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Application of Sorghum, Sunflower and Rice Water Extract Combinations Helps in Reducing Herbicide Dose for Weed Management in Rice

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ABSTRACT

Weeds pose a major threat to good harvests in transplanted rice. Conventionally weeds are controlled by herbicides, but this practice is costly and having generated environmental concerns demands to look for alternative methods that at least reduce herbicide usage without compromising yields. Allelopathic crop water mixtures in combination with reduced doses of three herbicides have been evaluated in 3-year field study carried out at Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan. Mixture of allelopathic crops water extracts of sorghum, sunflower and rice each at 15 L ha^{-1} was tank mixed with reduced rates (½ & $^1/_3$ of recommended rate) of three pre-emergence herbicides viz. butachlor, pretilachlor and ethoxysulfuronethyl for this purpose. Results revealed that combined application of mixture of allelopathic water extracts with ½ of the recommended dose of pre-emergence herbicides butachlor (600 g a.i. ha^{-1}), pretilachlor (313 g a.i. ha^{-1}) and ethoxysulfuronethyl (15 g a.i. ha^{-1}) reduced barnyard grass, flat sedge and crowfoot grass density by 75, 67 and 74% and their dry weight by 66, 71 and 76%, respectively, while $^1/_3$ of the recommended dose of butachlor (400 g a.i. ha^{-1}), pretilachlor (208 g a.i. ha^{-1}) and ethoxysulfuronethyl (10 g a.i. ha^{-1}) in combination with mixture of allelopathic water extracts reduced the density and dry weight of these weeds by 68, 60 and 67% and 63, 67 and 72%, respectively. Application of water extracts mixture with ½ of the label rates of pre-emergence herbicides improved rice grain yield by 61, 59 and 41%, respectively, while mixture of allelopathic extracts alone enhanced rice grain yield by 29% as compared with control. Study concluded that herbicide dosage can be reduced by 20-67%, when used in combination with mixture of allelopathic water extracts of sorghum, sunflower and rice. © 2010 Friends Science Publishers

Key Words: Rice; Reduced herbicides dose; Sorghum; Sunflower; Rice water extracts

INTRODUCTION

Rice is the second most important food crop after wheat in Pakistan. It accounts for 5.9% of the total value added in agriculture and 1.3% to GDP and is one of the main export items of the country (Government of Pakistan, 2009). Weed infestation is a major problem in rice cultures that leads to severe yield reduction ranging from 17% to 87% depending upon weed species and level of infestation (Moorthy & Sanjoy, 1999). Traditionally weeds are controlled by keeping water standing to a depth of about 7-8 cm for about 30 to 40 days after transplanting. But, due to scarcity of water such a practice is not being followed properly. Use of herbicides is quite effective, but concerns related to environment and development of herbicide resistant weed bio-types have demanded to look for means that reduce reliance upon herbicides and are more eco-friendly (Jamil *et al.*, 2009; Jabran *et al*., 2010). Sorghum (Putnam & DeFrank, 1979; Cheema *et al*., 2009), sunflower (Wilson & Rice, 1968; Leather, 1982) and rice (Dilday *et al*., 1994; Olofsdotter *et al*., 1995; Chung *et al*., 1997; Ahn & Chung, 2000; Ebana *et al*., 2001; Fageria & Baligar, 2003; Ma *et al.,* 2006; Farooq *et al*., 2008) are potent allelopathic plants and have been reported to have allelopathic effects on other plants.

Aqueous extract of sorghum inhibited weed growth by 28%, but is not effective for profitable crop production (Cheema *et al*., 2002a). Moreover, combination of two or more allelopathic aqueous extracts acted synergistically and caused more phytotoxic effects on weeds (Duke *et al.*, 2000; Jamil *et al.*, 2009). Previous studies revealed that mixtures of sorghum, sunflower and eucalyptus water extracts caused >70% weed suppression than sorghum water extract alone (Cheema *et al.,* 2002b). It indicates that efficacy of allelopathic aqueous extracts can be enhanced, when used in mixture than any of these used alone. Allelopathic extracts

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have also shown promising results, when used in combination with reduced doses of herbicides (Cheema *et al*., 2005; Iqbal & Cheema, 2007). Such a practice not only improves the efficacy of allelopathic extracts, but also helps reduce herbicide doses as well. In addition to low cost on weed control it may contribute towards environmental safety (Hussain *et al.*, 2007).

Suppressive effects of mixtures of allelopathic aqueous extracts of sunflower brassica and mulberry on broad leaved weeds have been well documented (Weston & Duke, 2003; Hong *et al*., 2004; Iqbal & Cheema, 2007). Suppressive effects of allelopathic sorghum extracts in combination with reduced dose of herbicides are also reported elsewhere (Cheema *et al*., 2002b). Nonetheless weed suppression potential of sorghum, sunflower and rice aqueous extracts in combination with reduced dose of herbicide/s has yet not been explored. This study was therefore carried out to evaluate combined effect of allelopathic aqueous extracts of sorghum, sunflower and rice in combination with reduced dose of three herbicides as against herbicides alone.

MATERIALS AND METHODS

Field trials were carried out at agronomic research area, University of Agriculture, Faisalabad (31.25 N, 73.09 E, 184.8 m altitude) for three years (2005-2007). Experiments were laid out in randomized complete block design (RCBD) with four replications Plot size was 7 m x 2.25 m. Besides recommended dose of three pre-emergence herbicides, butachlor (1200 g a.i. ha^{-1}), pretilachlor (625 g a.i. ha^{-1}) and ethoxysulfuronethyl (30 g a.i. ha^{-1}), mixture of aqueous extracts of three allelopathic crops sorghum, sunflower and rice each @ 15 L ha^{-1} were combined with ½ and $^1/_3$ of recommended dose of each herbicide. Mixture of allelopathic sorghum, sunflower and rice aqueous extracts each @ 15 L ha^{-1} was also used for comparison.

Allelopathic aqueous extracts were prepared by following the procedure of Cheema and Khaliq (2000). Concentrated allelopathic water extracts (WE's 10% w/v) were used in mixture and also combined with butachlor (600 & 400 g a.i. ha^{-1}), pretilachlor (313 & 208 g a.i. ha^{-1}) and ethoxysulfuronethyl (15 & 10 g a.i. ha^{-1}). A weedy check was maintained as control.

A field vacated by wheat crop was well-prepared, puddled and about 30 days old two seedlings per hill of fine rice cv. 'Basmati 385' were transplanted at plant into row distance of 22.5 cm. Fertilizers at 120 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} were applied in the form of urea, diammonium phosphate and sulphate of potash. Half of N along with whole of P and K were applied at transplanting, while remaining N was applied 30 days after transplanting. Crop was irrigated weekly till maturity and all other agronomic and plant protection practices were kept normal.

Two quadrats (of each 0.5 x 0.5 m) per plot were used for recording weed density. Weeds were clipped at ground level at 45 and 60 days after transplanting (DAT) and oven-dried at 70ºC for 48 h and dry weights recorded thereof. Yield and its attributes for rice grain yield wee at physiological maturity through following standard sampling procedures. Data collected were statistically analyzed using Fischer's analysis of variance technique on MSTATC computer package and the difference/s among the treatment means were compared by using the least significant difference (LSD) test at 0.05 probability level (Steel *et al*., 1997). As the year effect were non-significant so only three year average data are presented. Economics of various treatments were evaluated by employing economic and marginal analyses following procedures of Byerlee (1988).

RESULTS AND DISCUSSION

Dominant weed species present at the experimental site were barnyard grass (*Echinochloa crusgalli*), flat sedge (*Cyperus iria*) and crowfoot grass (*Dactyloctenum aegyptium*). Average data of three years field study revealed that all the weed control treatments suppressed weed density and dry weight of all weeds significantly at both 45 and 60 DAT as compared to control (Tables I & II), whereas the year effect was non-significant.

Application of butachlor at 600 g a.i. ha^{-1} (½ of label rate) tank mixed with mixture of allelopathic WE's combined with 50% of the label dose of each herbicide suppressed barnyard grass density in the range of 67 to 75% (Table I). Label rate of these herbicides suppressed barnyard grass density in the range 76-80%. Butachlor at 600 g a.i. ha^{-1} (½ of label rate) tank mixed with mixture of allelopathic WE's suppressed flat sedge density by 72% and 67% (45 & 60 DAT) as compared with control (Table I). At 45 DAT its suppressive effect was statistically at par with that of pretilachlor at 313 and 208 g a.i. ha^{-1} (½ & $^1/_3$ of label rates) and ethoxysulfuronethyl @ 15 g a.i. ha^{-1} (½ of label rate), when all were used in combination with mixture of allelopathic WE's.

Application of pretilachlor at 313 g a.i. ha^{-1} (½ of label rate), ethoxysulfuronethyl at 15 g a.i. ha^{-1} (½ of label rate) and 10 g a.i. ha^{-1} ($^1/_3$ of label rate) applied with mixture of allelopathic WE's suppressed crowfoot grass by 71-75% as compared to control (Table I). At 60 DAT, the suppressive effects (74-75%) of butachlor (600 g a.i. ha^{-1}), pretilachlor (313 g a.i. ha^{-1}) and ethoxysulfuronethyl (15 g a.i. ha^{-1}) applied with mixture of allelopathic WE's on crowfoot grass density were statistically at par with label rate of butachlor (1200 g a.i. ha^{-1}). Butachlor at 600 g a.i. ha^{-1} (½ of label rate) tank mixed with mixture of allelopathic sorghum, sunflower and rice water extracts each at 15 L ha^{-1} suppressed barnyard grass dry weight by 79%, which was statistically at par with that recorded for ethoxysulfuronethyl at 30 g a.i. ha^{-1} (Table II). It was followed by pretilachlor at 313 g a.i. ha^{-1} (½ of label rate) and butachlor at 600 g a.i. ha^{-1} (½ of label rate) applied in combination with mixture of allelopathic WE's. At 60 DAT, butachlor at 600 g a.i. ha^{-1} (½ of label rate) tank mixed with WE's suppressed barnyard grass biomass by 66% as compared with control and was

Table I: Weed density (0.25 m^{-2}) as affected by allelopathic crop water extracts in combination with pre-emergence herbicides in rice

Treatments (applied at 3 DAT)	Rate	Barnyard grass		Flat sedge		Crowfoot grass	
		45 DAT	60 DAT	45 DAT	60 DAT	45 DAT	60 DAT
Control		15.21 a †	20.29 a	12.88 a †	13.58 a	6.67 a †	10.71 a
Butachlor	1200 g a.i. ha^{-1}	3.69 f (-76)	4.06 g (-80)	2.10 f (-84)	2.83 f (-79)	1.67 de (-75)	2.52 de (-76)
Pretilachlor	625 g a.i. ha^{-1}	2.73 g (-82)	3.56 g (-82)	1.94 f (-85)	2.35 f (-83)	1.60 e (-76)	1.90 ef (-82)
Ethoxysulfuronethyl	30 g a.i. ha^{-1}	3.27 fg (-79)	3.85 g (-81)	1.75 f (-86)	2.88 f (-79)	1.08 f (-84)	1.56 f (-85)
Butachlor+sorghum + sunflower +rice water extracts	600 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	4.50 e (-70)	5.08 ef (-75)	3.56 e (-72)	4.50 e (-67)	2.08 cd (-69)	2.83 d (-74)
Butachlor+sorghum + sunflower +rice water extracts	400 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	5.40 cd (-65)	6.40 d (-68)	4.17 d (-68)	5.46 c (-60)	2.50 c (-63)	3.56 c (-67)
Pretilachlor+sorghum+sunflower +rice water extracts	313 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	5.08 cde (-67)	4.83 f (-76)	3.60 de (-72)	4.67 de (-66)	1.94 de (-71)	2.77 d (-74)
Pretilachlor+sorghum+sunflower +rice water extracts	208 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	5.44 c (-64)	5.48 ef (-73)	4.04 de (-69)	5.23 cd (-61)	2.46 c (-63)	4.06 c (-62)
Ethoxysulfuro + sorghum +sunflower + rice water extracts	15 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	4.73 de (-69)	5.77 de (-72)	4.04 de (-69)	4.29 e (-69)	1.65 de (-75)	2.71 d (-75)
Ethoxysulfuro + sorghum +sunflower + rice water extracts	10 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	5.40 cd (-65)	7.17 c (-65)	5.02 c (-61)	5.21 cd (-62)	1.83 de (-73)	3.54 c (-67)
Sorghum + sunflower +rice water extracts	WE each @15 L ha^{-1}	13.25 b (-13)	16.63 b (-18)	11.25 b (-13)	12.17 b (-10)	5.96 b (-11)	8.92 b (-17)
LSD (5%)		0.68	0.73	0.58	0.73	0.45	0.66

†=Means not sharing a letter in common differ significantly at 0.05 P; Values given in parenthesis show percent difference as compared with control; DAT=Days after transplanting; *Means of three years as year effect was non-significant

Table II: Weed dry weight (g 0.25 m^{-2}) as affected by allelopathic crop water extracts in combination with pre-emergence herbicides in rice

Treatments (applied at 3 DAT)	Rate	Barnyard grass		Flat sedge		Crowfoot grass	
		45 DAT	60 DAT	45 DAT	60 DAT	45 DAT	60 DAT
Control		7.32 a*†	13.24 a	6.47 a †	10.94 a	3.31 a †	8.81 a
Butachlor	1200 g a.i. ha^{-1}	0.78 i (-89)	3.25 f (-75)	2.01 e (-69)	2.85 g (-74)	0.97 f (-71)	1.77 fgh (-80)
Pretilachlor	625 g a.i. ha^{-1}	0.90 hi (-88)	3.62 f (-73)	2.04 e (-68)	2.77 g (-75)	1.08 ef (-67)	1.36 h (-85)
Ethoxysulfuronethyl	30 g a.i. ha^{-1}	1.15 gh (-84)	3.62 f (-73)	2.17 e (-66)	2.70 g (-75)	1.40 de (-58)	1.60 gh (-82)
Butachlor+sorghum + sunflower +rice water extracts (WE)	600 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	1.50 fg (-79)	4.47 e (-66)	2.81 d (-57)	3.22 fg (-71)	1.08 ef (-68)	2.10 efg (-76)
Butachlor+ sorghum + sunflower +rice water extracts	400 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	1.58 ef (-78)	4.84 de (-63)	3.32 d (-49)	3.61 ef (-67)	1.25 ef (-62)	2.42 de (-72)
Pretilachlor+sorghum+sunflower +rice water extracts	313 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	1.52 ef (-79)	5.33 cd (-60)	3.16 d (-51)	4.34 cd (-60)	1.18 ef (-64)	1.72 gh (-81)
Pretilachlor+sorghum+sunflower +rice water extracts	208 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	1.87 de (-74)	5.70 c (-57)	4.15 c (-36)	4.55 c (-58)	1.65 cd (-50)	2.26 def (-74)
Ethoxysulfuro + sorghum +sunflower + rice water extracts	15 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	2.03 cd (-72)	5.07 cde (-62)	4.46 bc (-31)	3.92 de (-64)	1.97 bc (-41)	2.76 cd (-69)
Ethoxysulfuro + sorghum +sunflower+rice water extracts	10 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	2.24 c (-69)	5.62 c (-58)	4.79 b (-26)	4.31 cd (-61)	2.29 b (-31)	3.13 c (-64)
Sorghum + sunflower +rice water extracts	WE each @15 L ha^{-1}	5.48 b (-25)	12.05 b (-9)	6.17 a (-5)	9.09 b (-17)	3.09 a (-7)	6.72 b (-24)
LSD (5%)		0.36	0.65	0.59	0.55	3.31	0.54

*Means of three years as year effect was non-significant; †Means not sharing a letter in common differ significantly at 0.05 P; Values given in parenthesis show percent difference as compared with control; DAT=Days after transplanting

statistically at par with $^1/_3$ of label rate of butachlor and ethoxysulfuronethyl 15 g a.i. ha^{-1} (½ label rate), when used with mixture of allelopathic WE's.

At 45 DAT application of butachlor at 600 g a.i. ha^{-1} applied with mixture of allelopathic WE's suppressed flat sedge biomass by 57% as compared with control (Table II) and it was statistically at par with lower dose of butachlor (400 g a.i. ha^{-1}) and pretilachlor (313 g a.i. ha^{-1}) applied in combination with WE's. At 60 DAT butachlor at ½ of its label rate applied with mixture of allelopathic WE's suppressed flat sedge biomass by 71% as compared with weedy check and it was statistically at par with the effects of butachlor and ethoxysulfuronethyl at their respective label rates.

Butachlor at ½ of its label rate tank mixed with sorghum, sunflower and rice water extracts each at 15 L ha^{-1} suppressed crowfoot grass dry weight by 68% (Table II) and it was statistically at par with the suppressive effects of butachlor and pretilachlor at their respective label rates. At 60 DAT application of pretilachlor at ½ of its label rate in combination with mixture of allelopathic WEs suppressed flat sedge biomass by 81% and it was statistically at par with the effects of pretilachlor (625 g a.i. ha^{-1}) and ethoxysulfuronethyl (30 g a.i. ha^{-1}).

Table III: Rice grain yield as affected by allelopathic crop water extracts in combination with pre-emergence herbicides

Treatments	Rate	Rice grain yield (Mg ha^{-1})
Control		2.22 g*†
Butachlor	1200 g a.i. ha^{-1}	3.93 a (77)
Pretilachlor	625 g a.i. ha^{-1}	3.86 b (74)
Ethoxysulfuronethyl	30 g a.i. ha^{-1}	3.87 ab (74)
Butachlor+sorghum+sunflower+rice water extract	600 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	3.57 c (61)
Butachlor+sorghum+sunflower+rice water extract	400 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	3.46 d (56)
Pretilachlor+sorghum+sunflower+rice water extract	313 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	3.53 c (59)
Pretilachlor+sorghum+sunflower+rice water extract	208 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	3.12 e (41)
Ethoxysulfuronethyl+sorghum+sunflower+rice water extract	15 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	3.13 e (41)
Ethoxysulfuronethyl+sorghum+sunflower+rice water extract	10 g a.i. ha^{-1} and WE each @ 15 L ha^{-1}	3.07 e (38)
Sorghum+sunflower+rice water extract	WE each @15 L ha^{-1}	2.87 f (29)
LSD (5%)		0.06

*Means of three years as year effect was non-significant; †Means not sharing a letter in common differ significantly at 0.05 P; Values given in parenthesis show percent difference as compared with control; DAT=Days after transplanting

Table IV: Average economic analysis for 2005-2007

Variables	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	Remarks
Av. paddy yield	2.22	3.93	3.86	3.87	3.57	3.12	3.46	3.13	3.53	3.07	2.87	Mg ha^{-1}
Adjusted grain yield	1.998	3.537	3.474	3.483	3.213	2.808	3.114	2.817	3.177	2.763	2.583	10% less than actual yield
Income from paddy yield	27473	48633	47767	47891	44178	38610	42817	38733	43683	37991	35516	Rs. 13750.00 Mg^{-1}
Av. Straw yield	5.73	8.26	8.07	8.27	7.70	7.93	7.52	6.66	6.73	6.83	6.09	Mg ha^{-1}
Adjusted straw yield	5.157	7.434	7.263	7.443	6.930	7.137	6.768	5.994	6.057	6.147	5.481	10% less than actual yield
Income from straw yield	2578	3717	3631	3721	3465	3568	3384	2997	3028	3073	2740	Rs. 500.00 Mg^{-1}
Gross income	30051	52351	51399	51613	47644	42179	46202	41731	46712	41064	38257	Rs. ha^{-1}
Herbicide cost	0.00	618	692	808	308.88	206	346	231	404	269	0.00	Machete @ Rs. 250/800 ml^{-1} Rifit @ Rs. 280/ 400 ml^{-1} Sunstar @ Rs. 327/ 80 gm
Cost of conc. WE	0.00	0.00	0.00	0.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	Rs. 2 0 L^{-1}
Spray application cost	0.00	100	100	100	100	100	100	100	100	100	100	Rs. 100.00 man^{-1} day^{-1} ha^{-1}
Sprayer rent	0.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	Rs. 50.00 spray^{-1}
Cost that vary	0.00	768	842	958	759	655.92	796	680	854	719	450	Rs. ha^{-1}
Net benefits	30051	51583	50557	50654	46884	41522	45405	41050	45858	40346	37807	Rs. ha^{-1}

T_1	Control (Weedy Check)	T_7	Pretilachlor @ 313 g a.i. ha^{-1} + sorghum + sunflower + rice water extract each at 15 L ha^{-1}
T_2	Butachlor @ 1200 g a.i. ha^{-1} 3-5 Days after transplanting (DAT)	T_8	Pretilachlor @ 208 g a.i. ha^{-1} + sorghum + sunflower + rice water extract each at 15 L ha^{-1}
T_3	Pretilachlor @ 625 g a.i. ha^{-1} 3-5 DAT	T_9	Ethoxysulfuron-ethyl @ 15 g a.i. ha^{-1} + sorghum + sunflower + rice water extract each at 15L ha^{-1}
T_4	Ethoxysulfuron-ethyl @ 30 g a.i. ha^{-1} 3-5 DAT	T_{10}	Ethoxysulfuron-ethyl @ 10 g a.i. ha^{-1} + sorghum + sunflower + rice water extract each at 15 L ha^{-1}
T_5	Butachlor @ 600 g a.i. ha^{-1}+sorghum+sunflower+rice water extract each at 15 L ha^{-1}	T_{11}	Sorghum + sunflower + rice water extract each at 15 L ha^{-1}
T_6	Butachlor @ 400 g a.i. ha^{-1}+sorghum+sunflower+rice water extract each at 15 L ha^{-1}		

The average of three years results revealed that grain yield of rice was improved significantly with all weed control treatments in present studies as compared with control (Table III). Maximum yield increase (74-77%) was obtained with application of label rates of herbicides. However, mixture of allelopathic extracts of sorghum, sunflower and rice, when applied in combination with butachlor 600 g a.i. ha^{-1} and pretilachlor 313 g a.i. ha^{-1} (½ of label rate of each) had statistically similar effect and improved rice grain yield by 61% and 59%, respectively as compared with control. Butachlor at $^1/_3$ of its label rate applied with mixture of allelopathic WE's enhanced grain yield by 56% as compared to control. The increased grain yield was possibly due to better weed control which resulted in better leaf area facilitating photosynthesis and hence more grain formation. Jabran *et al*. (2008) concluded that sorghum and sunflower crop WE's 15 L ha^{-1} each tank mixed with half dose of pendimethalin increased the seed yield of canola as compared with weedy check and full dose of pendimethalin.

Weed inhibition with use of mixtures of allelopathic water extracts may be due to presence of phytotoxins in sorghum [(gallic acid, protocateuic acid, syringic acid, vanillic acid, p-hydroxybenzoic acid. p-coumaric acid, benzoic acid, ferulic acid, m-coumaric acid, caffeic acids, p-hydroxybenzaldehyde & sorgoleone) (Cheema *et al*., 2009; Netzly & Butler, 1986)], sunflower [(chlorogenic acid, isochlorogenic acid, α-naphathol, scopolin & annuionones)

Table V: Average marginal analysis for 2005-2007

Treatments	Total cost that vary (Rs. ha^{-1})	Net benefits (Rs. ha^{-1})	Marginal cost (Rs. ha^{-1})	Marginal net benefits (Rs. ha^{-1})	Marginal rate of return (%)
Control (weedy check)	0.00	30051.00	-	-	-
Sorghum+sunflower+rice water extract each at 15 L ha^{-1}	450.00	37806.75	450.00	7755.75	1723.50
Butachlor @ 400 g a.i. ha^{-1}+sorghum+sunflower+rice water extract each at 15 L ha^{-1}	655.92	41522.58	205.92	3715.83	1804.50
Pretilachlor @ 208 g a.i. ha^{-1}+sorghum+sunflower+rice water extract each at 15 L ha^{-1}	680.63	41050.12	24.71	0.00	D
Ethoxysulfuron-ethyl @ 10 g a.i. ha^{-1}+sorghum+sunflower+rice water extract each at 15 L ha^{-1}	719.33	40345.42	38.70	0.00	D
Butachlor @ 600 g a.i. ha^{-1}+sorghum+sunflower+rice water extract each at 15 L ha^{-1}	758.88	46884.87	39.55	5362.29	13558.26
Butachlor @ 1200 g a.i. ha^{-1}	767.75	51583.00	8.87	4698.13	52966.52
Pretilachlor @ 313 g a.i. ha^{-1}+sorghum+sunflower+rice water extract each at 15 L ha^{-1}	795.94	45405.56	28.19	0.00	D
Pretilachlor @ 625 g a.i. ha^{-1}	841.88	50557.12	45.94	5151.56	11213.67
Ethoxysulfuron-ethyl @ 15 g a.i. ha^{-1} + sorghum + sunflower + rice water extract each at 15L ha^{-1}	854.00	45858.25	12.12	0.00	D
Ethoxysulfuron-ethyl @ 30 g a.i. ha^{-1}	958.00	50654.75	104.00	4796.50	4612.02

Cost that vary is some of all the costs (both cost & opportunity costs) that vary for a particular treatment; Marginal costs is increase in variable cost, which occur in changing from one production alternative to another; Marginal net benefit is increase in net benefit, which can be obtained by changing from one production alternative to another; Marginal are of return refers to ratio of marginal benefit to marginal cost expressed on percentage basis; D is dominated treatment that refers to treatment/s, which have higher costs but lower net benefits

(Macias *et al*., 1998; Macias *et al*., 2002; Anjum & Bajwa, 2005)] and rice [(coumaric acid, ferulic acid, p-hydroxybenzoic acid, p-coumaric acid, vanillic acid, o-hydroxyphenyl acetic acid) (Chou & Lin, 1976; Rimando *et al.,* 2001)]. Chon and Kim (2004) found that barley (*Hordeum vulgare* L.), oats (*Avena fatua* L.), rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) extracts significantly reduced root growth of alfalfa (*Medicago sativa* L.), barnyard grass (*Echinichloa crus-galli,* Beauv. var. *oryzicola Ohwi.*) and eclipta (*Eclipta prostrate* L.). More suppression of *Echinochloa crus-galli, Cyperus iria* and *Dactyloctenum aegyptium* with the combined application of sorghum, sunflower and rice water extracts indicated the synergistic mode of action of allelochemicals present in these extracts. Phytotoxins in such mixtures can replace one another on the basis of their biological exchange rate and may add to the potency of each other (Gerig & Blum, 1991). Jamil *et al*. (2009) reported that mixture of sorghum and sunflower aqueous extracts was more inhibitory to wild oat and canary grass than sorghum aqueous extract alone. Jabran *et al.* (2010) also concluded that mixture of allelopathic plant water extracts has great potential to suppress the weeds in canola. Such mixtures can be used in combination with reduced doses of herbicides to reduce reliance upon synthetic farm chemicals.

Economic and marginal analyses: Economic analysis and marginal rate of return (MRR) as presented in Tables IV and V revealed that application of label rates of pre-emergence herbicides gave maximum net benefits and label rates of butachlor and ethoxysulfuron-ethyl were the most economical treatments. A further perusal into marginal analysis revealed that mixture of allelopathic water extracts of sorghum, sunflower and rice tank mixed with half of the label dose of butachlor (600 g a.i. ha^{-1}) gave better marginal rate of return (MRR) as compared to label rate of pretilachlor. Jabran *et al*. (2008) also reported that WE's of sorghum and sunflower 15 L ha^{-1} each tank mixed with ½ of label rate of herbicide (pendimethalin, 600 g a.i. ha-1) in canola increased the net benefits as compared with control and label dose of pendimethalin (1200 g a.i. ha^{-1}).

CONCLUSION

Mixtures of allelopathic sorghum + sunflower + rice extracts can be combined with reduced dose (50-67%) of herbicides for effective weed control in rice fields without any loss in yield and net benefits in transplanted rice.

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