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RESEARCH ARTICLE

Sustainable Weed Management Strategies in Cotton Crop and Their Economical Performance in Semi-Arid Environment

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ABSTRACT

Economical weed control in cotton is considered as a big task to get maximum benefits especially in developing countries. For economic weed control analysis, a set of three experiments was conducted with different weed management practices including chemical, mechanical, irrigational and allelopathic extracts alone and in combination with each other. In first experiment, water extracts of brassica and sorghum were applied in combination with herbicide (*S-Metolachlor)* and intercultural practices. In second experiment, combination of post and pre-emergence herbicides along with mechanical weeding were evaluated in crop grown under different irrigation systems. While in third experiment, three factors (water extracts, herbicides and irrigation systems) were collectively studied for sustainable weed management. In first experiment, maximum net benefits (Rs. 78798 & 184755) were obtained where *S-Metolachlor* (2 L ha^{-1}) and both water extract (15 L ha^{-1}) were applied in combination with interculturing. In second experiment, manual weeding under drip irrigation method gave the maximum net benefits (Rs. 28603 & 79175). In third experiment, chemical treatment of *Pendimethalin* (2.5 L ha^{-1}) with drip irrigation method resulted in maximum net benefits (Rs. 153407 & 53493) during both years. Considering these findings, it can be concluded that integrated weed management strategies, either with chemical + water extracts, chemical + mechanical and chemical + improved irrigation system were found economical.

INTRODUCTION

High weed infestation is an important factor responsible for low yield of cotton (Fuente et al., 2014; Nadeem et al., 2013). Weeds compete not only for nutrients and moisture but also affect plant roots by releasing secondary substances into rhizosphere of the crop (Farooq et al., 2011). Weed competition in cotton was found more critical between 15-60 days (Sharma and Pampapathy, 2006). In cotton, weeds are reported liable for losses from 50 to 85 % subject to the nature and intensity of the weeds (Prabhu et al., 2012).

Weeds can be eradicated by different mechanical, biological, cultural or chemical methods (Marwat et al., 2013; Nadeem et al., 2013; Santos, 2009). However, adaptation of a specific method by farmers will depend upon its cost-effective efficacy. Moreover, selection of weed control method in cotton fields depends on its effectiveness for preventing weed interference with crop and lower seed maturity. Prabhu et al. (2012) suggested that while selecting a suitable weed management practice in cotton field, the farmer should also focus on weed interference with cotton crop affecting its lint yield and quality as weeds can reduce lint quality due to additional trash and staining of fibers leading to low grades that will result into lower economic returns. Considering these issues, weed management practice requires advance planting and timely execution of cotton crop. Any delay in timely sowing of cotton seeds may result in more usage of herbicide that will result in more financial inputs.

Mechanical and manual weeding has been adopted to control weeds and is more common (Ali et al., 2013; Papageorgiou et al., 2008). These practices need high cost in terms of machinery and fuel. A most common and easy way is the use of herbicides against specific weed in cotton. Herbicides act through the disruption of cell division and elongation that may interrupt weed seedling growth shortly after germination and mortality of weed plants (Dhuppar et al., 2013). However, use of herbicides in cotton for different types of weeds increase cost of production per unit area. In addition to mechanical and chemicals methods, extracts of specific plants with specific dilutions are also used as herbicides. Many plants release allelochemical compounds that cause growth inhibition to their neighboring plants. So, the usage of these allelochemicals in weed control has great potential for weed management (Cheema et al., 2009; Kruse et al., 2000). These allelochemicals are considered as environment friendly having capability to mitigate the issues raised by the use of synthetic chemicals (Iqbal and Cheema, 2007). It is very important to consider that all weeds cannot be controlled through applying allelochemicals, so these may be applied in combination with a lower dose of herbicides to control weeds (Cheema et al., 2000). Moreover, performance of allelopathic chemicals may be enhanced by using these in combination with herbicides (Cheema et al., 2005). Keeping in view, this study was carried out to find a suitable and cost effective combination of allelochemicals with herbicides or cultural practices for apposite and opportune control of weeds.

MATERIALS AND METHODS

Three experiments were conducted at two different sites viz. experimental farm of the Department of Agronomy, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Pakistan and Central Cotton Research Institute, Multan, Pakistan to explore the integrated approach of weed management in cotton crop during the years 2009-2011.

Allelopathic water extracts

Allelopathic crops of brassica and sorghum were harvested at maturity then the selected plants (free of diseases and insects) were rinsed with tap water to remove the sticky foreign contamination. These samples were laid down on glazed paper at ground level and dried them under the shade which almost remained at temperature of (35ºC ± 2) for period of one month. After drying, these plants were chopped into 2 cm pieces by using local electric fodder cutter. After chopping, this material was soaked in the distilled water for 24 h at the ratio of 1:10 (w/v) (Cheema et al., 2000). After soaking of this material, it was filtered through the local sieving machine having 10 and 60 mesh gradually and preserved them after boiling at 100 ºC for evaporation of water to get the required volume up to 20 times (5%) in plastic bottles. These plastic bottles were properly labeled with permanent marker and preserved in store room of our department. However, these prepared secondary metabolites are now ready for further process.

Crop husbandry

In first experiment, there were three factors under study viz. plant water extract, interculturing and weedicides. This experiment was conducted at experimental farm of the Department of Agronomy, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University Multan. Cotton cultivar (CIM-573) was used as test crop, which was sown on well prepared seed bed on 7th and 11th May of 2009 and 2010, respectively. Dibbling method was used for crop sowing on beds and furrows by keeping 75 cm of rows' distance. Treatments were allocated according to randomized complete block design (RCBD) where interculture practices (No interculturing (I_0) and (I_2) interculturing) were remained in main plots, while water extract WE_0: Water Extract (no application), WE_1: Water Extract (12 L ha^{-1}), WE_2: Water Extract (15 L ha^{-1}) in sub plot and weedicide treatment: W_0: *S-Metolachlor* (Zero application), W_1: *S-Metolachlor* (1 L ha^{-1}) W_2: *S-Metolachlor* (2 L ha^{-1}) in sub-sub plot with three replications. Pre-emergence herbicide (*S-Metolachlor*) was applied after crop sowing at three different rates of 0, 1 and 2 L ha^{-1} by knap sack hand sprayer in their respective plots. Similarly, the plant water extracts of Brassica and Sorghum at the rates of 0, 12 and 15 L ha^{-1} were applied in three split doses at appropriate time (7, 14 and 21 days after sowing) by knap sack hand sprayer with shield nozzle to protect the crop in their respective plots. One interculturing (25 days after sowing) and second interculturing (45 days sowing) were applied with tractor driven specified implement in their respective plots. The proposed levels of nitrogen fertilizer (115 kg ha^{-1}) were applied in the form of Urea (46% N) and basal dose of phosphorus was applied at the rate of 57 kg P_2O_5 in the form of TSP (46% P_2O_5). Phosphorous was applied with the first irrigation while the nitrogen was applied in three split doses. Initially, the split dose of nitrogen from urea was applied during first irrigation, second at the time of vegetative stage and lastly at the time of flower initiation stage.

Second experiment was conducted at Central cotton Research Institute Multan, Pakistan in a randomized complete block design with split plot arrangement, keeping irrigation treatment: I_1: Drip Irrigation, I_2: Furrow Irrigation in main plot and different weed control practices: $W.M_0$: Weedy Check, $W.M_1$: *Pendimethalin* at the rate of 2.5 Lha^{-1} (pre-emergence), $W.M_2$: *S-Metolachlor* at the rate of 2.0 Lha^{-1} (pre-emergence), $W.M_3$: *Glyphosate* 48% W/V SL at the rate of 4.7 Lha^{-1} (post-emergence), $W.M_4$: *Pendimethalin* (2.5 Lha^{-1}) + *Glyphosate* 48% W/V SL (4.7 Lha^{-1}), $W.M_5$: *S-Metolachlor* (2.0 Lha^{-1}) + *Glyphosate* 48% W/V SL (4.7 Lha^{-1}), $W.M_6$: Manual weeding (Two) in sub plot with three replications having a net plot size of 7 m x 3 m at second experimental site. Cotton cultivar CIM-557 was sown on well prepared seed bed on 21st and 18th May in 2009 and 2010, respectively. The planned study was initiated as the plants were grown on bed and furrows which were prepared by their respective primary and secondary tillage tools at 75 cm distance**.** The pre-emergence herbicide i.e., *Pendimethalin* at the rate of 2.5 Lha^{-1} was sprayed by knap sack hand sprayer same day before sowing in their respective plots. The crop was planted by dibbling of seeds manually. The other pre-emergence herbicides i.e., *S-Metolachlor* at the rate 2 Lha^{-1} were sprayed 24 hours after sowing in their respective plots. The post emergence herbicide i.e. *Glyphosate* at the rate of 4.7 Lha^{-1} was sprayed by knap sack hand sprayer with shield at nozzle to protect the crop at appropriate time. Two manual weeding were carried out at 25 and 45 days after sowing in respective plots. Drip irrigation system was installed in their respective plots. However, the remaining plots were irrigated by furrow irrigation system for this study. Same fertilizers in the form of N, P and K were applied as in first experiment. Recommended practices were made for plant protection and data recording.

Third experiment was also laid out in randomized complete block design with split-split plot arrangement keeping irrigation treatment I_1: Drip Irrigation, I_2: Furrow Irrigation in main plot, water extract treatment: $W.E_0$: Water Extract (Zero application), $W.E_1$: Water Extract (15 L ha^{-1}) in sub plot and weedicide treatment: W_0: Weedicide (Zero application), W_1: *Pendimethalin* (2 L ha^{-1}), W_2: *Glyphosate* (4.7 L ha^{-1}) in sub-sub plot replicated thrice having a net plot size of 7 m x 3 m at second experimental site. Cotton cultivar CIM-573 was sown on well prepared seed bed on 14th and 18th May in 2010 and 2011, respectively. The planned study was initiated as the plants were grown on bed and furrows, which were prepared by their respective primary and secondary tillage tools at 75 cm distance**.** The pre-emergence herbicide i.e., *Pendimethalin* at the rate of 2.5 Lha^{-1} was sprayed by knap sack hand sprayer same day before sowing in their respective plots. The crop was planted by dibbling of seeds manually. The post-emergence herbicide was sprayed at 38 and 40 days after sowing. Water extracts were sprayed at the rate of 0 and 15 Lha^{-1} in three split doses at appropriate times i.e. 7, 14 and 21 days after sowing, by using knap sack hand sprayer with shield nozzle to protect the crop in their respective plots. Drip irrigation system was installed in their respective plots accordingly whereas the remaining plots were irrigated by furrow irrigation system. The proposed levels of N fertilizer (115.0 kg ha^{-1}) were applied in the form of Urea (46% N) and basal dose of P was applied at the rate of 57.0 kg P_2O_5 in the form of TSP (46% P_2O_5). Cultural practices like protection measures were made out accordingly as and when required by the plant.

Economic analysis

Net returns

Net returns (Rs./ha) were calculated simply by subtracting total cost of cultivation from the gross returns of each treatments. However, mathematically expression pertaining to gross income and net return for each treatment were calculated as given below:

Gross Income = Seed Cotton yield (kg ha^{-1}) × Rate of seed Cotton / 40kg) + Sticks value

Net Income = Gross Income ha^{-1} – Total Cost of Production ha^{-1}

RESULTS

In first experiment, during both years interculturing+ *S-Metolachlor* at the rate of 2 Lha^{-1} + water extract at the rate of 15 Lha^{-1} (T_{18}) gave the maximum net benefits. This was followed by interculturing + *S-Metolachlor* at the rate of 2 Lha^{-1} + water extract at the rate of 12 Lha^{-1} (T_{15}). Maximum net benefit Rs. 78798 (2009) and Rs. 184755 (2010) was obtained from treatment (T_{18}) (Table 1a & b).

In second experiment, during both years, manual weeding under drip irrigation method (T_7) gave the maximum net benefits. This was followed by *S-Metolachlor* at the rate of 2 Lha^{-1} + Glyphosate at the rate of 4.7 Lha^{-1} + drip irrigation (T_6). Maximum net benefit Rs. 28606 (2009) and Rs. 79175 (2010) was obtained from treatment (T_7) (Table 2a & b).

In third experiment, during both years, *Pendimethalin* at the rate of 2.5 Lha^{-1} under drip irrigation method (T_5) gave the maximum net benefits. This was followed by *Glyphosate* at the rate of 4.7 Lha^{-1} + drip irrigation method (T_6). Maximum net benefit Rs. 153407 (2010) and Rs. 53493 (2011) was obtained from treatment (T_5) (Table 3a & b).

DISCUSSION

Weed infestation is a major problem in cotton crop in semi-arid environment of Pakistan. Environment friendly and cost-effective weed management strategies are being considered to adopt by farmers. Furthermore, it seems more difficult in lower economic or developing countries where farmers cannot make additional investments on crop production to reduce input cost. In Pakistan, various weed controlling strategies are being used to eradicate the weeds but the most prominent is the herbicides' application. Although herbicides have quick action but this practice is not affordable by all farmers due to higher cost of these chemicals. Moreover, these also exert environmental pressure to its surroundings influencing the human being. Another drawback of using herbicides is creating resistance in some cotton weeds which are not easy to control.

Table 1 (a): Economic analysis as affected by different weed management practices in upland Cotton with Brassica and Sorghum extracts along with *S-Metolachlor* (2009)

Economic parameter	No Interculture									Interculture									Remarks
	No water extract			Water extract (12 Lha^{-1})			Water extract (15 Lha^{-1})			No water extract			Water extract (12 Lha^{-1})			Water extract (15 Lha^{-1})			
	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	
Seed cotton yield	1332	1766	2596	1480	2092	2690	1521	2265	2737	3149	3248	3379	3172	3289	3533	3286	3360	3581	Kg ha^{-1}
Adjusted cotton yield	1199	1658	2336	1332	1883	2421	1369	2039	2463	2834	2923	3041	2855	2960	3180	2957	3024	3223	Kg ha^{-1}
Gross benefit	63547	87874	123808	70596	99799	128313	72557	108067	130539	150202	154919	161173	151315	156880	168540	156721	160272	170819	2120/40 kg
Cost of interculture	0	0	0	0	0	0	0	0	0	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000 ha^{-1}
Water extract cost	0	0	0	48	48	48	60	60	60	0	0	0	48	48	48	60	60	60	Rs. 60/15 L W.E preparation
Cost of herbicide	0	713	1425	0	713	1425	0	713	1425	0	713	1425	0	713	1425	0	713	1425	Rs. 570/800 ml
Sprayer rent	0	70	70	70	140	140	70	140	140	0	70	70	70	140	140	70	140	140	Rs. 70 ha^{-1}
Labor charges of spray	0	160	160	160	320	320	160	320	320	0	160	160	160	320	320	160	320	320	Rs. 160 ha^{-1}
Total cost that vary	0	943	1655	278	1221	1933	290	1233	1945	2000	2943	3655	2278	3221	3933	2290	3233	3945	Rs. ha^{-1}
Non-variable charges	88994	88994	88994	88994	88994	88994	88994	88994	88994	88994	88994	88994	88994	88994	88994	88994	88994	88994	Rs. ha^{-1}
Total expenditure	88994	89937	90649	89272	90215	90927	89284	90227	90939	90994	91937	92649	91272	92215	92927	91284	92227	92939	Rs. ha^{-1}
Net benefit	-24529	-1145	34077	-17758	10502	38304	-15809	18818	40518	60126	63900	69442	60961	65583	76531	66355	68963	78798	Rs. ha^{-1}

W_0: S-Metolachlor (zero application); W_1: S-Metolachlor (1 L ha^{-1}); W_2: S-Metolachlor (2 L ha^{-1}).

Table 1 (b): Economic analysis as affected by different weed management practices in upland Cotton with Brassica and Sorghum extracts along with *S-Metolachlor* (2010)

Economic Parameter	No Interculture									Interculture									Remarks
	No water extract			Water extract (12 L ha^{-1})			Water extract (15 L ha^{-1})			No water extract			Water extract (12 L ha^{-1})			Water extract (15 L ha^{-1})			
	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	
Seed cotton yield	1114	1270	2328	1178	2070	2432	1223	2134	2472	2648	2789	2906	2690	2823	3061	2788	2901	3159	Kg ha^{-1}
Adjusted cotton yield	1003	1143	2095	1060	1863	2189	1101	1921	2225	2383	2510	2615	2421	2541	2755	2509	2611	2843	Kg ha^{-1}
Gross benefit	106719	121615	222908	112784	198223	232909	117145	204394	236740	253551	267064	278236	257595	270363	293132	266958	277811	302495	4255/40 kg
Cost of intercultural	0	0	0	0	0	0	0	0	0	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000 ha^{-1}
Water extract cost	0	0	0	48	48	48	60	60	60	0	0	0	48	48	48	60	60	60	Rs.60/15L W.E preparation
Cost of herbicide	0	750	1500	0	750	1500	0	750	1500	0	750	1500	0	750	1500	0	750	1500	Rs. 600/800 ml
Sprayer rent	0	70	70	70	140	140	70	140	140	0	70	70	70	140	140	70	140	140	Rs. 70 ha^{-1}
Labor charges of spray	0	160	160	160	320	320	160	320	320	0	160	160	160	320	320	160	320	320	Rs. 160 ha^{-1}
Total cost that vary	0	980	1730	278	1258	2008	290	1270	2020	2000	2980	3730	2278	3258	4008	2290	3270	4020	Rs. ha^{-1}
Non-variable charges	113720	113720	113720	113720	113720	113720	113720	113720	113720	113720	113720	113720	113720	113720	113720	113720	113720	113720	Rs. ha^{-1}
Total expenditure	113720	114700	115450	113998	114978	115728	114010	114990	115740	115720	116700	117450	115998	116978	117728	116010	116990	117740	Rs. ha^{-1}
Net benefit	-7001	6915	107458	-1214	83245	117181	3135	89404	121000	137831	150364	160786	141597	153385	175404	150948	160821	184755	Rs. / ha

W_0: S-Metolachlor (zero application); W_1: S-Metolachlor (1 L ha^{-1}); W_2: S-Metolachlor (2 L ha^{-1}).

Table 2 (a): Effect of different chemical and mechanical weed management practices under different irrigation methods on economic analysis (2009)

Economic parameter	Drip Irrigation							Furrow Irrigation							Remarks
	W.M$_0$	WM$_1$	WM$_2$	W.M$_3$	W.M$_4$	W.M$_5$	W.M$_6$	W.M$_0$	WM$_1$	WM$_2$	W.M$_3$	W.M$_4$	W.M$_5$	W.M$_6$	
Seed Cotton yield	1017	1850	1951	1390	2110	2207	2376	855	1654	1826	1245	2005	2087	2133	Kg ha^{-1}
Adjusted Cotton yield	915	1665	1756	1251	1899	1986	2138	770	1489	1643	1121	1805	1878	1920	Kg ha^{-1}
Gross benefit	48511	88245	93063	66303	100647	105274	113335	40784	78896	87100	59386	95638	99550	101744	2120/40 kg
Cost of herbicides	0	1025	1426	3355	4380	4781	0	0	1025	1426	3355	4380	4781	0	Rs. ha^{-1}
Sprayer rent	0	70	70	70	140	140	0	0	70	70	70	140	140	0	Rs. 70 ha^{-1}
Labor charges of spray	0	160	160	160	320	320	0	0	160	160	160	320	320	0	Rs. 160 ha^{-1}
Cost of manual weeding	0	0	0	0	0	0	2990	0	0	0	0	0	0	2990	Rs.2990 ha^{-1}
Irrigation charges	5194	5194	5194	5194	5194	5194	5194	12588	12588	12588	12588	12588	12588	12588	Rs. ha^{-1}
Total cost that vary	5194	6449	6850	8779	10034	10435	8184	12588	13843	14244	16173	17428	17829	15578	Rs. ha^{-1}
Non-variable cost	76548	76548	76548	76548	76548	76548	76548	76548	76548	76548	76548	76548	76548	76548	Rs. ha^{-1}
Total expenditure	81742	82997	83398	85327	86582	86983	84732	89136	90391	90792	92721	93976	94377	92126	Rs. ha^{-1}
Net benefit	-33231	5248	9665	-19024	14065	18291	28603	-48353	-11495	-3692	-33335	1663	5173	9618	Rs. ha^{-1}

W.M$_0$: Weedy Check; W.M$_1$: *Pendimethalin* at the rate of 2.5 L ha^{-1} (pre-emergence); W.M$_2$: *S-Metolachlor* at the rate of 2.0 L ha^{-1} (pre-emergence); W.M$_3$: *Glyphosate* 48% W/V SL at the rate of 4.7 L ha^{-1} (post-emergence); W.M$_4$: *Pendimethalin* (2.5 L ha^{-1}) + *Glyphosate* 48% W/V SL (4.7 L ha^{-1}); W.M$_5$: *S-Metolachlor* (2.0 L ha^{-1}) + *Glyphosate* 48% W/V SL (4.7 L ha^{-1}); W.M$_6$: Manual weeding (Two).

Table 2 (b): Effect of different chemical and mechanical weed management practices under different irrigation methods on economic analysis (2010)

Economic parameter	Drip Irrigation							Furrow Irrigation							Remarks
	W.M$_0$	WM$_1$	WM$_2$	W.M$_3$	W.M$_4$	W.M$_5$	W.M$_6$	W.M$_0$	WM$_1$	WM$_2$	W.M$_3$	W.M$_4$	W.M$_5$	W.M$_6$	
Seed Cotton yield	812	1515	1615	1335	1750	1827	1907	727	1335	1339	1065	1575	1603	1692	Kg ha^{-1}
Adjusted Cotton yield	731	1364	1454	1202	1575	1644	1716	654	1202	1205	959	1418	1443	1523	Kg ha^{-1}
Gross benefit	77757	145076	154652	127840	167580	174954	182614	69618	127840	128223	101984	150822	153503	162026	4255/40 kg
Cost of herbicide	0	1112	1200	3355	4467	4555	0	0	1112	1200	3355	4467	4555	0	Rs. ha^{-1}
Sprayer rent	0	70	70	70	140	140	0	0	70	70	70	140	140	0	Rs. 70 ha^{-1}
Labor charges of spray	0	160	160	160	320	320	0	0	160	160	160	320	320	0	Rs. 160 ha^{-1}
Cost of manual weeding	0	0	0	0	0	0	2990	0	0	0	0	0	0	2990	Rs. 2990 ha^{-1}
Irrigation charges	3786	3786	3786	3786	3786	3786	3786	17057	17057	17057	17057	17057	17057	17057	Rs. ha^{-1}
Total cost that vary	3786	5128	5216	7371	8713	8801	6776	17057	18399	18487	20642	21984	22072	20047	Rs. ha^{-1}
Non-variable cost	96663	96663	96663	96663	96663	96663	96663	96663	96663	96663	96663	96663	96663	96663	Rs. ha^{-1}
Total expenditure	100449	101791	101879	104034	105376	105464	103439	113720	115062	115150	117305	118647	118735	116710	Rs. ha^{-1}
Net benefit	-22692	43285	52773	23806	62204	69490	79175	-44102	12778	13073	-15321	32175	34768	45316	Rs. ha^{-1}

W.M$_0$: Weedy Check; W.M$_1$: *Pendimethalin* at the rate of 2.5 L ha^{-1} (pre-emergence); W.M$_2$: *S-Metolachlor* at the rate of 2.0 L ha^{-1} (pre-emergence); W.M$_3$: *Glyphosate* 48% W/V SL at the rate of 4.7 L ha^{-1} (post-emergence); W.M$_4$: *Pendimethalin* (2.5 L ha^{-1}) + *Glyphosate* 48% W/V SL (4.7 L ha^{-1}); W.M$_5$: *S-Metolachlor* (2.0 L ha^{-1}) + *Glyphosate* 48% W/V SL (4.7 L ha^{-1}); W.M$_6$: Manual weeding (Two).

Table 3 (a): Economic analysis as affected by application of *Pendimethalin* and *Glyphosate* along with Brassica and Sorghum extracts in upland Cotton under drip and furrow irrigation methods (2010)

Economic parameter	Drip irrigation						Furrow irrigation						Remarks
	No water extract			Water extract (15 L ha^{-1})			No water extract			Water extract (15 Lha^{-1})			
	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	
Seed Cotton yield	1246	2503	2035	1324	2668	2435	1122	1752	1582	1182	2066	1810	Kg ha^{-1}
Adjusted Cotton yield	1121	2253	1832	1192	2401	2192	1010	1577	1424	1064	1859	1629	Kg ha^{-1}
Gross benefit	119317	239687	194872	126786	255488	233176	107443	167772	151492	113188	197840	173326	4255/40 kg
Water extract cost	0	0	0	60	60	60	0	0	0	60	60	60	Rs. 60/15 L W.E preparation
Cost of herbicide	0	1112	3355	0	1112	3355	0	1112	3355	0	1112	3355	Rs. 570/800 ml
Sprayer rent	0	70	70	140	140	140	0	70	70	140	140	140	Rs. 70/ha
Labor charges of spray	0	160	160	320	320	320	0	160	160	320	320	320	Rs. 160/ha
Irrigation charges	3786	3786	3786	3786	3786	3786	17057	17057	17057	17057	17057	17057	Rs. ha^{-1}
Total cost that vary	3786	5128	7371	4306	5418	7661	17057	18399	20642	17577	18689	20932	Rs./ha^{-1}
Non-variable cost	96663	96663	96663	96663	96663	96663	96663	96663	96663	96663	96663	96663	Rs. ha^{-1}
Total expenditure	100449	101791	104034	100969	102081	104324	113720	115062	117305	114240	115352	117595	Rs. ha^{-1}
Net benefit	18868	137896	90838	25817	153407	128852	-6277	52710	34187	-1052	82488	55731	Rs. ha^{-1}

W_0: Weedicide (Zero application); W_1: *Pendimethalin* (2 L ha^{-1}); W_2: *Glyphosate* (4.7 L ha^{-1}).

Table 3 (b): Economic analysis as affected by application of *Pendimethalin* and *Glyphosate* along with Brassica and Sorghum extracts in upland Cotton under drip and furrow irrigation methods (2011)

Economic parameter	Drip irrigation						Furrow irrigation						Remarks
	No water extract			Water extract (15 L ha^{-1})			No water extract			Water extract (15 Lha^{-1})			
	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	W_0	W_1	W_2	
Seed Cotton yield	1567	2867	2519	1611	3110	2738	1352	2500	2119	1452	2805	2397	Kg ha^{-1}
Adjusted Cotton yield	1410	2580	2267	1450	2799	2464	1217	2250	1907	1307	2524	2157	Kg ha^{-1}
Gross benefit	88125	161250	141688	90625	174938	154000	76063	140625	119188	81688	157750	134813	2500/40 kg
Water extract cost	0	0	0	75	75	75	0	0	0	75	75	75	Rs. 75/15 L W.E Preparation
Cost of herbicide	0	2085	3572	0	2085	3572	0	2085	3572	0	2085	3572	Rs. ha^{-1}
Sprayer rent	0	80	80	160	160	160	0	80	80	160	160	160	Rs. 80 ha^{-1}
Labor charges of spray	0	200	200	400	400	400	0	200	200	400	400	400	Rs. 200 ha^{-1}
Irrigation charges	6472	6472	6472	6472	6472	6472	24213	24213	24213	24213	24213	24213	Rs. ha^{-1}
Total cost that vary	6472	8837	10324	7107	9192	10679	24213	26578	28065	24848	26933	28420	Rs. ha^{-1}
Non-variable cost	112253	112253	112253	112253	112253	112253	112253	112253	112253	112253	112253	112253	Rs. ha^{-1}
Total expenditure	118725	121090	122577	119360	121445	122932	136466	138831	140318	137101	139186	140673	Rs. ha^{-1}
Net benefit	-30600	40160	19111	-28735	53493	31068	-60403	1794	-21130	-55413	18564	-5860	Rs. ha^{-1}

W_0: Weedicide (Zero application); W_1: *Pendimethalin* (2 L ha^{-1}); W_2: *Glyphosate* (4.7 L ha^{-1}).

Keeping in view these prevailing problems, three experiments were conducted for economic analysis of different weed management strategies to find out a successful and cost-effective approach. Different yield and quality parameters were studied in these experiments while in this article, we just evaluated the economic benefits of the used possible options of controlling weeds. In the conducted experiments the integrated weed management approach performed better as compared with the sole technique.

In spite of having some negative impacts (Judith et al., 2001) herbicides are efficient source for controlling weeds (Khaliq et al., 2011), while allelopathic potential of sorghum and brassica for controlling weeds have shown best results in sole application as well as in combination with herbicides (Khaliq et al., 2012). That was the possible reason of giving best results for weed management in the first experiment.

Although in present scenario we cannot go for complete elimination of herbicides but we can reduce its dose by integrating with other weed control options. This technique showed maximum benefit in term of lint quality, cost-effectiveness, reduced risk of herbicides in insect pest or weeds and environment (Ali et al., 2013). Herbicides contained heavy metals which are leathal for the soil, water as well as for the plants. So, reducing dose of herbicides indirectly reduce the soil, air and water pollution. In second experiment, irrigation factor was included along with chemical/mechanical weed control methods. Results showed that crop grown under drip irrigation and with mechanical weeding gave maximum benefits. It might be attributed to site specific application of the irrigation water as drip irrigation provides water in the root zone of the plants while its surroundings remain dry which hinders weed seed to emerge. Moreover, it has been previously bound in literature that drip irrigation not only enhanced water use efficiency but it also reduced the inputs for weed management and improved problem soils making it more cost-effective approach (Hanson et al., 2009, Ayars et al., 2015). Moreover, drip irrigation system along with mulching restrict weed growth with crop yield of capsicum, sesame and cotton (Choudary et al., 2012). Regarding the adoption of drip irrigation system, farmers are reluctant as they perceive that installation of this system is expensive while the farmers can be given awareness that this irrigation system involves initial cost in its installation and they can get more benefits in the future cultivation. Results of third experiment also revealed higher benefit under drip irrigation along with herbicide application. Efficiency of herbicides (Khaliq et al., 2011) and installation of drip irrigation system (Pandya et al., 2014) for controlling weeds has given best results in previous studies. These approaches showed that we can reduce weed infestation just with the combination of appropriate irrigation method along with herbicide application for sustainable crop production.

In conclusion, integrated weed management either with chemical + water extracts, chemical + mechanical and chemical + drip irrigation found economically sound. Therefore, being economical and environment friendly, these practices need to be disseminated for sustainable crop production.

Authors' Contributions

All authors contributed equally in this manuscript.

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