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Bio-economic assessment of chemical and non-chemical weed management strategies in dry seeded fine rice (*Oryza sativa* L.)

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Dry seeding of rice offers potential to be opted as a resource conservation technology but its sustainability is endangered by heavy weed infestation. Experiments were conducted during summer season of 2009 to look for effective and economically viable weed control method(s) in dry seeded rice. Four mulching materials of natural origin as sorghum, sunflower and wheat residues each soil incorporated at 8 t ha^{-1} and black polyethylene sheet strips as artificial origins were used. A weedy check and manual weeding were included for comparison. Label doses of post emergence herbicides, bis-pyribac sodium and penoxsulam, at 30 and 15 g a.i. ha^{-1} were also used. Manual weeding accounted for maximum (99%) inhibition in weed density and dry weight. Bispyribac sodium suppressed weed count and dry weight by ≈ 80%. Among non-chemical weed management strategies, sorghum residues scored over 50% reduction in weed density and dry weight. Plastic sheet strips were least effective against weeds. Manual weeding scored highest paddy yield of 4.17 t ha^{-1}. Bispyribac sodium with 3.51 t ha^{-1} paddy yield appeared superior to penoxsulam. Sorghum, sunflower and wheat residues resulted in statistically similar paddy yields of 2.85, 2.80 and 2.58 t ha^{-1}, respectively. Bispyribac sodium exhibited maximum marginal rate of return of 23076%. Chemical control proved to be a viable strategy with higher economic returns.

Key words: Weeds, crop residues, bispyribac sodium, penoxsulam, weed suppression, grain yield.

INTRODUCTION

Weeds are the most threatening biological constraint to direct seeded rice cultures (Phuong et al., 2005; Rao et al., 2007). Rice yields might be reduced up to 60% or even a complete crop failure may occur due to heavy weed infestation (Ghosh and Sharma, 1997; Chae and Ghu, 1999). Cultural and/or chemical methods are generally employed to control weeds. Manual weeding, though effective is getting increasingly difficult due to labor scarcity, rising wages and its dependence on weather conditions. Moreover, allowing weeds to reach sufficient size to be pulled out and the presence of perennial weeds that fragment on pulling are other related concerns (Rao et al., 2007). Thus, herbicide usage seems indispensable for weed management in

direct seeded rice (Azmi et al., 2005). Several pre-emergence herbicides applied either alone or supplemented with hand weeding have been reported to provide fairly adequate weed suppression in direct seeded rice (Moorthy and Manna, 1993; Pellerin and Webster, 2004; Baloch et al., 2005). However, limited application time frame (0 to 5 days after sowing; DAS) and requirement of critical water regime are associated challenges. In this scenario, post-emergence herbicides appear to be superior.

Development of resistance in some previously susceptible weed species, as well as serious environmental concerns owing to high residual effects of herbicides in soil are major drawbacks associated with herbicide usage (Ahn et al., 2005). In fact, much focused work has been done during last two decades on plant derived materials, as an environment friendly alternative approach for weed control in field crops (Kuk et al.,

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2001). Utilization of allelopathic properties of native plant/crop species offers promising opportunities for this purpose (Ahn et al., 2005; Matloob et al., 2010) and can be helpful in controlling weeds infestation (Weston and Duke, 2003).

Crop residues pose allelopathic as well as a physical effect on the growth and development of subsequent crops and weeds (Purvis et al., 1985; Mason-Sedun et al., 1986). A variety of allelochemicals, particularly the phenolics are released from decomposing crop residues in soil (Nelson, 1996) that can manipulate plant species (Waller, 1987; Thorne et al., 1990) resultantly contributing to overall decline in the density and vigor of the weed community (Liebman and Gallandt, 1997; Gallandt et al., 1999). Weston (1996) proposed that exploitation of crop residues as surface mulch can suppress weeds and can be helpful in reducing reliance on herbicides.

Phytotoxicity of dried sunflower residues and leaf powder has been reported (Narwal, 1999; Batish et al., 2002). Incorporation (*in situ*) of whole sorghum plant or its various parts alone or mixed with each other was found to suppress weed growth in wheat (Cheema and Khaliq, 2000). Cheema et al. (2004) reported that sorghum mulch (10 to 15 t ha^{-1}) decreased the dry weight of purple nuts edge by 38 to 41%, compared to control. Wheat has also been successfully used as a cover crop in various cropping systems (Putnam et al., 1983). Wheat straw mulch significantly inhibited emergence, seedling growth and dry matter accumulation of various weed species (Muminovic, 1991).

Modern agriculture is productivity oriented and emphasizes on economic viability and sustainability of the system. Such an approach demands a weed management strategy that is selective, efficient and cost-effective with little or no adverse ecological effects. The economic evaluation of any technique is also essential for its adoption at farmer's level. Direct seeding rice cultures face severe weed infestation and there is dire need to look for various approaches for their control. The present study was designed to evaluate the bio economic efficiency of different weed control methods in dry seeded rice.

MATERIALS AND METHODS

Seed source

Seed of rice cv. Super basmati was obtained from Rice Research Institute, Kala Shah Kaku. For all the treatments, selected healthy seeds were used.

Site description

The proposed study was conducted at Agronomic Research Farm, University of Agriculture Faisalabad, (31.25°N latitude, 73.09°E longitude, 184 m above sea level) during summer season of 2009. Soil of experimental site belongs to Lyallpur soil series (Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid in USDA

classification and Haplic Yermosols in FAO classification). The pH of saturated soil paste was 7.6 and total soluble salts were 0.79 dS m^{-1}. Organic matter, total nitrogen, available phosphorus and potassium were 0.71%, 0.062%, 13.1, and 179 ppm, respectively. Due to high evapo-transpiration, Faisalabad features an arid climate with mean annual rainfall of about 200 mm. The research farm is irrigated by Rakh branch originating from Lower Chenab that comes out of Chenab River at Head Khanki.

Experimentation

The experiment was laid out in randomized complete block design (RCBD) with four replications. The net plot size was 6 x 2.70 m. The seeds were osmo-hardened with 2.2% CaCl$_2$ prior to sowing (Farooq et al., 2006). Crop was planted in the first fortnight of July 2009 with single row hand drill, using a seed rate of 75 kg ha^{-1} in 22.5 cm spaced rows. A basal fertilizer dose of 125 kg N, 75 kg P$_2$O$_5$ and 60 kg K$_2$O ha^{-1} was applied. Fertilizers used were urea (46% N), diammonium phosphate (18% N: 46% P$_2$O$_5$) and sulphate of potash (50% K$_2$O). The whole of phosphorus and potassium and half of nitrogen were applied during seed bed preparation at sowing. The remaining half nitrogen was applied in two splits at tillering and panicle initiation, respectively.

Preparation of plant residues

Field grown mature plants of sorghum, sunflower and wheat, free of disease and insect attack, were collected from the Agronomic Research Area, University of Agriculture, Faisalabad. These plants were chopped into about 3 to 5 cm pieces with an electric fodder cutter. Whole plant residues were mixed into the soil *in situ*.

Treatment application

Four mulching materials of natural (sorghum, sunflower, and wheat residues each soil incorporated at 8 t ha^{-1}) and artificial (black polyethylene sheet strips) origins were used to control weeds. A weedy check and manual weeding (twice by hoeing/hand pulling at 15 and 25 DAS) were also included. Label doses of two post emergence herbicides, bis-pyribac sodium and penoxsulam at 30 and 15 g a.i. ha^{-1}, respectively were also used. Herbicides were applied at 15 DAS using a Knapsack hand sprayer fitted with T-Jet nozzle at a pressure of 207 k Pa and volume of spray (300 L ha^{-1}) was determined after calibration.

Harvesting and data collection

Data on weeds (density, dry weight) were recorded at 30 DAS from two randomly selected quadrats (50 x 50 cm) from each experimental unit. Weeds were clipped from ground surface and their biomass was recorded. These were dried in an oven at 70°C for 48 h and dry weights determined. Data on weed count and dry weights were used to compute different indices as follows:

1. Weed persistence index (WPI):

$$WPI = \frac{Dry\,matter\,of\,weeds\,in\,treated\,plots}{Dry\,matter\,of\,weeds\,in\,control} \cdot \frac{Weed\,count\,in\,control}{Weed\,count\,in\,treated\,plots}$$

2. Treatment efficiency index (TEI):

$$TEI = \frac{YT - YC}{YC} \cdot 100 \left/ \frac{DMT}{DMC} \cdot 100 \right.$$

Where YT and YC stands for the yields of treatment and control, respectively; while DMT and DMC are weed dry matter in treatment and control, respectively.

Productive tillers (m^{-2}) of rice were counted from two randomly selected sites from each plot and were averaged. Number of grains per panicle was recorded from 15 randomly selected plants taken from each plot and averaged thereof. A random sample of grains was taken from the produce of each plot to record 1000-kernel weight after manual counting. Crop was harvested, tied into bundles in respective plots and was manually threshed to determine grain yield and is reported on t ha^{-1} basis.

Statistical and economic analyses

The data collected were subjected to Fisher's analysis of variance using "MSTATC" statistical package and least significance difference (LSD) at 0.05 probability was employed to compare the differences among treatments' means (Steel et al., 1997). Economic and marginal analyses based on variable costs and prevailing market prices of herbicides and rice were carried out to look into comparative benefits of different treatments. Gross income and net benefit (the value of increased yield produced as a result of weed management practices, less the cost of such practices) was computed as described by CIMMYT (1988). Marginal rate of return (MRR) was calculated as follows:

$$MRR\ (\%) = \frac{Change\ in\ net\ benefit}{Change\ in\ variable\ cost} \cdot 100$$

RESULTS AND DISCUSSION

Weed growth

Predominant weeds at the experimental site were *Trianthema portulacastrum*, *Echinochloa colona*, *Dactyloctenium aegyptium*, *Elusine indica*, *Echinochloa cruss-galli*, *Spergula arvensis*, *Leptochloa chinensis*, *Cyperus rotundus* and *Cyperus iria*. All the treatments significantly suppressed total weed density (0. 25 m^{-2}) as compared with control (Figure 1a). Maximum reduction (99%) in weed density over control was obtained with manual weeding. Bispyribac sodium was quite effective and reduced total weed density by more than 80%. Soil incorporation of chopped sorghum residues at 8 t ha^{-1} suppressed weed density by 54% and were similar to that recorded for penoxsulam scoring 61% reduction. Chopped sunflower and wheat residues suppressed weed count by 51 and 45%, respectively and were statistically similar. Plastic mulch strips between rice rows was the least affective treatment that recorded only 33% reduction in total weed density.

Significantly lower weed dry biomass was observed in all treatments (Figure 1b). Maximum (99%) reduction in weed dry weight was recorded in manual weeding. Bispyribac sodium and penoxsulam reduced weed dry weight by 78 and 60%, respectively over control. Among non-chemical means, incorporation of chopped sorghum and sunflower residues suppressed weed dry weight by 51% and 48%, respectively, and were statistically similar.

Minimum (17%) suppression in weed dry weight was posed by placing plastic sheet strips within rice rows.

Suppressive effects on weed number and biomass accumulation by crop residues were attributed to the presence of phytotoxins in these residues that were released in their immediate vicinity by leaching and through decomposition. Allelopathic compounds in crop residues that were incorporated into the soil probably were solubilized rapidly and hampered germination and subsequent seedling weed growth and contributing to overall decline in the density and vigor of the weed community (Liebman and Gallandt, 1997; Gallandt et al., 1999). Sorghum contains several phytotoxins such as gallic acid, protocatechuic acid, syringic acid, vanillic acid, p-hydroxybenzoic acid, p-coumaric acid, benzoic acid, ferulic acid, m-coumaric acid, caffeic acids, p-hydroxybenzaldehyde and sorgoleone (Netzly and Butler, 1986; Cheema et al., 2009). Sunflower also contains allelochemicals viz. chlorogenic acid, isochlorogenic acid, α-naphthol, scopolin and annuionones (Macias et al., 2002; Anjum and Bajwa, 2005). The allelopathic activity of wheat has been attributed to hydroxamic acids and its related compounds and phenolic acids (Blum et al., 1991; Copaja et al., 1999; Wu et al., 2001; Huang et al., 2003). Residue species varied in their severity against weeds eliciting sorghum as the more toxic one. The variable influence of sorghum, sunflower and wheat residues on weed growth may be due to the type and concentration of allelochemicals present in these species. However, use of crop residues provided fairly good control of broad-leaved weeds but poor control of grasses and sedges. Nonetheless, limited activity and selectivity remains a big deal with natural weed control (Duke et al., 2001; Bhowmik and Inderjit, 2003) beside higher costs involved in their use.

Manual weeding was effective in reducing weed count and biomass. This practice helped eradicate weeds which were further suppressed by shading effect of rice (Baloch et al., 2005). Bispyribac sodium provided excellent weed control and reduced weed density and dry weight to the tune of >80 and 78%, respectively. It is a member of pyrimidinyloxy benzoic chemical family and inhibits acetolactate synthase enzyme in susceptible plants thus retarding the synthesis of branch chain amino acids (Darren and Stephen, 2006). The effectiveness of Bispyribac sodium as a post emergence herbicide is reported elsewhere by Mahajan et al. (2009). Penoxsulam proved inferior in suppressing weeds particularly grasses as repeated and higher flushes of *D. aegyptium* and *E. indica* were observed during crop growth.

Weed persistence and treatment efficiency indices

Weed persistence index exhibits the resistance of weeds to tested treatments. A lower weed persistence index value meant a higher level of weed control efficacy of
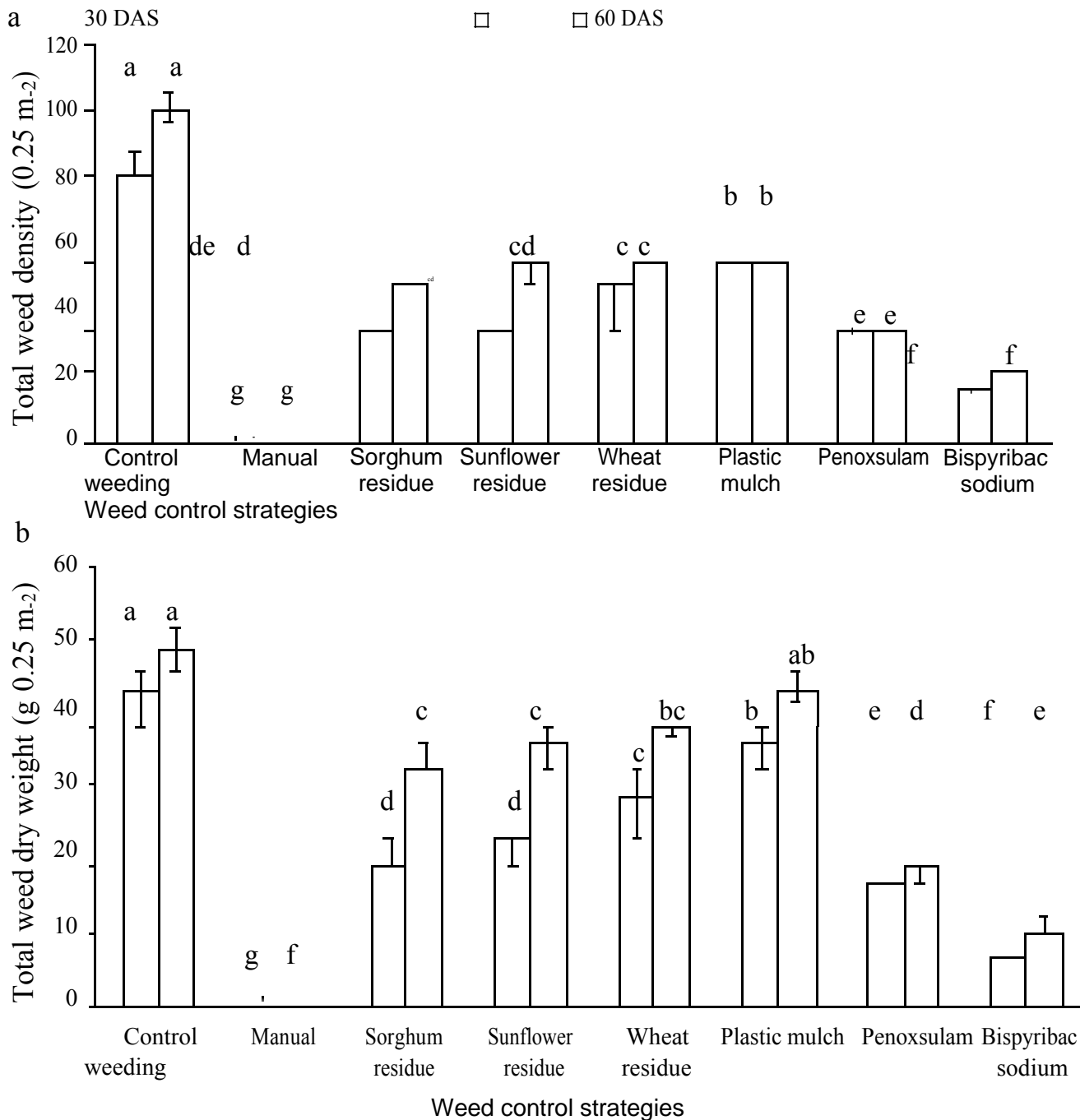
Figure 1. Influence of different wed control strategies on weed density and dry weight in dry seeded fine rice. Vertical bars above mean denote standard error of four replicates. Means with different letters differ significantly at 5% level of probability by LSD test.

given treatment. Lowest weed persistence index value (0.28) was noticed for manual weeding while maximum (1.69) was recorded for plastic sheet strips within rice rows. Plastic sheets strips treatment was overwhelmed by the presence of *Cyperus* spp. as inter-row and grasses as intra-row weeds (Figure 2a). Bispyribac sodium scored a persistence index of 0.88. Such a higher value was attributed to persistence shown by

D. aegyptium and *E. indica*. As the persistence index accounted for both weed density and dry weights, the suppression in its value depicts that bispyribac sodium not only minimized weed density but also averted weed dry matter except the two weed species mentioned. Treatment efficiency index was calculated to further measure the effectiveness of any particular weed control treatment to eradicate weeds. Manual weeding showed
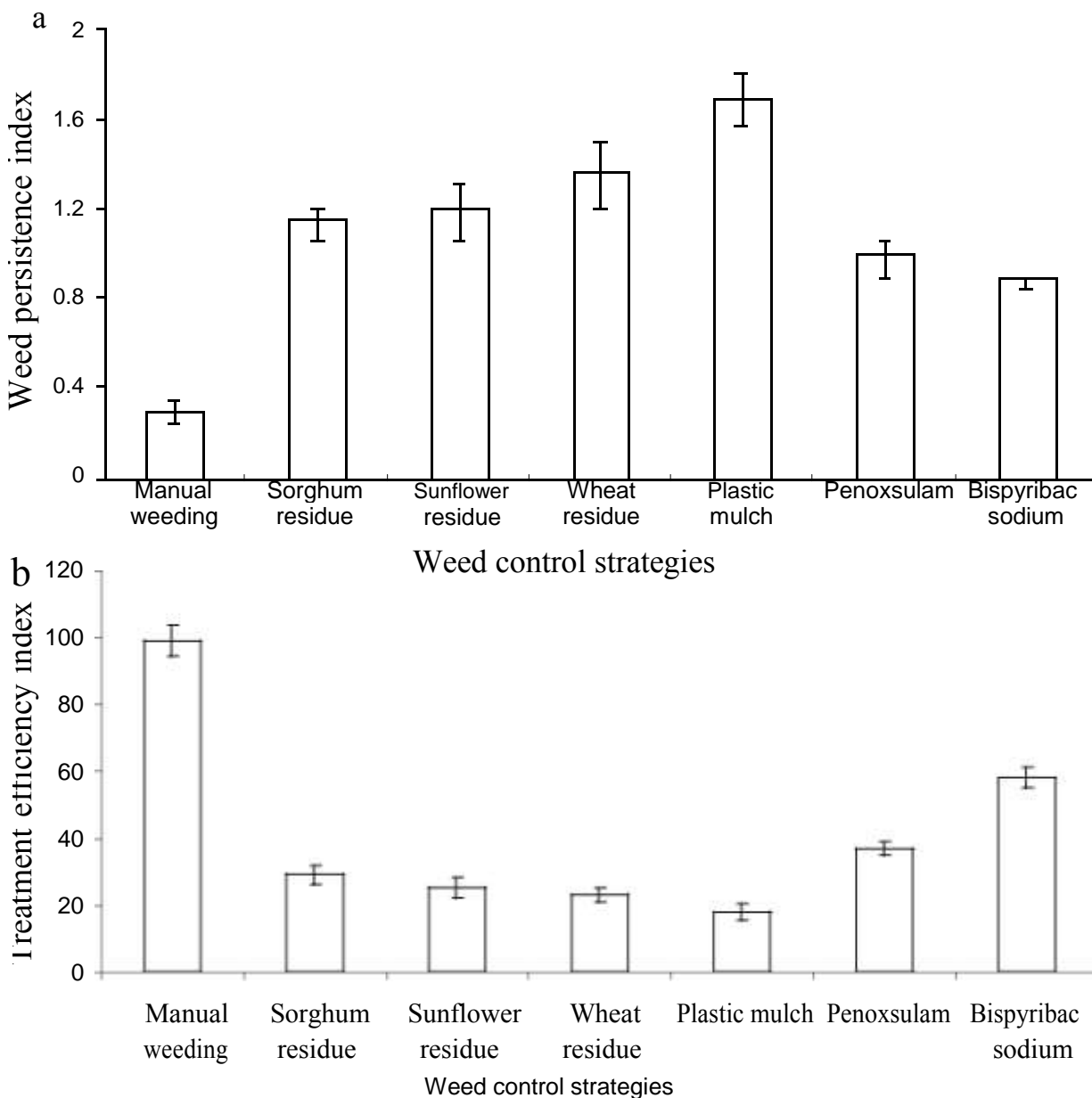
Figure 2. Influence of different weed control strategies on (a) weed persistence index and (b) treatment efficiency index in dry seeded fine rice. Vertical bars above mean denote standard error of four replicates.

99% efficiency as it completely knocked out the weeds (Figure 2b). Bispyribac sodium was the second effective treatment regarding its efficacy (>50%).

Rice yield and yield components

Data on rice grain yield and its components revealed a positive influence of all weed control treatments on these over control (Table 1). Highest number of productive tillers (341 m^{-2}) was recorded where weeds were controlled by manual weeding. Bispyribac sodium was

the second best treatment with 279 productive tillers per unit area (m^{-2}). Incorporation of sorghum and sunflower residues recorded statistically similar number of productive tillers. Manual weeding also accounted for maximum panicle length (18.57 cm), grains per panicle (117), 1000-grain weight (18.52 g), number of grains per panicle (116.66) and was at par with post emergence application of bispyribac sodium and penoxsulam regarding these traits.

Manual weeding scored highest rice yield (4.17 t ha^{-1}) as against the lowest (0.73 t ha^{-1}) recorded for control. Among the herbicides, bispyribac sodium (3.51 t ha^{-1})

Table 1. Influence of different weed control strategies on yield and yield components in dry seeded fine rice.

	Productive tillers (m^{-2})	Branches per panicle	Panicle length (cm)	Grains per panicle	1000-grain weight (g)	Grain yield ($t\ ha^{-1}$)
T_1	68.63^f	8.12^d	15.70^e	80.35^e	15.74^c	0.73^g
T_2	340.90^a (397)	13.90^a (71)	18.57^a (18)	116.66^a (45)	18.5^a (18)	4.17^a (471)
T_3	219.40^d (263)	11.78^{bc} (45)	17.85^{abc} (14)	105.03^{abc} (31)	17.61^{ab} (12)	2.85^{cd} (290)
T_4	216.80^d (216)	11.47^{bc} (41)	17.60^{bc} (12)	99.79^{bcd} (24)	17.25^{abc} (10)	2.80^{cd} (283)
T_5	189.75^e (176)	11.64^{bc} (43)	17.80^{bc} (13)	95.87^{cd} (19)	16.13^{bc} (2)	2.58^{de} (253)
T_6	184.88^e (169)	10.86^c (34)	17.45^c (11)	91.19^{de} (13)	15.86^c (0.76)	1.83^f (147)
T_7	199.50^{de} (191)	12.16^b (50)	17.92^{abc} (14)	110.66^{ab} (38)	17.64^{ab} (120)	3.03^c (315)
T_8	279.25^b (307)	12.34^b (52)	18.30^{ab} (17)	110.51^{ab} (38)	17.75^a (13)	3.51^b (381)
LSD	18.680	1.131	0.760	13.024	1.599	0.365

*Means with different letters differ significantly at 5% level of probability, **Figures given in parenthesis show percent decrease over control. T_1 = Control; T_2 = Manual weeding (twice) at 15 and 25 DAS; T_3 = Sorghum residue (8 t ha^{-1}) incorporated within rice rows (7 DAS); T_4 = Sunflower residue (8 t ha^{-1}) incorporated within rice rows (7 DAS); T_5 = Wheat residue (8 t ha^{-1}) incorporated within rice rows (7 DAS); T_6 = Plastic mulch strips within rice rows (7 DAS); T_7 = Penoxsulam at 15 g a.i. ha^{-1} (15 DAS); T_8 = Bis-pyribac sodium at 30 g a.i. ha^{-1} (15 DAS).

Table 2. Economic analysis of different weed control strategies in dry seeded fine rice.

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	Remarks
Paddy yield	740	4180	3500	2810	2580	2430	3030	3510	kg/ha
10% loss (paddy)	74	418	350	281	258	243	303	351	To bring at farmer level
Adjusted paddy yield	666	3762	3150	2529	2322	2187	2727	3159	10% discount
Income from paddy yield	22477.5	126967.5	106312.5	85353.75	78367.5	73811.25	92036.25	106616.25	PKR 1350/40 kg
Straw yield	3670	10000	8590	8070	7550	6960	8520	8610	Kg/ha
10% loss (straw)	367	1000	859	807	755	696	852	861	To bring at farmer level
Adjusted straw yield	3303	9000	7731	7263	6795	6264	7668	7749	10% discount
Income from straw yield	825.75	2250	1932.75	1815.75	1698.75	1566	1917	1937.25	PKR 10/40 kg
Gross income	23303.25	129217.5	108245.25	87169.5	80066.25	75377.25	93953.25	108553.5	PKR ha^{-1}
Hand weeding (twice)	0	2000	0	0	0	0	0	0	PKR 200 per man (5 man day^{-1} ha^{-1})
Cost of sorghum residues	0	0	10000	0	0	0	0	0	PKR 50/40 kg
Cost of sunflower residues	0	0	0	3000	0	0	0	0	PKR 15/40 kg
Cost of wheat residues	0	0	0	0	40000	0	0	0	PKR 200/40 kg
Cost of plastic mulch	0	0	0	0	0	61538	0	0	PKR 61538 ha^{-1}
Cost of bispyribac sodium	0	0	0	0	0	0	0	1125	PKR 1125 ha^{-1}
Cost of penoxsulam	0	0	0	0	0	0	1062.5	0	PKR 1062.5 ha^{-1}
Residue preparation cost	0	0	1000	1000	1000	0	0	0	PKR 200 per man (5 man day^{-1} ha^{-1})

Table 2. Contd.

Electricity charges	0	0	2000	2000	2000	0	0	0	PKR 8/40 kg
Residue application cost	0	0	400	400	400	0	0	0	PKR 200 per man (2 man day^{-1} ha^{-1})
Mulch application cost	0	0	0	0	0	400	0	0	PKR 200 per man day^{-1} ha^{-1}
Spray application cost	0	0	0	0	0	0	200	200	PKR 200 per man (1 man day^{-1} ha^{-1})
Spray rent	0	0	0	0	0	0	150	150	PKR 150 per spray
Cost that varied	0	2000	13400	6400	43400	61938	1412.5	1475	PKR ha^{-1}
Net benefit	23303.25	127217.5	94845.25	80769.5	36666.25	13439.25	92540.75	107078.5	PKR ha^{-1}

T_1 = Control; T_2 = Manual weeding (twice) at 15 & 25 DAS; T_3 = Sorghum residue (8 t ha^{-1}) incorporated within rice rows (7 DAS); T_4 = Sunflower residue (8 t ha^{-1}) incorporated within rice rows (7 DAS); T_5 = Wheat residue (8 t ha^{-1}) incorporated within rice rows (7 DAS); T_6 = Plastic mulch strips within rice rows (7 DAS); T_7 = Penoxsulam at 15 g a.i. ha^{-1} (15 DAS); T_8 = Bis-pyribac sodium at 30 g a.i. ha^{-1} (15 DAS).

Table 3. Dominance and Marginal analysis of different weed control strategies in dry seeded fine rice.

Treatments	Total cost that vary	Net benefit	Marginal costs	Marginal net benefits	Marginal rate of return (%)
			(PKR ha^{-1})		
T_1	0	23303	-	-	-
T_7	1412	92540	1412	69237	4903
T_8	1475	107078	63	14538	23076
T_2	2000	127217	525	20139	3836
T_4	6400	80769	4400	-	D
T_3	13400	94845	11400	-	D
T_5	43400	36666	41400	-	D
T_6	61938	13439	59938	-	D

T_1 = Control; T_2 = Manual weeding (twice) at 15 & 25 DAS; T_3 = Sorghum residue (8 t ha^{-1}) incorporated within rice rows (7 DAS); T_4 = Sunflower residue (8 t ha^{-1}) incorporated within rice rows (7 DAS); T_5 = Wheat residue (8 t ha^{-1}) incorporated within rice rows (7 DAS); T_6 = Plastic mulch strips within rice rows (7 DAS); T_7 = Penoxsulam at 15 g a.i. ha^{-1} (15 DAS); T_8 = Bis-pyribac sodium at 30 g a.i. ha^{-1} (15 DAS)

appeared superior in enhancing rice yield over penoxsulam (3.03 t ha^{-1}). Incorporation of chopped sorghum, sunflower and wheat residue at 8 t ha^{-1} resulted in rice yields of 2.85, 2.80 and 2.58 t ha^{-1}, respectively.

The increase in paddy grain yield with efficient weed control treatments may be attributed to better crop growth in the absence of weed-crop competition for any of the growth factor. Sultana

(2000) observed that weed infestation of 100 to 200 weeds m^{-2} reduced paddy yield by 51 to 64% compared with weed-free conditions. Rice plots without such competition recorded higher number of productive tillers over control because of the greater space capture by rice plants. The canopy closure occurred earlier due to better competitive ability and nutrient efficiency (Baloch et al., 2005). Mahajan et al. (2009) concluded that herbicides

are the most effective means of securing rice yields against weeds and bispyribac sodium registered no statistically significant difference in rice yield when compared with weed free treatment. The findings in the foregoing also coincide with those reported by Cheema and Khaliq (2000) who stated that soil incorporation of sorghum stalks in soil increased wheat yield up to 17% over control. Bhatt and Tewari (2006)

concluded that maximum grain yield of rice (5.5 t ha^{-1}) was recorded in weed free plots. Subhas and Jitendra (2001) reported a higher grain yield and better weed control with hand weeding.

Economic and marginal analyses

All weed control methods came up with higher net benefits over control (Table 2). Economic analysis revealed that maximum net benefits of 127217 PKR (Pakistani Rupees) ha^{-1}, (1 US$= 85 PKR) was obtained with manual weeding. Bispyribac sodium ranked second with net benefits of 107078 PKR ha^{-1}. Marginal and dominance analyses give a deeper insight into the relative outcome of per unit additional investment made on a specific weed control method. Bispyribac sodium was identified as the best treatment with MRR of 23076%. Penoxsulam and manual weeding exhibited MRR of 4903 and 3836%, respectively (Table 3). Thus, it is inferred that although manual weeding realized higher net benefits, MRR did not increase as compared with herbicides due to higher cost involved. The cost-effectiveness of bispyribac sodium as a post emergence herbicide for weed management in aerobic rice is in line with Mahajan et al. (2009).

Use of herbicide was an efficient and cost-effective method for weed control in dry seeded rice. Manual weeding can be adopted where cheap labor is available. Nonetheless, the use of crop residues was an environmentally benign approach, but the level of weed suppression as well as higher costs involved could not confirm its viability. Further investigations into residue combination and screening of new herbicide molecules need to be carried out in this direction.

REFERENCES

Ahn JK, Hahn SJ, Kim JT, Khanah TD, Chung IM (2005). Evaluation of allelopathic potential among rice (*Oryza sativa* L.) germination for control of *Echinochloa crus-galli* P. Beauv in the field. Crop Prot., 24: 413-419.

Anjum T, Bajwa R (2005). A bioactive annuionone from sunflower leaves. Phytochemistry, 66: 1919-1921.

Azmi M, Chin DV, Vongsaroj P, Johnson DE (2005). Emerging issues in weed management of direct seeded rice in Malaysia, Vietnam, and Thailand. In: Toriyama K, Heong KL, Hardy B, (Eds.) "Rice is Life: Scientific Perspectives for the 21st Century", International Rice Research Institute, Los Ban˜os, Philippines, and Japan International Research Center for Agricultural Sciences, Tsukuba, Japan,pp. 196-198.

Baloch MS, Hassan G, Morimoto T (2005). Weeding techniques in transplanted and wet-seeded rice in Pakistan. Weed Biol. Manag., 5: 190-196.

Batish DR, Tung P, Singh HP, Kohli RK (2002). Phytotoxicity of sunflower residues against some summer season crops. J. Agron. Crop Sci., 188: 19-24.

Bhatt MD, Tewari A (2006). Losses in growth and yield attributes due to weed composition in transplanted paddy in Terai Region. Scientific World, 4: 99-101.

Bhowmik PC, Inderjit (2003). Challenges and opportunities in implementing allelopathy for natural weed management. Crop Prot.,

22: 661-671.

Blum V, Wentworth TR, Klein K, Worsham AD, King LD, Gerig TM, Lyu SW (1991). Phenolic acid content of soils from wheat no-till, wheat-conventional till and follow conventional till soybeans cropping systems. J. Chem. Ecol., 17: 1045-1068.

Chae JC, Ghu JO (1999). Occurrence and control of weeds in direct seeded rice paddy in Korea. J. Weed Sci. Tech., 44: 391-404.

Cheema ZA, Khaliq A, Saeed S (2004). Weed control in maize (*Zea mays* L.) through sorghum allelopathy. J. Sustain. Agric. 23: 73-86.

Cheema ZA, Mushtaq MN, Farooq M, Hussain A, Din IU (2009). Purple nutsedge management with allelopathic sorghum. Allelopathy J., 23: 305-312.

Cheema ZA, Khaliq A (2000). Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi arid region of Punjab. Agric. Ecosys. Environ., 79: 105-112.

CIMMYT (1988). From agronomic data to farmer recommendations: An economics training manual. Mexico. D. F.

Copaja SV, Nicol D, Wratten SD (1999). Accumulation of hydroxamic acids during wheat germination. Phytochemistry, 50: 17-24.

Darren WL, Stephen EH (2006). Foliar and root absorption and translocation of bispyribac-sodium in cool-season turfgrass. Weed Technol., 20: 1015-1022.

Duke SO, Scheffler BE, Dayan FE (2001). Allelochemicals as herbicides. In: Bonjoch NP, Reigosa MJ (Ed.). 1st European OECD Allelopathy Symposium: Physiological Aspects of Allelopathy. GAMESAL, SA, pp. 47-59.

Farooq M, Basra SMA, Afzal I, Khaliq A (2006). Optimization of hydropriming techniques for rice seed invigoration. Seed Sci. Technol., 34: 507-512.

Gallandt E, Liebman M, Huggins DR (1999). Improving soil quality: implications for weed management. J. Crop Prod., 2: 95-121.

Ghosh A, Sharma AR (1997). Effect of seed rates, seed density and nitrogen on performance of flood prone low land rice. IRRN, 22: 37-38.

Huang Z, Haig T, Wu H, An M, Prately J (2003). Correlation between phytotoxicity on annual ryegrass (*Lolium rigidum*) and production dynamics of allelochemicals within root exudates of an allelopathic wheat. J. Chem. Ecol., 29: 2263-2279.

Kuk YI, Burgos NR, Talbert RE (2001). Evaluation of rice by-products for weed control. Weed Sci., 49: 141-149.

Liebman M, Gallandt ER (1997). Many little hammers: ecological approaches for management of crop-weed interactions. In: Jackson LE (ed.). Ecology in Agriculture. San Diego, CA: Academic Press, Inc. pp. 291-343.

Macias FA, Ascension T, Galindo JLG, Rosa M, Varela AJ, Molinillo JMG (2002). Bioactive terpinoids from sunflower leaves cv. Peredovick. Phytochemistry, 61: 687-692.

Mahajan G, Chauhan BS, Johnson DE (2009). Weed management in aerobic rice in Northwestern Indo-Gangetic Plains. J. Crop Improv., 23: 366-382.

Mason-Sedun W, Jessop RS, Lovett JV (1986). Differential phytotoxicity among species and cultivars of the genus Brassica to wheat. Plant Soil, 93: 3-16.

Matloob A, Khaliq A, Farooq M, Cheema ZA (2010). Quantification of allelopathic potential of different crop residues for the purple nutsedge suppression. Pak. J. Weed Sci. Res., 16: 1-12.

Moorthy BTS, Manna GB (1993). Studies on weed control in direct seeded upland rainfed rice. Indian J. Agric. Res., 27: 175-180.

Muminovic S (1991). Allelopathic effect of straw of crops on growth of weeds. Savremena-Poljoprivreda, 39: 27-30.

Narwal SS (1999). Allelopathy update: Basic and Applied Aspects. Science Publishers Inc., Enfield, New Hampshire, USA, pp. 335-348.

Nelson CJ (1996) Allelopathy in cropping systems. Agron. J., 88: 991-996.

Netzly DH, Butler LG (1986). Roots of sorghum exude hydrophobic droplets containing biologically active components. Crop Sci., 26: 775-780.

Pellerin KJ, Webster EP (2004). Imazethapyr at different rates and timings in drill and water seeded imidazolinone-tolerant rice. Weed Technol., 18: 223-227.

Phuong LT, Denich M, Vlek PLG, Balasubramanian V (2005). Suppressing weeds in direct-seeded lowland rice: Effects of methods and rates of seeding. J. Agron. Crop Sci., 191: 185-194.

Purvis CE, Jessop RS, Lovett JV (1985). Selective regulation of germination and growth of annual weeds by crop residues. Weed Res., 25: 415-421.

Putnam AR, Defrank J, Barnes JB (1983). Exploitation of allelopathy for weed control in annual and perennial cropping systems. J. Chem. Ecol., 9: 101-111.

Rao AN, Jhonson DE, Sivaprasad V, Ladha JK, Mortimer AM (2007). Weed management in direct seeded rice. Adv. Agron., 93: 153-255.

Steel RGD, Torrie JH, Dickey D (1997). Principles and Procedures of Statistics: A Biometrical Approach. 3rd Ed. McGraw Hill Book Co. Inc. New York, pp. 172-177.

Subhas C, Jitendra P (2001). Effect of rice (*Oryza sativa*) culture, nitrogen and weed control on nitrogen competition between scented rice and weeds. Ind. J. Agron., 46: 68-74.

Sultana R (2000). Competitive ability of wet-seeded boro rice against *Echinochloa crusgalli* and *Echinochloa colonum*. M.Sc. thesis. Angladesh Agricultural University, Mymensingh, Bangladesh.

Thorne RLZ, Waller GR, McPherson JK, Krenzer Jr. EG, Young CC (1990). Autotoxic effects of old and new wheat straw in conventional-tillage wheat soil. Botanical Bulletin Academia Sinica, 31: 35-39.

Waller GR (1987). Allelochemicals, Role in Agriculture and Forestry. ACS Symposium Series No. 330. Washington, D.C: American Chemical Society.

Weston LA (1996). Utilization of allelopathy for weed management in agro-ecosystems. Agron. J., 88: 860-866.

Weston LA, Duke SO (2003). Weed and crop allelopathy. Crit. Rev. Plant Sci., 22: 367-389.

Wu H, Prately J, Lemerle D, Haig T, An M (2001). Screening methods for the evaluation of crop allelopathic potential. Bot. Rev., 67: 403-415.