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Weed seedbank dynamics: Estimation and management in groundnut

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ABSTRACT

Effective weed management necessitates sound knowledge of weed seedbank dynamics. The experiment was laid out in split plot design with three replications. The main plots have three residue management treatments and sub-plots comprised seven weed management treatments. Results revealed that highest pod yield (1.47 t/ha) was recorded under wheat residue incorporation *fb* soil solarization. Among weed management, the highest pod yield (1.68 t/ha) and haulm yield (3.35 t/ha) was recorded with weed free and unweeded check registered lowest pod yield (722 kg/ha). The lowest dry weight of weeds was obtained under wheat residue incorporation *fb* soil solarization and weed free. Wheat residue incorporation *fb* soil solarization depleted correspondingly 54 (25.32%), 10 (5.29%) and 32 (16.16%) seeds per core from the initial weed seedbank in 2014, 2015 and pooled results, respectively. The highest seedbank depletion was observed with weed free by depletion of 147 (68.37%), 123 (68.20%) and 135 (68.29%) weed seeds per core. Pendimethalin 900 g/ha as pre-emergence *fb* IC and HW at 45 DAS depleted 129 (59.84%), 103 (57.09%) and 116 (58.59%) weed seeds per core. Pendimethalin 900 g/ha as pre-emergence *fb* pre-mix imazethapyr + imazamox 70 g/ha as post-emergence at 25 DAS depleted 126 (58.40%), 101 (55.86%) and 113 (57.24%) weed seeds per core and suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW at 45 DAS depleted 116 (53.85%), 86 (47.64%) and 101 (51.01%) weed seeds per core in 2014, 2015 and pooled results, respectively as compared to the initial weed seedbank. While, unweeded check resulted in to addition of 609 (283.31%), 695 (384.16%) and 652 (329.41%) weed seeds per core sample (15 cm depth and 4 cm diameter) in the soil weed seedbank in comparison to initial weed seedbank.

INTRODUCTION

The weed seedbank is the main source of weeds in agricultural fields. Most weeds start their life cycle from a single seed in the soil. If these weeds escape control, they grow and produce thousands of seeds, depending on the species. These seeds are returned to the soil seedbank and become the source of future weed populations. Therefore, knowledge of seed return and seedbank dynamics can help in future weed management. The weed seedbank refers to the natural storage of seeds and vegetative propagules, often dormant, within the soil of most ecosystems. Understanding the dynamics of weed seedbanks is an essential first step in improving weed management plans. Lack of weed seedbank studies represents an important knowledge gap for producers. This study aims to acquire the information on weed seedbank dynamics and its management by integrating cultural, physical and chemical methods. Management of weeds in particular area would require prior information regarding weed seedbank which can helpful in designing weed management practices related to a particular microclimate in an area. Thus, there will almost always be some weeds that tolerate, or even thrive on, whatever combination of seedbank management strategies to be adopted.

Effective weed management requires knowledge of weed seedbank dynamics, germination pattern and environmental conditions suitable for seedling emergence. Weed seedbank affects the weed flora and its density because of the good relationship between the weed flora and the weed seedbank in the soil (Sousa *et al.* 2003). In principle of reducing weed seedbank, there are three approaches to reduce the seedbank size: i) kill the seeds while they are in the soil (using chemical compounds), ii) stimulate germination of seeds and destroy the seedlings called as 'suicidal' germination, and iii) remove weeds before seed set. Based on these three principles, the integrated approach has to be selected for managing weed seedbank, which involves wheat residue management, solarisation, stale seedbed, suicidal germination, herbicides, hand weeding, and inter-culturing techniques. Very meagre efforts were made to estimate weed seedbank in soil and practically very little research work was carried out regarding weed seedbank estimation under the influence of different weed management practices. Wheat (*Rabi*)-fallow (summer)-groundnut (*Kharif*) is the pre-dominant crop sequence in the Saurashtra region of Gujarat state in India. Owing to labour shortage and its high cost, harvesting of wheat is mostly carried out by combine harvester, which left large quantities of wheat residue. Now their usefulness considered as an important resource that can bring significant physical, chemical, biological changes into the soil and suppresses weeds and prevent weed seeds to recycle in soil (Sharma 2014). Considering the facts and views highlighted, an experiment was undertaken to study weed seedbank dynamics estimation and management in groundnut.

MATERIALS AND METHODS

A field experiment was conducted at Weed Control Research Farm, Department of Agronomy, Junagadh Agricultural University, Junagadh (Gujarat) during *Kharif* seasons of 2014 and 2015. The soil of the experimental field was clayey in texture and slightly alkaline in reaction, medium in organic carbon, low in available N, medium in available P and K. The experiment was laid out in a split plot design with three replications. The main plots comprised residue management treatments, *viz*. burning of wheat residues, wheat residue incorporation by rotavator *fb* soil solarization with 25 µm polythene sheet for 15 days and wheat residue incorporation by rotavator *fb* application of *Trichoderma viride* 5 kg/ha + 20 kg N/ha and sub plots contained weed management treatments, *viz*. stale seedbed (pre-sowing irrigation *fb* killing the weed flush by subsequent tillage) *fb* IC and HW at 45 DAS, suicidal germination (application of ethylene 2000 ppm + KNO_3 2000 ppm with pre-sowing irrigation) *fb* killing the weed flush by subsequent tillage) *fb* intercultural (IC) and hand weeding (HW) at 45 DAS, pendimethalin 900 g/ha as PE *fb* IC and HW at 45 DAS, HW and IC at 15 DAS *fb* pre-mix imazamox + imazethapyr 70 g/ha as PoE at 25 DAS, pendimethalin 900 g/ha as PE *fb* pre-mix imazamox + imazethapyr 70 g/ha as PoE at 25 DAS, weed free-three IC + five HW and unweeded check. The groundnut (cv. *Gujarat Groundnut-20*) was sown at 60 x 10 cm spacing using seed rate of 120 kg/ha. The crop was fertilized with 12.5-25-50 kg N-P-K/ha. The herbicides were sprayed as per treatments using knapsack sprayer fitted with flat-fan nozzle using spray volume of 500 L/ha water. Data were recorded and statistically analyzed for level of significance.

Weed seedbank estimation: Five soil samples were taken from the experimental soil before sowing of the crop and one composite sample was prepared, while plot-wise samples were taken after harvest of the crop. The soil samples were drawn by core sampler of 4 cm in diameter from 15 cm depth as per the FAO protocol (Forcella *et al.* 2011). Each soil core was individually bagged and numbered. Seed extraction was done by sieving of the samples through copper sieves of 5 mm in diameter. This was followed by their rinsing by water and sieving of the samples through a descending series of sieves up to sieve of 0.5 mm in diameter. Seeds were then dried at the room temperature and separated manually. Determination of the separated seeds was performed visually and sample-wise seed count was recorded. Species wise weed seed identification was determined by growing weed seeds in controlled conditions. Total viable and non-viable/dormant seeds were also recorded.

RESULTS AND DISCUSSION

Crop yields

Residue management and weed management treatments significantly influenced groundnut yield (**Table 1**). Significantly, the highest pod yield (1.47 t/ha) was recorded under the wheat residue incorporation *fb* soil solarization with increased magnitude of 14.2% over the burning of residues. Among the weed management, significantly, the highest pod yield (1.68 t/ha) and haulm yield (3.35 t/ha) was recorded under the weed free, which was statistically at par with the treatments pendimethalin *fb* imazethapyr + imazamox and pendimethalin *fb* IC and HW with increased magnitude of 124.9 and 124.5%. Conversely, the unweeded check registered significantly the lowest pod yield (722 kg/ha). The higher yield under these treatments could be ascribed to lower dry weight of weeds ultimately reduced the crop-weed competition hence less nutrients removed by the weeds and better utilization of nutrients by the crop. Conversely, burning of residues and unweeded check recorded lowest pod and haulm yields. Deprived growth and development of the crop under the treatment owing to severe crop-weed competition for resources might have poor yields. These findings are in agreement with earlier reports (Khairnar *et al.* 2014, Kumbar *et al.* 2014, and Sharma 2014).

Weed flora

The following weed species were observed during both the years of experiment:

Weed species		% dominance at experimental site	
		2014	2015
Monocots	*Echinochloa colona*	23.65	53.76
	Eluropus villosus	14.86	1.55
	Indigofera glandulosa	6.53	5.80
	Brachiaria ramosa	2.03	-
	Dactyloctenium aegyptium	-	3.68
Dicots	*Ammannia baccifera*	18.02	-
	Leucas aspera	5.40	1.47
	Digera arvensis	2.70	5.40
	Commelina benghalensis	2.03	2.61
	Eclipta alba	2.03	5.72
	Portulaca oleracea	1.58	0.98
	Commelina nudiflora	0.68	0.57
	Phyllanthus niruri	0.45	1.88
	Euphorbia hirta	-	1.14
	Parthenium hysterophorus	-	0.65
	Tridax procumbens	-	0.57
Sedge	*Cyperus rotundus*	20.04	14.22

Weed seedbank dynamics and weed indices

Significantly the lowest dry weight of weeds and weed seedbank, lowest weed index and higher weed control index was recorded under the wheat residue incorporation *fb* soil solarization and weed free (**Table 1**). Among the weed management pendimethalin *fb* imazamox + imazethapyr, pendimethalin *fb* IC and HW and suicidal germination *fb* tillage *fb* IC and HW. Soil solarization might have destroyed weed seeds and propagules present in the upper soil, but not so effective against sedge propagules existed deeper in soil, hence there would be less population of weeds than other treatments, while *Trichoderma viride* might have decomposed weed seeds and propagules which reflected in less number of weeds and ultimately lower weed biomass under both these treatments. This might be attributed to the effective control of weeds under these treatments through hand weeding or integration of hand weeding with herbicides, which reflected in a smaller number of weeds and ultimately lower weed biomass and weed seedbank. In addition to this, dense crop canopy might have suppressed weed growth and ultimately less biomass. These findings are in conformity with those reported by Forcella *et al.* (1993), Khankhane *et al.* (2009) and Branko *et al.* (2011).

Different residue management treatments significantly influenced the status of final soil weed seedbank after harvesting of crop. Significantly, the lowest weed seedbank (161, 171 and 166 weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014, 2015 and pooled results, respectively) was estimated under the treatment wheat residue incorporation *fb* soil solarization. While, the highest soil weed seedbank (259 and 250 weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014 and pooled results, respectively) was estimated with the treatment burning of wheat residues, which was statistically at par with the treatment wheat residue incorporation *fb* application of *Trichoderma viride* + N having weed seeds of 234 and 240 in 2014 and pooled results, respectively (**Table 2**). On an average, the treatment wheat residue incorporation *fb* soil solarization depleted correspondingly 54 (25.32%), 10 (5.29%) and 32 (16.16%) seeds per core from the initial weed seedbank in 2014, 2015 and pooled results, respectively. On the contrary, on an average of both the years, the treatments burning of wheat

Table 1. Groundnut yields, weed indices and status of weed seedbank under various residue and weed management strategies

Treatment	Pod yield (t/ha)	Haulm yield (t/ha)	Weed index (%)		Dry weight of weeds (kg/ha)		Weed control efficiency (%)		Number of weed seeds/core	
			2014	2015	2014	2015	2014	2015	2014	2015
Residues management									215 (initial)	181 (initial)
Burning of wheat residues	1.28	3.11	-	-	1142	1419	-	-	259	242
Wheat residue incorporation *fb* soil solarization	1.47	2.86	-	-	687	951	-	-	161	171
Wheat residue incorporation *fb* *T. viride* + N	1.36	3.13	-	-	813	1229	-	-	234	245
LSD (p=0.05)	0.07	NS	-	-	151	200	-	-	45	51
Weed management										
Stale seedbed *fb* IC and HW	1.08	2.88	38.07	32.72	979	1272	62.38	66.90	168	170
Suicidal germination *fb* tillage *fb* IC and HW	1.59	3.14	6.62	4.35	788	870	68.97	77.21	99	95
Pendimethalin *fb* IC and HW	1.62	3.22	4.65	1.91	521	553	79.94	85.49	86	78
HW and IC *fb* imazethapyr + imazamox	1.26	3.16	25.18	24.26	770	1188	70.56	68.98	191	180
Pendimethalin *fb* imazethapyr + imazamox	1.62	3.27	4.35	2.70	489	628	81.04	83.67	89	80
Weed free	1.68	3.35	0.00	0.00	40	58	98.49	98.48	68	58
Unweeded check	0.72	2.21	55.10	59.32	2577	3825	0.00	0.00	824	876
LSD (p=0.05)	0.08	0.29	-	-	128	159	-	-	50	56

Groundnut yields are pooled of two years; IC- Intercultural; HW- Hand weeding residues and wheat residue incorporation *fb* application of *Trichoderma viride* + N resulted in to addition of 52 and 42 weed seeds per core sample (15 cm depth and 4 cm diameter) (26.50 and 21.03%) in the soil weed seedbank, respectively as compared to initial soil weed seedbank.

Different weed management treatments displayed their significant influence on soil weed seedbank. The lowest number of weed seeds (68, 58 and 63 weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014, 2015 and pooled results, respectively) was found under the treatment weed free, which was statistically at par with the treatments pendimethalin *fb* IC and HW, pendimethalin *fb* imazethapyr + imazamox and suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW. Whereas, the highest number of weed seeds (824, 876 and 850 weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014, 2015 and pooled results, respectively) was observed under the treatment unweeded check. However, all the treatments have depleted weed seedbank over the treatment unweeded check during both the years of investigation. On an average of both years, the weed seedbank depleted over the control treatments for all treatments were 80.10, 88.60, 90.40, 78.20, 90.00 and 92.60%, respectively. Weed management treatments depleted weed seedbank except the treatment unweeded check. On an average, higher seedbank depletion was observed with the treatments weed free with depletion of 147 (68.37%), 123 (68.20%) and 135 (68.29%) weed seeds per core sample (15 cm depth and 4 cm diameter), pendimethalin *fb* IC and HW depleted 129 (59.84%), 103 (57.09%) and 116 (58.59%) weed seeds per core, pendimethalin *fb* imazethapyr + imazamox depleted 126 (58.40%), 101 (55.86%) and 113 (57.24%) weed seeds per core and suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW depleted 116 (53.85%), 86 (47.64%) and 101 (51.01%) weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014, 2015 and pooled results, respectively as compared to the initial weed seedbank. On the contrary, the unweeded check resulted in to addition of 609 (283.31%), 695 (384.16%) and 652 (329.41%) weed seeds per core sample (15 cm depth and 4 cm diameter) in the soil weed seedbank in comparison to the initial weed seedbank of soil (**Table 2**). The weed parameters and weed seedbank findings are parallel to those of Sousa *et al*. (2003), Chauhan *et al*. (2006), Mishra *et al*. (2010), Nyambilila *et al*. (2010) and Sharma (2014).

Species wise weed seeds were identified from initial and final soil sample by growing the weed seeds and sprouted weeds were counted and classified as monocot, dicot, sedge and dormant or non-viable. Data presented indicated that initial weed seedbank was dominated by monocot weed seeds of 100 (46.51%), followed by dicot weed seeds of 77 (35.81%), dormant or non-viable weed seeds of 30 (13.95%) and sedge weed seeds of 8 (3.72%) totalling to 215 seeds per core sample (15 cm depth and 4 cm diameter) in 2014. But in 2015, the weed seedbank was dominated by dicot weed seeds of 86 (47.51%), followed by monocots weed seeds of 60 (33.15%), dormant or non-viable weed seeds of 25 (13.81%) and sedge weed seeds of 11 (6.08%) totalling to 181 seeds per core sample (15 cm depth and 4 cm diameter) (**Table 3**).

Species wise addition or depletion in soil weed seedbank over initial status also presented in **Table 4**

Table 2. Addition/depletion in weed seedbank over initial status

Treatment	Number of weed seeds/core					
	2014		2015		Average	
	Final	Addition (+) / Depletion (-)	Final	Addition (+) / Depletion (-)	Final	Addition (+) / Depletion (-)
Initial weed seedbank		215		181		198
Residues management						
Burning of wheat residues	259	+44 (+20.53)	242	+61 (+33.60)	250	+52 (+26.50)
Wheat residue incorporation *fb* soil solarization	161	-54 (-25.32)	171	-10 (-5.29)	166	-32 (-16.16)
Wheat residue incorporation *fb T. viride* + N	234	+19 (+8.99)	245	+64 (+35.33)	240	+42 (+21.03)
Weed management						
Stale seedbed *fb* IC and HW	168	-47 (-21.96)	170	-11 (-6.08)	169	-29 (-14.70)
Suicidal germination *fb* tillage *fb* IC and HW	99	-116 (-53.85)	95	-86 (-47.64)	97	-101 (-51.01)
Pendimethalin *fb* IC and HW	86	-129 (-59.84)	78	-103 (-57.09)	82	-116 (-58.59)
HW and IC *fb* imazethapyr + imazamox	191	-24 (-11.06)	180	-1 (-0.80)	185	-13 (-6.37)
Pendimethalin *fb* imazethapyr + imazamox	89	-126 (-58.40)	80	-101 (-55.86)	85	-113 (-57.24)
Weed free	68	-147 (-68.37)	58	-123 (-68.20)	63	-135 (-68.29)
Unweeded check	824	+609 (+283.31)	876	+695 (+384.16)	850	+652 (+329.41)

Figures in parentheses indicate percent addition or depletion and **5** for the year 2014 and 2015, respectively. The probable estimation of weed seedbank size per hectare with addition and depletion in the size of weed seedbank at harvest over initial status also given for experimentations (**Table 6** and **7**).

The weed seedbank was dominated by monocot weed seeds under wheat residue incorporation *fb* application of *Trichoderma viride* + N, while that by dicot weed seeds under burning of wheat residues and wheat residue incorporation *fb* soil solarisation (**Table 3**). The dynamics of post-harvest soil weed seedbank was significantly influenced by different residue management treatments. The treatment wheat residue incorporation *fb* soil solarization contained the lowest soil weed seedbank. While, the highest soil weed seedbank was estimated with burning of wheat residues in 2014 and pooled results and wheat residue incorporation *fb* application of *Trichoderma viride* + N in 2015. On an average, the treatment wheat residue incorporation *fb* soil solarization depleted 32.00 seeds per core (16.16%) from the initial weed seedbank. On the contrary, the treatment burning of wheat residues and wheat residue incorporation *fb* application of *Trichoderma viride* + N resulted in addition of 52.00 (26.50%) and 42.00 (21.03%) weed seeds per core sample (15 cm depth and 4 cm diameter) in the soil weed seedbank, respectively as compared to the initial soil weed seedbank. Though the distribution of weed seeds in soil is heterogeneous, most of the seeds of annual weeds are present in upper 5-7.5 cm soil layer, soil solarisation might have desiccated these weed seeds by high temperature under moist condition and thus depleted weed seedbank. Weed seedbank affects the weed flora and its density because of good relationship between the weed flora and the weed seedbank in the soil. Forcella *et al.* (1993), Mishra and Singh (2008), Branko *et al.* (2011), Forcella *et al.* (2011), Arora and Tomar (2012) and Hosseini *et al.* (2014) also studied weed seedbank dynamics. During 2014 and 2015, the weed seedbank was dominated by dicot weed seeds

Table 3. Species wise number of weed seeds (2014 and 2015)

Treatment	Number of weed seeds/core (2014)					Number of weed seeds/core (2015)				
	Total	Monocot	Dicot	Sedge	Dormant or non-viable	Total	Monocot	Dicot	Sedge	Dormant or non-viable
Initial weed seedbank (total weed seeds)	215	100(46.5)	77(35.8)	8(3.7)	30(13.9)	181	60(33.1)	85(47.0)	11(6.1)	25(13.8)
Residues management										
Burning of wheat residues	259	95(36.8)	107(41.3)	7(2.5)	50(19.3)	242	120(49.6)	83(41.3)	9(3.8)	30(12.3)
Wheat residue incorporation *fb* soil solarization	161	61(37.9)	64(39.8)	3(2.1)	32(19.9)	171	85(49.9)	65(39.8)	6(3.5)	15(8.6)
Wheat residue incorporation *fb T. viride* + N	234	106(45.4)	82(35.1)	5(2.3)	41(17.3)	245	129(52.6)	83(35.1)	8(3.3)	25(10.1)
Weed management										
Stale seedbed *fb* IC and HW	168	43(25.8)	82(48.9)	2(1.5)	40(23.7)	170	52(30.5)	89(52.4)	5(3.1)	24(14.0)
Suicidal germination *fb* tillage *fb* IC and HW	99	26(26.4)	56(56.6)	4(3.8)	13(13.5)	95	30(31.1)	46(47.9)	6(6.8)	13(13.9)
Pendimethalin *fb* IC and HW	86	21(24.0)	42(49.0)	2(1.9)	22(25.5)	78	23(29.5)	39(50.1)	5(6.0)	11(14.0)
HW and IC *fb* imazethapyr + imazamox	191	54(28.2)	111(58.0)	8(4.2)	19(9.7)	180	54(29.9)	96(53.1)	10(5.7)	20(11.0)
Pendimethalin *fb* imazethapyr + imazamox	89	23(26.0)	46(51.4)	4(4.1)	17(19.0)	80	24(30.1)	39(49.0)	7(8.3)	10(12.4)
Weed free	68	14(21.2)	31(45.4)	1(2.0)	21(31.4)	58	19(32.0)	28(47.5)	4(7.1)	7(12.6)
Unweeded check	824	432(52.4)	223(27.1)	15(1.8)	154(18.7)	876	579(66.1)	204(23.2)	17(1.9)	77(8.7)

Figures in parentheses indicate species wise weed seedbank percent over total weed seedbank in respective treatments

Table 4. Species wise addition/depletion in soil weed seedbank over initial status (2014)

Treatment	Number of weed seeds per core							
	Monocot		Dicot		Sedge		Dormant/non-viable	
	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)
Initial weed seedbank	100		77		8		30	
Residues management								
Burning of wheat residues	95	-5 (-4.6)	107	+30 (+39.1)	7	-1 (-17.9)	50	+20 (+66.8)
Wheat residue incorporation *fb* soil solarization	61	-39 (-38.9)	64	-13 (-16.8)	3	-5 (-58.3)	32	+2 (+6.8)
Wheat residue incorporation *fb T. viride* + N	106	+6 (+6.3)	82	+5 (+6.6)	5	-3 (-32.1)	41	+11 (+35.1)
Weed management								
Stale seedbed *fb* IC and HW	43	-57 (-56.6)	82	+5 (+6.6)	2	-6 (-69.4)	40	+10 (+33.0)
Suicidal germination *fb* tillage *fb* IC and HW	26	-74 (-73.9)	56	-21 (-27.3)	4	-4 (-52.8)	13	-17 (-55.6)
Pendimethalin *fb* IC and HW	21	-79 (-79.3)	42	-35 (-45.3)	2	-6 (-79.2)	22	-8 (-27.0)
HW and IC *fb* imazethapyr + imazamox	54	-46 (-46.1)	111	-34 (-43.9)	8	-0 (-0.0)	19	-11 (-38.1)
Pendimethalin *fb* imazethapyr + imazamox	23	-77 (-76.9)	46	-31 (-40.5)	4	-4 (-54.2)	17	-13 (-43.7)
Weed free	14	-86 (-85.6)	31	-46 (-59.9)	1	-7 (-83.3)	21	-9 (-28.9)
Unweeded check	432	+432 (+331.8)	223	+146 (+189.9)	15	+7 (+86.1)	154	+124 (+414.1)

Figures in parentheses indicate per cent addition or depletion in all the weed management treatments except the unweeded check, which was dominated by monocot weed seeds (**Table 4** and **5**).

On an average, higher seedbank depletion was observed with the treatment weed free with depletion of 135 (68.29%) weed seeds per core sample (15 cm depth and 4 cm diameter) from initial seedbank, which might be due to regular removal of weeds before seed production. The treatment pendimethalin *fb* IC and HW depleted 116 (58.59%) weed seeds per core, because pre-emergence applied pendimethalin controlled weeds right from the start and weeds those escaped were controlled by hand weeding, hence not allowed weeds to set seeds and reduced the size of soil weed seedbank. The treatment pendimethalin *fb* imazethapyr + imazamox depleted 113 (57.24%) weed seeds per core sample (15 cm depth and 4 cm diameter), which might be due to pre-emergence applied pendimethalin controlled weeds right from the start and weeds those escaped were controlled by subsequent post-emergence imazethapyr + imazamox and hence not allowed weeds to set seeds and depleted the size of soil weed seedbank. Likewise, the treatment suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW depleted 101 (51.01%) weed seeds per core sample. In this treatment, before sowing of crop the weed seed germination enhancing chemicals were applied in soil which emerged out the weeds at a time from soil and these weeds were destroyed by the subsequent tillage and weeds emerged later were removed by manual weeding. Hence weeds were removed before seed setting, which ultimately depleted soil weed seedbank. On the contrary, the unweeded check resulted in to addition of 652 (329.41%) weed seeds per core in the soil weed seedbank in comparison to the initial weed seedbank of soil (**Table 4** and **5**). It might be due to abundant weed seed production

Table 5. Species wise addition/depletion in soil weed seedbank over initial status (2015)

Treatment	Number of weed seeds per core							
	Monocot		Dicot		Sedge		Dormant/non-viable	
	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)
Initial weed seedbank	60		85		11		25	
Residues management								
Burning of wheat residues	120	+60 (+100.0)	83	-2 (-2.5)	9	-2 (-16.9)	30	+5 (+19.2)
Wheat residue incorporation *fb* soil solarization	85	+25 (+42.3)	65	-20 (-23.1)	6	-5 (-45.9)	15	-10 (+41.1)
Wheat residue incorporation *fb T. viride* + N	129	+69 (+115.0)	83	-2 (-2.2)	8	-3 (-26.4)	25	+0 (+0.0)
Weed management								
Stale seedbed *fb* IC and HW	52	-8 (-13.7)	89	+4 (+4.8)	5	-6 (-52.5)	24	-1 (-4.4)
Suicidal germination *fb* tillage *fb* IC and HW	30	-30 (-50.7)	46	-39 (-46.4)	6	-5 (-41.4)	13	-12 (-47.1)
Pendimethalin *fb* IC and HW	23	-37 (-61.7)	39	-46 (-54.0)	5	-6 (-57.6)	11	-14 (-56.4)
HW and IC *fb* imazethapyr + imazamox	54	-6 (-10.4)	96	+11 (+12.4)	10	-1 (-6.1)	20	-5 (-20.4)
Pendimethalin *fb* imazethapyr + imazamox	24	-36 (-59.8)	39	-46 (-53.9)	7	-4 (-39.4)	10	-15 (-60.4)
Weed free	19	-41 (-69.1)	28	-57 (-67.6)	4	-7 (-62.6)	7	-18 (-70.7)
Unweeded check	579	+519 (+865.7)	204	+119 (+139.6)	17	+6 (+51.5)	77	+52 (+206.2)

Figures in parentheses indicate percent addition or depletion

Table 6. Estimation of weed seedbank per hectare in 15 cm soil depth (2014)

Treatment	Bulk density (mg/m^3) (A)	Bulk density (kg/m^3) (A x 1000) (B)	Volume of one ha 15 cm soil depth (m^3) (C)	Weight of soil per ha up to 15 cm (kg) (B x C) (D)	Vol. of core sample 4 cm diameter and 15 cm length (m^3) ($\pi r^2 h$) (E)	Weight of core sample BD=w/v (A x E) (F)	Soil weed seedbank per core sample (G)	Estimated weed seeds per ha in 15 cm depth (= D x G/F) (x 10^{10} seeds)
Initial weed seedbank	1.36	1360	1500	2040000	0.00942	0.0128	215	3.42
Residues management								
Burning of wheat residues	1.31	1312	1500	1967857	0.00942	0.0124	259	4.13
Wheat residue incorporation *fb* soil solarization	1.30	1301	1500	1951429	0.00942	0.0123	161	2.56
Wheat residue incorporation *fb T. viride* + N	1.29	1288	1500	1932143	0.00942	0.0121	234	3.73
Weed management								
Stale seedbed *fb* IC and HW	1.31	1306	1500	1958333	0.00942	0.0123	168	2.67
Suicidal germination *fb* tillage *fb* IC and HW	1.30	1304	1500	1956667	0.00942	0.0123	99	1.58
Pendimethalin *fb* IC and HW	1.29	1293	1500	1940000	0.00942	0.0122	86	1.37
HW and IC *fb* imazethapyr + imazamox	1.30	1298	1500	1946667	0.00942	0.0122	191	3.04
Pendimethalin *fb* imazethapyr + imazamox	1.31	1308	1500	1961667	0.00942	0.0123	89	1.42
Weed free	1.28	1284	1500	1926667	0.00942	0.0121	68	1.08
Unweeded check	1.31	1309	1500	1963333	0.00942	0.0123	824	13.12

Table 7. Estimation of weed seedbank per hectare in 15 cm soil depth (2015)

Treatment	Bulk density (mg/m^3) (A)	Bulk density (kg/m^3) (A x 1000) (B)	Volume of one ha 15 cm soil depth (m^3) (C)	Weight of soil per ha up to 15 cm (kg) (B x C) (D)	Vol. of core sample 4 cm diameter and 15 cm length (m^3) ($\pi r^2 h$) (E)	Weight of core sample BD=w/v (A x E) (F)	Soil weed seedbank per core sample (G)	Estimated weed seeds per ha in 15 cm depth (= D x G/F) (x 10^{10} seeds)
Initial weed seedbank	1.32	1320	1500	1980000	0.00942	0.0124	181	2.88
Residues management								
Burning of wheat residues	1.29	1289	1500	1933571	0.00942	0.0121	242	4.13
Wheat residue incorporation *fb* soil solarization	1.29	1287	1500	1930000	0.00942	0.0121	171	2.56
Wheat residue incorporation *fb* *T. viride* + N	1.28	1277	1500	1915000	0.00942	0.0120	245	3.73
Weed management								
Stale seedbed *fb* IC and HW	1.29	1290	1500	1935000	0.00942	0.0122	170	2.71
Suicidal germination *fb* tillage *fb* IC and HW	1.29	1288	1500	1931667	0.00942	0.0121	95	1.51
Pendimethalin *fb* IC and HW	1.29	1287	1500	1930000	0.00942	0.0121	78	1.24
HW and IC *fb* imazethapyr + imazamox	1.29	1288	1500	1931667	0.00942	0.0121	180	2.86
Pendimethalin *fb* imazethapyr + imazamox	1.29	1287	1500	1930000	0.00942	0.0121	80	1.27
Weed free	1.26	1260	1500	1890000	0.00942	0.0119	58	0.92
Unweeded check	1.29	1290	1500	1935000	0.00942	0.0122	876	13.95

which were returned to the soil and increased the soil weed seedbank. Forcella *et al.* (1993), Branko *et al.* (2011), Forcella *et al.* (2011), Arora and Tomar (2012), Hosseini *et al.* (2014) and Gohil *et al.* (2016) also studied weed seedbank dynamics.

Conclusion

It can be concluded that effective management of soil weed seedbank in *Kharif* groundnut can be achieved by incorporation of wheat residues in soil by rotavator followed by soil solarization with 25 µm polythene sheet for 15 days during hot summer or application *Trichoderma viride* 5 kg/ha + 20 kg N/ha and pre-emergence application of pendimethalin 900 g/ha supplemented with either IC and HW at 45 DAS or pre-mix imazamox + imazethapyr 70 g/ha as post-emergence at 25 DAS or suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW at 45 DAS, resulting in to less problems of weeds in the next growing season.

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