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Integration of Pre and Non-Selective Post-Emergence Herbicides and Cultural Method for Weed Control in Cotton and Its Effect on Succeeding Crops

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ABSTRACT. *An experiment was conducted to evaluate sequential application of non-selective post-emergence herbicides and integrated method for weed control in cotton. The results were compared with the recommended practice of hand weeding (HW) twice and pre-emergence application of pendimethalin 1.0 kg + HW as well as a weed free situation. The results revealed that the maximum seed cotton yield of 1634 kg ha^{-1} could be obtained with a weed free situation and comparable yields are possible with glyphosate 2.05 kg ha^{-1} + HW (1412 kg ha^{-1}) and glufosinate 0.45 kg ha^{-1} + HW (1368 kg ha^{-1}). Maintaining weed free situation by manual weeding throughout the crop period gave the highest net return (Rs. 23,589 ha^{-1}) followed by glyphosate 1.025 kg + HW and glyphosate 2.05 kg (Rs. 20,926 and Rs. 20,720 ha^{-1}, respectively) as well as glufosinate 0.45 kg + HW (Rs. 20,331 ha^{-1}). However, the B:C ratio was low in weed free treatment (2.29) and glyphosate 2.05 kg + HW (2.33) compared to glyphosate 1.025 kg + HW (2.43) due to higher cost of weeding and chemical, respectively. Unweeded control recorded the least net return (Rs. 2458 ha^{-1}). Results on bioassay of herbicide residues indicated that none of the herbicides evaluated for the chemical control of weeds in cotton persisted in the soil to the level of affecting the germination and growth of succeeding crops such as finger millet and cucumber.*

INTRODUCTION

Cotton production in India stood at 17.6 million bales from 9.17 million ha of sown area during 1996–97. Out of which 0.27 million ha with a production of 0.60 million bales (Bardhan, 1998) is from Tamil Nadu. The area and production of cotton in various states of the country show a declining trend in the recent years due to various production and economic constraints.

Weed competition is one of the important biological constraint in cotton cultivation (Rajeswari and Charyulu, 1997). There were many methods adopted by farmers for control of weeds in the field and chemical method of weed control has been proved to be the best (Sharma and Angiras, 1997). However, complete control of weeds cannot be achieved by using any one method alone. Pre-emergence application of herbicides that kill the germinating weed seeds would be appropriate for minimising only the early weed competition, but fails to give a long-term weed control in a long duration crop like cotton, where the problem of late emerging weeds is more serious (Patil *et al.*, 1997). Directed spray of non-selective post-emergence herbicides on the weed foliage cause death of weeds due to its translocated or contact action. Being a wide spaced crop, information on effect

of positional selective use of non-selective post-emergence herbicides on weeds and cotton yield is limited and hence the present study was undertaken during the long rainy season (*rabi*) 1997-98.

MATERIALS AND METHODS

A field experiment was conducted at Tamil Nadu Agricultural University, Coimbatore during *rabi* (August-February) 1997-98. The soil was a well drained clay loam in texture with a fertility status of low (141 kg ha^{-1}), medium (21 kg ha^{-1}), high (412 kg ha^{-1}) in available nitrogen, phosphorus and potassium, respectively. The following 12 weed management treatments were studied in 3 replicates in a randomized block design.

Table 1. Treatment details.

Notation	Treatments
T_1	Pendimethalin 1.0 kg ha^{-1} (3 DAS) + HW (40 DAS)
T_2	Pendimethalin 1.0 kg ha^{-1} (3 DAS) + glyphosate 1.025 kg ha^{-1} (40 DAS)
T_3	Glufosinate 0.3 kg ha^{-1} (30 DAS) + HW (60 DAS)
T_4	Glufosinate 0.375 kg ha^{-1} (30 DAS) + HW (60 DAS)
T_5	Glufosinate 0.45 kg ha^{-1} (30 DAS) + HW (60 DAS)
T_6	Paraquat 0.6 kg ha^{-1} (30 DAS) + HW (60 DAS)
T_7	Glyphosate 1.025 kg ha^{-1} (30 DAS) + HW (60 DAS)
T_8	Glyphosate 2.05 kg ha^{-1} (30 DAS) + HW (60 DAS)
T_9	Glyphosate 1.025 kg ha^{-1} (30 DAS) + glyphosate 1.025 kg ha^{-1} (60 DAS)
T_{10}	Weed free (Hand weeding at 20, 40, 60 and 80 DAS)
T_{11}	Hand weeding twice (20 and 40 DAS)
T_{12}	Unweeded control

DAS - Days after sowing HW - Hand weeding

The cotton variety MCU 5 was sown with 75×30 cm spacing and 80:40:40 kg N, P_2O_5 and K_2O ha^{-1} was applied. Weed flora in 0.5×0.5 m area in net plot was counted and classified as grasses, sedges and broad leaved weeds. The weeds removed from this sampling area after counting were first sun dried, then oven dried at 65±5°C, weighed and the dry matter expressed in kg ha^{-1}. The weed control efficiency was calculated by using the formula given by Mani *et al.* (1973).

$$WCE\ \% = \frac{WDW\ of\ the\ control\ plot - WDW\ of\ the\ treated\ plot}{WDW\ of\ the\ control\ plot} \times 100$$

WCE - Weed control efficiency WDW - Weed dry weight

Five cotton plants were randomly selected from each net plot for recording observations.

Pendimethalin was applied as pre-emergent herbicide and glyphosate, glufosinate and paraquat were applied as directed post-emergence spray using knapsack sprayer and hood attached with floodjet (WFN 78) nozzle using a spray volume of 900 l ha^{-1}. The crop was sown on 4.9.97 and harvested in 5 pickings ending 12.3.98.

Immediately after harvest of cotton crop, soil from each treatment plot was taken for bioassay study. Two kg of composite soil sample taken from each plot was filled in polythene bags. Test crops *viz.*, cucumber (10 seeds) and Finger millet (20 seeds) were sown in these bags separately. Germination percentage at 10 DAS, biomass and plant height at 30 DAS were recorded for both test crops.

RESULTS AND DISCUSSION

Weed flora of the experimental field

Analyses of relative density of individual weed species revealed that the weed flora of the experimental field was dominated by broad leaved weeds (64.1%) comprising major species of *Commelina benghalensis* L., *Trianthema portulacastrum* L., *Parthenium hysterophorus* L., *Euphorbia hirta* L., *Flaveria australasica* Hook. and *Digera arvensis* Forsk.. The grassy weeds constituted 25.5% with major share of *Cynodon dactylon* L. Pers., followed by *Dactyloctenium aegyptium* Beauv.. The sedges *Cyperus rotundus* L. and *Cyperus esculentus* L. constituted 10.4% of the total weed density of the field.

Effect of treatments on weeds

Data on weed count at 30 DAS revealed that significantly low weed number m^{-2} was present in hand weeding (HW) treatment (weeded only once at 20 DAS) and weed free condition (T_{10}). Before post-emergence application of non-selective herbicides in the respective treatments, pendimethalin 1.0 kg ha^{-1} (T_1 and T_2) applied as pre-emergence showed a marked reduction in weed density. However, the weed densities were significantly higher than hand weeding and weed free treatments (Table 2). This was due to the continued growth of regenerated weeds favoured by continuous rainfall received during the cropping season which may also have lowered the efficacy of pendimethalin.

At 60 DAS, lowest weed population was recorded in plots treated with glyphosate 2.05 kg ha^{-1} (T_8) applied at 30 DAS which is comparable with weed free treatment (T_{10}), glyphosate 1.025 kg ha^{-1} (T_7), glufosinate 0.45 kg ha^{-1} (T_5) and paraquat 0.6 kg ha^{-1} (T_6) applied plots. Satao *et al.* (1998a and 1998b) reported that weed population in glufosinate 0.45 kg, paraquat 0.6 kg, glyphosate 2.05 kg and glyphosate 1.025 kg applied plots were on par. Adequate soil moisture provided by continuous monsoon rains resulted in late emergence of weeds and hence the weed population in hand weeded plots as well as plots treated with pre-emergence herbicide was more at this stage even after a follow up HW. At 90 DAS, glyphosate 2.05 kg ha^{-1} + HW recorded the lowest weed density followed by

glyphosate 1.025 kg ha^{-1} + HW and glufosinate 0.45 kg ha^{-1} + HW. Weed density observed in glyphosate 2.05 kg applied treatments was lower than treatment applied with glyphosate 1.025 kg ha^{-1} (Detroja *et al.*, 1992). Highest weed count m^{-2} was recorded in untreated plot both at 60 and 90 DAS.

Table 2. Weed density (SQR (x+.05) transformed) m^{-2} as affected by weed control treatments in cotton.

Treatments	* Weed density m^{-2}		
	30 DAS	60 DAS	90 DAS
T_1 - Pendi 1.0 + HW	6.78	5.64	6.87
T_2 - Pendi 1.0 + Gly 1.025	6.36	5.34	5.67
T_3 - Glu 0.3 + HW	10.16	8.11	4.71
T_4 - Glu 0.375 + HW	9.19	7.47	3.97
T_5 - Glu 0.45 + HW	10.78	4.74	2.35
T_6 - Para 0.6 + HW	10.32	5.21	2.12
T_7 - Gly 1.025 + HW	9.99	4.30	1.65
T_8 - Gly 2.05 + HW	9.75	2.67	1.29
T_9 - Gly 1.025 + Gly 1.025	9.75	4.33	2.91
T_{10} - Weed free	3.53	4.22	2.68
T_{11} - 2 HW	3.31	6.91	7.01
T_{12} - Unweeded control	10.76	12.35	12.13
SE_D	0.74	0.82	6.78
CD (P=0.05)	1.53	1.71	1.62

DAS - Days after sowing; Gly - Glyphosate; Pendi - Pendimethalin; Glu-Glufosinate; Para - Paraquat; HW - Hand weeding
SE_D - Standard deviation of the sampling distribution
CD (P=0.05) - Product of standard error and t value with 5% probability level at error degrees of freedom

At the early crop growth stage (30 DAS), the lowest weed dry weight was noticed in weed free treatment, which was similar to the plots which received one hand weeding at this stage (Table 3). The weed biomass in pre-emergence herbicide applied plots (T_1 and T_2) was moderate compared to the plots where a weed control treatment was not imposed at this stage. At 60 DAS, weed free, pendimethalin + glyphosate and pendimethalin + HW treatments restricted the weed biomass to a minimum. Pendimethalin 1.0 kg ha^{-1} as pre emergence sprays coupled with hand weeding minimized weed dry weight equal to sequential application of pendimethalin + glyphosate (Patil *et al.*, 1997). However, as the crop growth stages advanced (60 and 90 DAS) the weed dry weight gradually increased in pre-emergent herbicide applied treatments and manually weeded plots as a result of germination and growth of next flush of weeds after seasonal rains. Post emergent spray of glufosinate 0.375 kg and 0.45 kg (Satao *et al.*, 1998a), glyphosate 1.025 kg and 2.05 kg (Satao *et al.*, 1998b) caused appreciable decrease in dry weight of weeds due to herbicidal

weed control and manual weeding removed the left out weeds (Patil *et al.*, 1997). Rajeswari and Charyulu (1997) reported that glyphosate 1.0 kg ha^{-1} and paraquat 0.6 kg ha^{-1} reduced the dry weight of weeds by 90.0 and 94.8%, which are in confirmation with the present results.

Table 3. Weed dry weight (log (x+ 1) transformed) (kg ha^{-1}) and weed control efficiency (%) as affected by weed control treatments in cotton.

Treatments	*Weed dry weight (kg ha^{-1})			Weed control efficiency (%)	
	30 DAS	60 DAS	90 DAS	60 DAS	90 DAS
T_1 - Pendi 1.0 + HW	2.50	2.46	2.67	85.5	75.6
T_2 - Pendi 1.0 + Gly 1.025	2.50	2.44	2.68	83.8	75.5
T_3 - Glu 0.3 + HW	2.68	2.72	2.31	69.8	89.6
T_4 - Glu 0.375 + HW	2.79	2.61	2.20	76.4	91.9
T_5 - Glu 0.45 + HW	2.93	2.58	2.12	78.0	93.3
T_6 - Para 0.6 + HW	2.74	2.56	2.14	77.4	92.9
T_7 - Gly 1.025 + HW	2.86	2.57	2.12	78.6	93.3
T_8 - Gly 2.05 +HW	2.84	2.53	2.06	80.2	93.9
T_9 - Gly 1.025 + Gly 1.025	2.60	2.59	2.16	77.9	92.5
T_{10} - Weed free	1.74	1.70	1.91	97.2	95.8
T_{11} - 2 HW	1.75	2.47	2.60	88.0	79.4
T_{12} - Unweeded control	2.75	3.24	3.28	0.0	0.0
SE_D	0.34	0.04	0.02		
CD (P=0.05)	0.70	0.08	0.04		

DAS - Days after sowing; Gly - Glyphosate; Pendi - Pendimethalin; Glu - Glufosinate; Para - Paraquat; HW - Hand weeding
SE_D - Standard deviation of the sampling distribution of a statistic
CD (P=0.05) - Product of standard error and t value with 5% probability at error degrees of freedom

At 90 DAS, glyphosate 2.05 + HW significantly reduced the weed dry weight and the figure was at par with weed free situation. Glyphosate 1.025 kg + HW, glufosinate 0.45 kg + HW and paraquat 0.6 kg + HW were statistically similar in reducing weed dry weight at this stage.

Weed control efficiency (WCE) on the basis of weed dry weight under unweeded control is presented in Table 3. Invariably, weed free treatment recorded the highest weed control efficiency at 60 and 90 DAS. At 60 DAS, HW twice, pendimethalin + HW and sequential application of pendimethalin + glyphosate recorded higher WCE next to weed free treatment. At 90 DAS, post-emergence control of established weeds with non-selective herbicides recorded WCE more than 90% while, weed control efficiency with

pendiemthalin + HW or pendimethalin + glyphosate as well as hand weeding twice was less than 80%.

Effect of treatments on crop growth

Weed free condition throughout the crop period produced the maximum number of bolls plant^{-1} (17.6) which was comparable with glufosinate 0.45 kg, glyphosate 1.025 kg and glyphosate 2.05 kg, treatments with a follow up hand weeding. The lowest number of bolls per plant (7.6) was observed in unweeded plots. Almost all the weed control treatments produced bolls of similar mean weight (4.08 to 4.40 g boll^{-1}) except pendimethalin + glyphosate (3.93 g) and unweeded plots (3.97 g) (Table 4).

Table 4. Yield components, seed cotton yield and economics of cotton as affected by weed control treatments.

Treatments	No. of bolls per plant	Boll weight (g)	Seed cotton yield (kg ha^{-1})	Net return (Rs. ha^{-1})	B:C ratio
T_1 - Pendi 1.0 + HW	15.2	4.22	1154	14520	1.96
T_2 - Pendi 1.0 + Gly 1.025	13.2	4.40	1027	11142	1.73
T_3 - Glu 0.3 + HW	11.4	3.93	812	6077	1.41
T_4 - Glu 0.375 + HW	13.6	4.18	991	10596	1.71
T_5 - Glu 0.45 + HW	16.2	4.24	1368	20331	2.37
T_6 - Para 0.6 + HW	14.8	4.16	1325	19576	2.36
T_7 - Gly 1.025 + HW	16.0	4.19	1384	20926	2.43
T_8 - Gly 2.05 + HW	15.8	4.19	1412	20720	2.33
T_9 - Gly 1.025 + Gly 1.025	14.6	4.34	1336	19505	2.32
T_{10} - Weed free	17.6	4.19	1634	23589	2.29
T_{11} - 2 HW	15.2	4.08	1215	16710	2.15
T_{12} - Unweeded control	7.6	3.97	591	2458	1.19
SE_D	0.7	0.20	76		
CD (P=0.05)	1.6	0.41	158		

DAS - Days after sowing; Gly - Glyphosate; Pendi - Pendimethalin; Glu - Glufosinate; Para - Paraquat; HW - Hand weeding
SE_D - Standard deviation of the sampling distribution of a statistic
CD (P=0.05) - Product of standard error and t value with 5% probability at error degrees of freedom

Effect of treatments on seed cotton yield and economics

Highest seed cotton yield (1634 kg ha^{-1}) was obtained from weed free treatment which was comparable with glyphosate 2.05 kg ha^{-1} + HW (1412 kg ha^{-1}). Panwar *et al.* (1995) also reported higher seed cotton yield under weed free condition. Post-emergence spray of glyphosate 1.025 kg + HW, glufosinate 0.45 + HW as well as sequential

application of glyphosate 1.025 kg + glyphosate 1.025 kg and paraquat 0.6 kg were also observed as the best alternative treatments as they gave seed cotton yield statistically at par with glyphosate 2.05 kg ha^{-1} + HW. These results confirm those reported by Satao (1998a and 1998b).

Weed free treatment gave the maximum net return (Rs. 23,589), while the Benefit Cost (B:C) ratio was comparatively low (2.29) due to increased cost of manual weeding (Table 4). Among the currently evaluated treatments, glyphosate 2.05 or 1.025 kg and glufosinate 0.45 kg each with one HW gave substantially higher net returns (Table 4). Sequential application glyphosate + glyphosate (T_9) and post-emergence application of paraquat 0.6 kg + HW (T_6) could also be rated as economically viable treatments with next best economic returns of Rs. 19,505 and 19,576 as net income, respectively.

Bioassay of herbicide residues

The pot experiment carried out to assess the residual effect of herbicides on the succeeding crop (finger millet and cucumber) reveals that the germination per cent of the test crops is not affected by the treatments (Table 5). Similarly, there was no significant

Table 5. Effect of herbicide residue on germination (per cent), plant height (cm) and dry weight (g $plant^{-1}$) of test crops.

Treatments	Germination (%)		Plant height (cm)		Biomass production (g $plant^{-1}$)	
	F	C	F	C	F	C
T_1 - Pendi 1.0 + HW	76.6	80.0	52.7	40.0	2.57	2.41
T_2 - Pendi 1.0 + Gly	86.7	63.3	52.9	41.1	2.61	2.44
T_3 - Glu 0.3 + HW	90.0	80.0	50.9	41.1	2.49	2.50
T_4 - Glu 0.375 + HW	85.0	86.7	53.2	40.2	2.56	2.45
T_5 - Glu 0.45 + HW	88.3	90.0	53.4	41.2	2.53	2.34
T_6 - Para 0.6 + HW	91.7	86.6	52.9	41.5	2.59	2.35
T_7 - Gly 1.025 + HW	91.7	93.3	53.1	41.3	2.45	2.36
T_8 - Gly 2.05 + HW	95.0	96.7	53.5	40.0	2.52	2.44
T_9 - Gly 1.025 + Gly	90.0	86.7	53.7	41.3	2.44	2.25
T_{10} - Weed free	86.7	86.8	52.5	40.9	2.49	2.46
T_{11} - 2 HW	83.3	86.7	53.0	40.9	2.41	2.35
T_{12} - Unweeded control	83.3	90.0	54.1	43.3	2.52	2.49
SE_D	5.94	10.6	5.37	4.38	0.10	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS

F - Finger millet; C - Cucumber; DAS - Days after sowing; Gly - Glyphosate; Pendi - Pendimethalin; Glu - Glufosinate; Para - Paraquat; HW - Hand weeding
SE_D - Standard deviation of the sampling distribution of a statistic
CD (P=0.05) - Product of standard error and t value with 5% probability at error degrees of freedom

difference in height and dry matter production of the test crops at 30 DAS. These results, thus indicate that none of the herbicides evaluated for the chemical control of weeds in cotton persisted in the soil to the level of affecting the germination and growth of succeeding crops such as finger millet and cucumber.

CONCLUSIONS

It can be concluded that integrated weed management (IWM) practices of post-directed application of glyphosate 2.05 or 1.025 kg ha^{-1} at 30 DAS with one hand weeding at 60 DAS and higher dose of glufosinate 0.45 kg ha^{-1} at 30 DAS with a follow up hand weeding at 60 DAS could offer better weed control during the critical period of weed competition. This would increase the yield and economics of winter irrigated cotton compared to the presently recommended weed control method of either manual weeding (HW twice; 20 and 40 DAS) or integrated weed management practice of pendimethalin 1.0 kg (3 DAS) + HW (40 DAS). Post-emergence application of paraquat 0.6 kg ha^{-1} at 30 DAS with one hand weeding at 60 DAS and sequential application of glyphosate 1.025 kg ha^{-1} + glyphosate 1.025 kg ha^{-1} at 30 and 60 DAS could be considered as suitable alternative weed management practices on the basis of better weed control, seed cotton yield and economic indices.

Bioassay studies on possible herbicide residues to succeeding finger millet and cucumber indicated that the herbicides used in this experiment have no significant phytotoxic effect on germination and growth of the succeeding crops.

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