.5	12±06	nd	nd	12±06	nd	nd	nd	37±19	49±14
Hedyotis auricularia	nd	25±06	111±55	nd	nd	nd	nd	nd	nd	86±43
Emilia javanica	12±6	nd	12±6	nd	nd	nd	nd	nd	nd	nd
Theriophonum minutum	19±9.5	nd	99±25	nd	12±6	nd	25±12	nd	nd	nd
Ocimum sanctum	nd	nd	nd	nd	nd	nd	nd	37±19	nd	nd
Commelina benghelensis	nd	309±76	nd	nd	nd	nd	nd	nd	nd	nd
Crassocephules crepidiodes	nd	25±12	nd	nd	nd	nd	nd	nd	nd	37±19
Scoparia dulcis	19±9	25± 6	12±6	nd	nd	nd	nd	19±9	161±73	25±12
Cyperus rotundus	111±35	124±41	99±49	nd	173±42	457±92	154±46	37±19	259±76	12±6
Bulbostylis barbata	31±15	37±12	86±19	nd	25±12	12±06	19±85	nd	nd	25±12
Digitaria sanguinalis	nd	nd	12±06	25±06	nd	nd	nd	nd	nd	nd
Paspalum conjugatum	nd	nd	25±13	nd	nd	nd	nd	nd	nd	nd
Axonophus compressus	nd	62±12	37±12	nd	nd	nd	19±9	nd	nd	nd
Brachairia subquadripora	nd	nd	nd	nd	nd	37±19	25±12	nd	nd	nd
Total spp No.	**18**	**19**	**21**	**7**	**15**	**15**	**17**	**11**	**11**	**16**

* se nd: not detected

Table 4b. Mean number of weed seedlings emerged from soil weed seed bank at 0-5 cm depth 12 months after imposition of treatments in June 1995 (No./ m^2)

Species	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Stemodia verticillata	57±17*	126±30	34±5.5	57±14	138±32	99±49	138±47	115±29	138±25	57±21
Peperomia pellucida	149±54	92±25	57±5.5	92±33	69±30	80±35	23±6.5	46±16	183±72	207±72
Molligo pentaphylla	471±134	1525±557	413±62	1261±295	929±214	585±134	447±84	1032±219	161±22	172±32
Oldenlandia corymbosa	92±39	310±74	814±128	401±20	321±106	138±32	677±301	287±122	23±6.6	57±22
Lindernia cordifolia	34±5.5	149±14.5	57±14.5	34±17	138±29	69±17	80±35	23±6.5	22±11	11±05
Borreria latifolia	nd	103±11	115±22	413±69	11±05	34±9.5	126±14.5	11±5.5	23±6.5	103±14.5
B. leavis	nd	nd	43±9.5	195±38	69±13	11±05	nd	11±05	23±12	11±05
B. ocymoides	80±17	252±53	46±9.5	57±9.5	23±10	nd	80±17	92±46	23±11	35±11
Desmodium heterophyllum	34±0	23±11	23±6.5	46±9.5	46±14	34±05	11±	80±26	11±5.5	nd
Oxalis barrelieri	69±20	264±45	138±16	172±52	103±25	11±5	252±12	46±13	149±46	161±38
Mitrocapan villosum	34±17	80±17	nd	nd	nd	nd	46±9.5	57±11	23±12	23±12
Crotolaria juncia	23±12	nd	nd	11±5.5	nd	11±5	nd	nd	nd	nd
Physalis angulata	23±12	nd	229±28	nd	nd	nd	11±5.5	11±5.5	nd	nd
Cleomi viscosa	nd	57±14.5	92±16	34±11	nd	nd	11±5.5	11±5.5	11±5.5	nd
Hedyotis auricularia	nd	11±6.5	46±8.5	11±5.5	nd	nd	nd	11±5.5	11±5.5	nd
Hyptis suavaeolens	11±5.5	nd	34±5.5	23±11	11±5	nd	nd	nd	nd	nd
Phylanthus neruri	11±5.5	34±5.5	23±11	nd	23±10	23±5.5	23±6.5	nd	nd	23±12
P. urinaria	45±16	nd	11±5.5	nd	23±10	nd	nd	nd	nd	nd
Mikenia scandens	nd	11±6	34±12	nd	nd	nd	nd	nd	nd	nd
Scoparia dulcis	nd	11±6	nd	15±6.5	241±98	nd	nd	69±27	11±5.5	23±12
Commelina benghelensis	nd	nd	nd	34±11	nd	nd	nd	nd	nd	nd
Theriophonum minutum	nd	nd	nd	nd	nd	nd	92±46	nd	nd	nd
Begonia hirtella	nd	nd	nd	nd	nd	nd	23±6	nd	nd	nd
Eleutheranthera ruderalis	nd	nd	23±6	11±5.5	nd	nd	11±5.5	11±5.5	nd	69±27
Cyperus rotundus	195±45	298±22	115±36	344±22	218±33	126±26	126±31	69±28	149±30	184±33
Bulbostylis barbata	34±17	172±41	69±12	80±27	34±15	nd	23±6.5	23±6.5	nd	11±5
Digitaria sanguinalis	11±6	298±127	103±15	115±36	195±30	nd	nd	57±5.5	nd	68±13
Perotis indica	34±17	11±5.5	23±6.5	23±6.5	11±5	11±5	nd	nd	11±6.5	nd
Brachairia subquadripora	11±5.5	nd	11±6	nd	23±10	nd	25±12	11±5.5	nd	nd
Eragrostis pilosa	nd	nd	nd	nd	23±10	nd	nd	nd	nd	nd
Paspalum conjugatum	nd	23±6.5	23±6.5	23±11	nd	nd	nd	nd	nd	nd
Total spp No.	**21**	**25**	**24**	**23**	**23**	**13**	**19**	**22**	**19**	**16**

* se nd: not detected

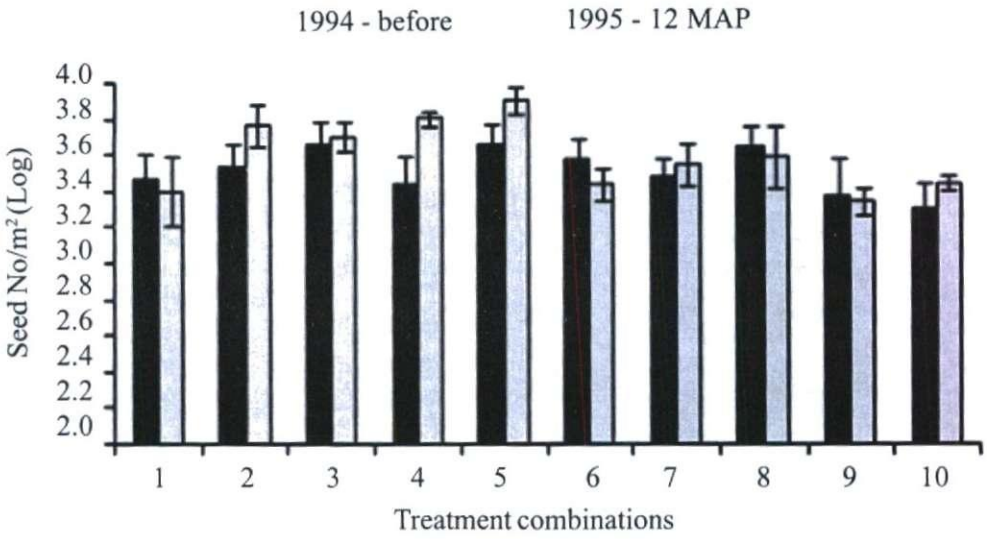

Figure 1. Mean weed seed density of the soil weed seed bank at 0 – 15 cm depth as affected by different weed management treatments

consequence, final density in each hand weeding at 6, 12, 18 weeks intervals and slash weeding every six months treatments, 12 MAP was significantly greater (p=0.05) than that of hand weeding every 2 weeks and all chemical weeding treatments (Table 3 and Figure 1). However, none of the seed densities under various treatments recorded at the end of 12 months was significantly different from that of before imposition of each treatment *i.e.* in 1994 (Figure 1).

A lower weed seed density was thus maintained with frequent hand weeding every two weeks (Figure 1). The weed species composition particularly the 'soft herbs' was virtually similar in both years although seed number of species such as *Mollugo pentaphylla* had been increased (Table 4 b). Increment of seed density in the above species may probably be due to the seed influx from the surrounding area. Relatively a greater species diversity is also observed in this treatment (18 and 21 species before and 12 MAP, respectively) may probably be due to less intense intra-specific competition (Table 4). Such a lower seed density may be attributed to the lower seed influx from *in situ* production as weeds were removed during the onset of early vegetative growth phase preventing reproductive output. Furthermore, seeds in the soil might have germinated fast since there was no barrier or weed cover on the ground surface. Thompson (1992) had also shown that in undisturbed soils, the surface soil (1-2 cm) from which most seedlings emerge becomes rapidly exhausted of buried seeds.

Higher seed densities in the treatments of hand weeding every 6, 12 and 18 weeks at 0-5 cm depth compared to hand weeding every 2 weeks was mainly attributed to the

greater species diversity (23-25) which resulted in the presence of a high seed count (Table 4 b). The greatest density recorded (4168 m^{-2}) in hand weeding every 6 weeks treatment has contributed about 66% to the total seed density at 0-15 cm depth (Table 3). Such a high density was mainly attributed to the early reproduction and high fecundity rate of annual 'soft herbs' such as *M. pentaphylla, O. corymbosa, S. verticillta, P. pellucida* and *L. cordifolia* and; *Borreria* species, *Oxalis barrelieri, M. villosum* and *Cleomi viscosa*. Seeds of grass species *D. sanguinalis* and sedges, *C. rotundus* and *B. barbata* also largely contributed at 0-5 cm depth (Table 4 b).

In plots manually weeded both at 12 and 18 week intervals, about 60% of the total seed density at 0-15 cm depth was represented by the seeds found within 0-5 cm upper layer. Also in the plots hand weeded every 12 weeks, soft herbs such as *M. pentaphylla, O. corymbosa,* and species of *Oxalis barrelieri, Cleomi viscosa, C. rotundus* and *D. sanguinalis* were present largely in the upper layer. The high seed density in the treatment of hand weeding every 18 weeks was mainly attributed to the high seed count of *M. pentaphylla, O. corymbosa, Borreria spp, Oxalis barrelieri, C. rotundus* and *D. sanguinalis*. Particularly, a massive production of seeds of *B. latifolia* was recorded. *B. latifolia* is the commonest weed species found in low-grown tea and it characterises a high fecundity rate within 12-20 weeks after germination (Prematilake, 1997).

Higher densities in the above hand weeding treatments recorded 12 MAP was thus, as a consequence of subsequent replenishment of the seedbank with *in situ* seed rain, which further depended upon the frequency of weeding and the type of weeds present.

The seed density in slash weeded unmulched plots every 6 weeks at 0-5 cm depth was also attributed to higher seed counts of soft herbs such as *M. pentaphylla, O. corymbosa, Lindernia cordifolia, S. verticillta, P. pellucida*; broad leaf species, *Oxalis barrelieri* and *Scoparia dulcis* and; *C.rotundus* and *D.sanguinalis*. The highest total density of 8228 m^{-2} recorded in this treatment, 12 MAP was thus resulted from an initial high density (5114 m^{-2}) as well as the *in situ* production of seeds from weeds left as a live ground cover in tea inter-rows. The seeds of *M. pentaphylla, O. corymbosa* and *rhizomes of C. rotundus* were largely contributed to the seed bank as they could thrive in compact soil. However, many seeds were present at 5-15 cm depth and cracks formed by excessive drying of soils during dry spell followed by washing out of small seeds with rains into the cracks and coarse textured soil might explain such an increased density at deep layer. This is also in agreement with the findings of Harper (1977) and Hopkins and Graham (1983).

Impact of various herbicide combinations

Weed seed density in herbicide treated plots 12 MAP was not significantly different from that of before imposition of treatments, indicating the maintenance of the *status quo* weed control (Figure 1). Many authors have also concluded that effective weed control with herbicides has led to a decreased seedbank (Hurle, 1974; Fogelfors, 1991). There was a successful control of weeds particularly with Oxyfluorfen + Paraquat thereby weed seed production has been minimized, recording the least seed count. Initial lower seed stock together with meagre production of seeds of soft herbs and some common weeds were the constituents in seed bank. Similarly in Glyphosate treated plots, the species number was confined to 13, with the presence of seeds of soft herbs such as *M. pentaphylla, O. corymbosa, P. pellucida; Borreria species* and sedge *C. rotundus.* These former two are known to be tolerant for Glyphosate (Table 4b).

However, in 2,4-D + Paraquat and Glufosinate Ammonium treatments, a significantly greater seed density was recorded when compared to Glyphosate and Oxyfluorfen + Paraquat treatments at 0-5 cm depth (Table 3). This was caused by high species diversity (19) and presence of seeds of *Oxalis barrelieri* and *Borreria* species and rhizomes of *C. rotundus* in 2,4-D + Paraquat treated plots. Being a selective broad weed killer 2,4-D + Paraquat had not controlled *C. rotundus* and *D. sanguinalis.* These other broad leaved weeds were also not properly killed by both treatments.

Relatively a greater seed density in Glufosinate Ammonium treated plots compared with Oxyfluorfen + Paraquat treatment was ascribed to both initial and final seed densities. Presence of seeds from higher number of species (19) and higher number of seeds of *M. pentaphylla* and *O. corymbosa* and *D. heterophyllum, B. ocymoides* and *Scoparia dulcis* were observed at the end of 12 months (Table 4b). *M. pentaphylla* was also initially present in higher number. Whereas, such swelling of the seed bank did not reflect remarkably in the final density *i.e.* 12 MAP in these two treatments (Figure 1).

In all herbicide combinations, the frequent reporting of 'soft herbs' may be represented mainly by the original seed stock. Furthermore, being floras with a very short life span, they had an opportunity to emerge as seedlings and produce seeds *in situ* during the time gap between two herbicide spraying and from uatteneded weeds by herbicides. Seed dispersal from surrounding fields is also quite possible.

Rhyzomes of *C. rotundus* also frequently occurred before and after imposition of all treatments in varying degrees. It is known to be a tolerant species for number of herbicides. It is also capable of producing a net work of corms and underground tubers, asexually. Buried rhizomes may have thus been grown and multiplied during the course

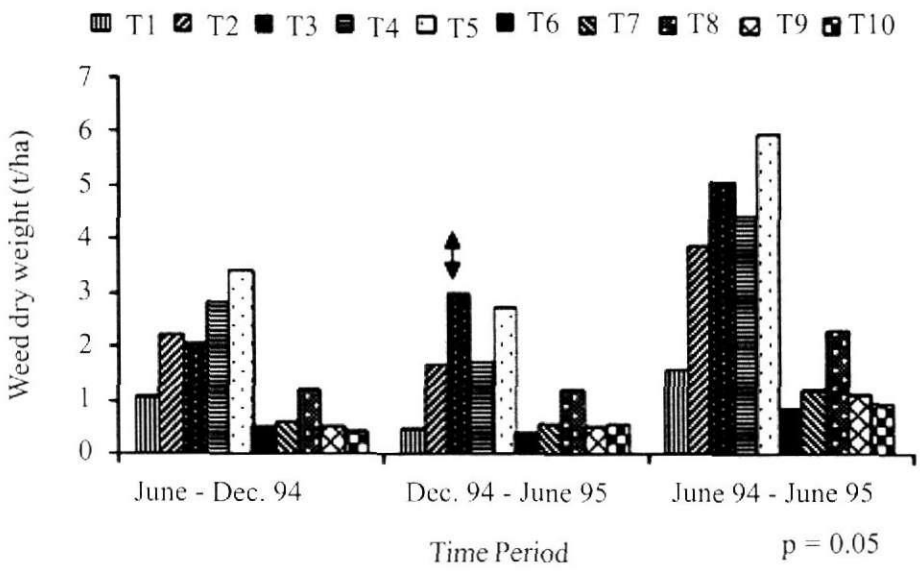

Figure 2. Mean weed dry weight (t/ha) as affected by various manual and chemical weed management methods during the period of 15th June 94 -15th June 95

Manual weeding (mulched): **T1** - every two weeks; **T2** - every six weeks; **T3** - every 12 weeks; **T4** - every 18 weeks; and
(unmulched): T5 - every six weeks (slash weeding);
Chemical weeding (mulched): **T6** - glyphosate (0.99 kg a.i ha^{-1}) + kaolin (3.42 kg ha^{-1}); **T7** - 2, 4 -D (0.73 kg a.i ha^{-1})/ paraquat (0.15-0.22 kg a.i ha^{-1}); **T8** - glufosinate ammonium (0.2 kg a.i ha^{-1}); **T9** - oxyfluorfen (0.29 kg a.i ha^{-1}) / paraquat (0.15-0.22 kg a.i ha^{-1}); and
(**Unmulched**): **T10** - oxyfluorfen (0.29 kg a.i ha^{-1}) / paraquat (0.15-0.22 kg a.i ha^{-1}).

Source: Prematilake, K G (1997)

of 12 months in the soil. More than 1100-8700 tubers and corms /m^2 have been reported worldwide (Siriwardana and Nishimoto, 1987).

The pattern of the presence of weed seeds under different treatments also reflect in the amount of weed dry matter production at different phases of the study showing a similar trend as shown in the Figure 2. Hence, there was a very good correlation *between weed dry matter yield and the seed density in soil* (Figure 3). This too witnesses that the high seed density is as a consequence of heavy weed growth and *in situ* seed production particularly in manually weeded plots.

Weed infestation had been increased with time interval and type of weeding in manually weeded treatment, where weed seed production had also been increased.

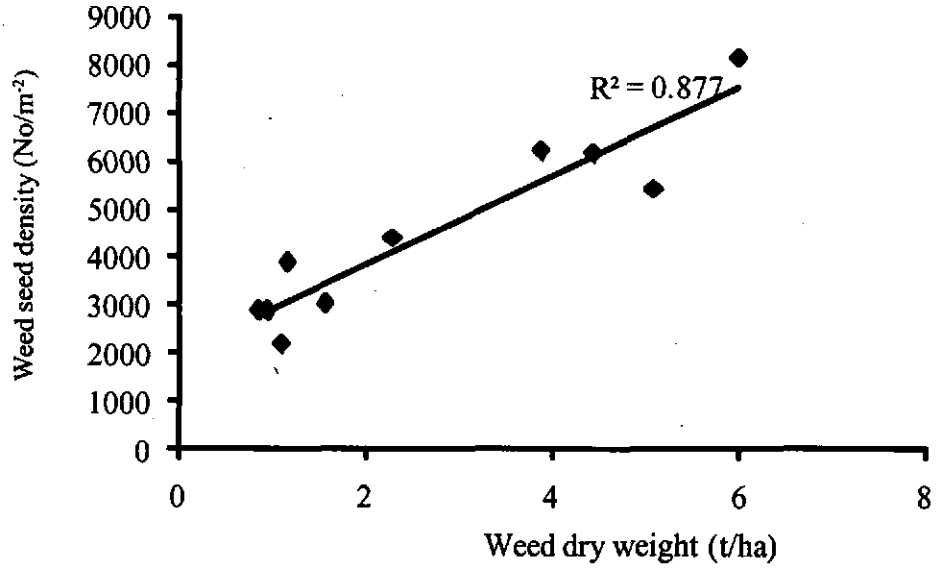

Figure 3. Correlation between weed biomass production and weed seed bank

Impact of mulching

There was no significant difference in seed number between unmulched plots slash weeded and mulched plots hand weeded every 6 weeks and; also between unmulched and mulched plots treated with Oxyfluorfen + Paraquat. Seed density in Oxyfluorfen + Paraquat in mulched plots would have been further reduced if the 2nd and 3rd round of Oxyfluorfen + Paraquat combination was applied to bare soil before mulching. The little swelling in seed density in unmulched plots may be ascribed to direct deposition of seeds on bare tea inter rows by immigrating from elsewhere.

CONCLUSIONS

Manual weeding at intervals of <12 weeks could appreciably maintain a lower weed seed density as it could prevent or minimize replenishment of the seedbank in soil by keeping weeds under control before they reach the reproductive phase. In contrast, delayed weeding has increased the seedbank due to *in situ* seed rain from many common and few uncommon weed species. Maintaining a live weed cover on tea inter-rows with regular slashing was ineffective in terms of the seedbank and it is also not practical. Chemical weeding has resulted in the least weed seed density as weed growth was arrested at early phase of growth. On this context, Oxyfluorfen + Paraquat combination or Glyphosate herbicide is found to be more promising. Weed species composition has been narrowed down in chemical treatments compared to manual weeding. Whereas, mulching of tea inter-rows has very little or no impact on the presence of the weed seed bank.

The seeds of 'Soft herbs' have represented in the seed bank at higher numbers in the upper layer and found to be persistent in soil prior to and after imposition of all treatments. Their presence should be promoted. Care should also be given to control *C. rotundus*, which is found to be persistent under all treatments.

The soil weed seedbank in young tea fields could thus be kept under check with an integrated approach, where the weeds are removed manually at an interval of <12 weeks and a suitable herbicide combination such as Oxyfluorfen and Paraquat is rationally used following all precautionary measures at correct time. However, the time of manual weeding has also to be adjusted keeping in mind that ground should be free of weeds before manuring of tea. Experiment should be repeated in other tea growing regions too as types of weeds in these regions are different.

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