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RESEARCH

BIO-ECONOMIC AND QUALITATIVE IMPACT OF REDUCED HERBICIDE USE IN DIRECT SEEDED FINE RICE THROUGH MULTIPURPOSE TREE WATER EXTRACTS

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Weed control program should be environmentally benign and cost-effective so that reduced herbicide use can help meet these goals. Field trials were conducted to assess the bio-economic and qualitative impact of reduced doses (25 and 50% of label dose) of a postemergence pyrimidinyloxybenzoic acid herbicide (bispyribac-sodium) applied alone or in combination with multipurpose tree (eucalyptus [*Eucalyptus camaldulensis* Dehnh.], mango [*Mangifera indica* L.], and mulberry [*Morus alba* L.]) water extracts in direct seeded rice (*Oryza sativa* L.) fields. The label dose of bispyribac-sodium and penoxsulam along with weed control were included for comparison. Tank mixing of multipurpose tree water extracts with reduced herbicide doses accounted for > 55% suppression in weed density and > 75% in dry weight; they were quite higher than those recorded for the same herbicide doses used alone. A combination of these extracts with 50% reduced dose of bispyribac-sodium improved rice yield and quality attributes similar to the label dose of this herbicide. Despite the higher net benefits associated with label herbicide dose, the maximum marginal rate of return was achieved with a tank mix of 25% label herbicide dose with multipurpose tree water extracts.

Key words: Reduced dose, weed suppression, yield, kernel quality, *Oryza sativa*.

Direct seeding of rice (*Oryza sativa* L.) has the potential to attain high water productivity and eliminate the edaphic conflict in Punjab's rice-wheat (*Triticum aestivum* L.) cropping system (Khaliq *et al*., 2011a). Heavy weed infestation and shifts in weed population are major constraints in the sustainability of direct seeded rice (DSR). An appropriate weed management strategy has always been a major focus and key element for successful DSR. Such a strategy is of the utmost significance to secure yields and the involved production costs, as well as to minimize any negative effect on product quality. Good stand and high yield of dry direct seeded rice has a higher correlation with timely and effective weed control. Traditionally, weeds are controlled through cultural and/or chemical methods. 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 a 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, using herbicides is obligatory for weed management in direct seeded rice (Jaya Suria *et al*., 2011). Several studies (Gitsopoulos and Froud-Williams, 2004; Adigun *et al*., 2005; Singh *et al*., 2006; 2008; Mahajan *et al*., 2009) have concluded that chemical weed control is feasible since it is quick, easy, and economical.

Although efficient, the judicious use of herbicides has also been questioned since it is widely believed that they cause resistance in some previously susceptible weed species; serious environmental concerns also arise due to their high residual effects in the soil (Ahn *et al*., 2005; Khaliq *et al*., 2011b). An international survey conducted in 70 000 fields revealed that over 383 biotypes of 208 weed species (122 dicots and 86 monocots) have evolved to be resistant to herbicides (Heap, 2012). Resistance of rice weeds to a number of herbicides has been reported (Rao *et al*., 2007) since they only target a few molecular sites (Duke, 1990). In fact, 270 herbicides covering the global market represent only 17 modes of action with almost half of them acting as acetolactate synthase (ALS), PS II, and Protox inhibitors (Macías *et al*., 2007).

A lot of work has recently focused on plant-derived materials as an alternative to herbicides (Kuk *et al*., 2001). Allelopathy has emerged as a potential tool and as an alternative to herbicides for weed management (Tesio and Ferrero, 2010). Multipurpose tree species with allelopathic potential can be exploited for sustainable weed management (Singh *et al*., 2003). Suppressive allelopathic effects of eucalyptus (Verdeguer *et al*., 2009), mango (Javaid *et al*., 2010), and mulberry (Haq *et al*., 2010) against weeds have recently been documented. Different plant species contain allelochemicals that vary in type and concentration (Xuan *et al*., 2004). Furthermore,

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allelopathic activity is attributed to the combination and interaction of numerous allelochemicals instead of a single compound (Einhellig, 1996). The allelopathic potential of plant species can be exploited in many ways. Using water extracts of these species seems to be one possible tool. Although the use of allelopathic water extracts is economical and environmentally friendly, reduction in weed biomass is less than with herbicides and manual weeding. However, it may be possible to use these allelopathic water extracts in combination or with a reduced dose of herbicides to increase their efficacy and reduce the use of herbicides (Mushtaq *et al*., 2010). Allelopathic substances in combination with lower doses of herbicides can be an important step in recent times.

In our preliminary studies, water extracts of these trees were found to inhibit rice weed growth (Khaliq *et al*., 2012). However, the suppressive effects of tank mixing these extracts have not yet been documented against weeds of direct seeded rice fields. Moreover, there is little information regarding the influence of tank mixing these water extracts in combination with a lower herbicide dose on weeds of direct seeded rice. The following study was therefore designed to evaluate the influence of allelopathic plant water extracts alone and in combination with a reduced dose of herbicide on direct seeded rice and its associated weeds.

MATERIALS AND METHODS

Site description

The proposed study was conducted at the Agronomic Research Farm, University of Agriculture Faisalabad (31.25° N, 73.09° E, 184 m a.s.l.). The soil of the experimental site belongs to the Lyallpur soil series (Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid in USDA classification and Haplic Yermosols in FAO classification). Saturated soil paste pH was 7.7 and total soluble salts were 0.79 dS m^{-1}. Organic matter, total N, available P and K were 0.74%, 0.055%, 7.1 mg kg^{-1}, and 183 mg kg^{-1}, respectively. Due to high evapotranspiration, Faisalabad features an arid climate with a mean annual rainfall of approximately 200 mm.

Experimentation

The experiment was laid out in a randomized complete block design (RCBD) with four replicates during the summers of 2009 and 2010. The net plot size was 6 m × 2.70 m. Seed of the popular rice cv. Super basmati was obtained from the Rice Research Institute, Kala Shah Kaku. In both years, the crop was sown in the first week of July with a single row hand drill at a seed rate of 75 kg ha^{-1} and maintaining a distance of 22.5 cm between crop rows. A basal fertilizer dose of 125 kg N, 55 kg P_2O_5, and 40 kg K_2O ha^{-1} was applied. Fertilizers were urea (46% N), diammonium phosphate (18% N, 46% P_2O_5), and sulfate of potash (50% K_2O). All P and K and half of N were applied at sowing. The remaining half of N was top dressed in two splits at tillering and panicle initiation. The first irrigation was applied 10 d after sowing (DAS), and the crop was subsequently irrigated as and when needed; 14 irrigations were applied until crop maturity, when it was manually harvested.

Extract preparation

Eucalyptus, mulberry, and mango leaves were collected from plants available in the surrounding area. These were stored and dried in the shade to avoid possible leaching by rain water. Leaves were chopped separately with an electric fodder cutter into 2-3 cm pieces and soaked in water for 24 h at room temperature (25 ± 5 °C) with a 1:10 ratio (w/v). The soaked material was filtered through 10 and 60-mesh sieves. The respective leachates were boiled at 100 °C to increase the concentration by 20 times for easy handling and application; they were stored for subsequent use. Previous studies revealed that boiling did not affect the nature, relative composition, and efficacy of leachates (Jamil *et al*., 2009). To exclude the notion of inhibitory effects owing to pH and osmotic potential of the plant water extracts, these two attributes were measured for each water extract. The pH and electrical conductivity (EC) of these extracts was determined with digital pH and conductivity meters (HI 9811-5, Hannah Instruments, Woonsocket, Rhode Island, USA). The osmotic potential (-MPa) of different extract concentrations was determined by multiplying EC (dS m^{-1}) by -0.036. In this experiment, pH and osmotic potential of the different extracts ranged between 6.2 and 6.8 and -0.05 and -0.09 MPa, respectively. The literature shows that these pH values and osmotic potential were unlikely to prevent plant growth and any growth inhibition was presumably thought to be due to inhibitory compounds present in such extracts (Chon *et al*., 2003).

Treatment application

Concentrated water extracts of each tree species at 18 L ha^{-1} were applied alone and in combination with bispyribac-sodium [2,6-bis(4,6-dimethoxypyrimidin-2-yloxy) benzoic acid] at 15 and 7.5 g ai ha^{-1} (50 and 25% of label dose, respectively). The label dose of bispyribac-sodium (30 g ai ha^{-1}) and penoxsulam (3-(2,2-difluoroethoxy)-N-(5,8-dimethoxy[1,2,4]triazolo[1,5-c]pyrimidin-2-yl)-α,α,α-trifluorotoluene-2-sulfonamide) at 15 g ai ha^{-1} was used for comparison. Weed control was also maintained. Herbicides and their combinations with allelopathic plant water extracts were applied at 15 DAS the rice. Spraying was done with a Knapsack sprayer fitted with a flat fan nozzle and spray volume (300 L ha^{-1}) was determined by water calibration.

Data collection

Data of weed attributes (density and dry weight) were recorded for each experimental unit from two randomly selected quadrants (50 × 50 cm) at 15 and 30 d after treatment (DAT). Weeds were counted and clipped from the ground surface, dried in an oven at 70 ºC for 48 h, and dry weight was recorded. Data of rice yield attributes were recorded from 15 randomly selected plants from each plot and the mean was calculated. Productive tillers (m^{-2}) were counted from two randomly selected sites from each plot and averaged. The crop was harvested, tied into bundles in their respective plots, and biological yield of the sun-dried samples was recorded. Each experimental plot was manually threshed and grain yield recorded (t ha^{-1}). A random sample of rice kernels was taken from the production of each plot. One thousand kernels were counted manually and weighed with an electric balance.

Kernel length and width were determined with a digital Vernier caliper. Abortive, chalky, opaque, and normal kernels were separated by positioning the panicle in front of a common electric bulb fitted with a flexible stand as a light source; this is expressed as the total percentage. Kernel N was determined by micro-Kjeldhal digestion followed by ammonia distillation; it was transformed into kernel protein by a multiplication factor of 5.95 (AOAC, 1990). Kernel amylose contents were determined as per Juliano (1971). The intensity of blue color was read out in a UV visible spectrophotometer meter (UV-4000, ORI, Germany) at 620 nm. The water absorption ratio (WAR) of kernels was calculated as suggested by Juliano *et al*. (1965):

$$WAR = \frac{\text{Weight of cooked rice}}{\text{Weight of raw rice}}$$

Statistical and economic analyses

The data collected were subjected to Fisher's ANOVA technique with the "MSTATC" statistical package (Freed and Scott, 1986); the least significance difference test at $P \leq 0.05$ probability was applied to compare the differences among treatment means. Year effect was found to be non-significant so the 2-yr mean will be presented and discussed in its respective section.

Economic and marginal analyses based on variable costs and prevailing herbicide and rice market prices were carried out. Gross income and net benefit (the value of yield benefit as a result of any practice less the cost of such a practice) were calculated as described by CIMMYT (1988). The marginal rate of return (MRR) was calculated as follows:

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

RESULTS AND DISCUSSION

Weed growth

Field observations revealed that weed flora of the experimental site was comprised of horse purslane (*Trianthema portulacastrum* L.), jungle rice (*Echinochloa colona* [L.] Link), crowfoot grass (*Dactyloctenium aegyptium* L. Willd.), and barnyard grass (*Echinochloa crus-galli* [L.] P. Beauv.) The local climate and experimental site soil moisture regimes promoted weed diversity as well as their growth primarily because the fields were not immersed under water. The weeds that are otherwise non-native to rice fields and those normally controlled by flooding in transplanted rice were abundant in the experimental plots. Rao *et al*. (2007) attributed greater weed pressure in dry seeded rice to the absence of flooding, dry tillage, and alternate wetting and drying during crop establishment.

Total weed density (both narrow and broad-leaved) was significantly influenced ($P \leq 0.05$) by different treatments (Table 1); the difference was more pronounced for either one whether an herbicide dose was used alone or in combination with allelopathic plant water extracts. Tank mixing bispyribac-sodium at 15 and 7.5 g ai ha^{-1} with allelopathic plant water extracts suppressed horse purslane density by 89 and 83% and 63 and 62% at 15 and 30 DAT, respectively (Table 1). The corresponding inhibition in barnyard grass and jungle rice density ranged from 43-49% and 51-62% and 57-63% and 52-60%, respectively, at these times. However, these treatments provided a small reduction in crow foot grass density. Bispyribac-sodium at 15 and 7.5 g ai ha^{-1} tank mixed with allelopathic plant water extracts also recorded similar ($P \leq 0.05$) total weed density. When applied alone at reduced rates, this herbicide recorded a lesser reduction in weed density in most cases. The label dose of bispyribac-sodium suppressed horse purslane (85-92%), barnyard grass (49-88%), and jungle rice (68-74%) density.

Table 1. Influence of multipurpose tree water extracts applied alone and in combination with reduced herbicide doses on weed density in direct seeded fine rice (mean of 2009 and 2010).

Treatments		Weed density (0.25 m^{-2})									
		Horse purslane		Barnyard grass		Jungle rice		Crowfoot grass		Total weeds	
Extract/herbicide	Dose ha^{-1}	15 DAT	30 DAT	15 DAT	30 DAT	15 DAT	30 DAT	15 DAT	30 DAT	15 DAT	30 DAT
Control (weed control)	-	66.63a	47.50a	26.63a	21.25a	54.50a	46.88a	26.88a	13.50a	174.60a	129.10a
Eucalyptus+mulberry+mango leaf extracts	Each at 18 L	64.38a	38.13b	6.12e	16.25b	29.00b	31.75b	16.63d	11.63b	116.10b	97.75b
Eucalyptus+mulberry+mango leaf extracts+bispyribac-sodium	Each at 18 L + 15 g ai	7.12de	17.38e	13.63c	12.13d	23.63d	17.50d	21.38b	9.12cd	65.75d	56.13e
Eucalyptus+mulberry+mango leaf extracts+bispyribac-sodium	Each at 18 L + 7.5 g ai	11.13c	18.00e	10.13d	10.38e	25.88c	18.63d	19.38c	8.00d	66.50d	55.00e
Bispyribac-sodium	15 g ai	8.25d	20.88d	14.00c	14.25c	22.38d	23.38c	15.88de	9.88c	60.50e	68.38d
Bispyribac-sodium	7.5 g ai	16.88b	24.75c	16.00b	17.63b	29.63b	22.63c	12.63g	12.13ab	75.13c	77.13c
Bispyribac-sodium	30 g ai	5.12e	7.12f	3.25f	10.88de	14.00e	15.13e	14.50ef	8.00d	36.88g	41.13f
Penoxsulam	15 g ai	2.50f	4.38g	5.50e	6.75f	21.63d	11.00f	13.88fg	4.25e	43.50f	26.38g

DAT: Days after treatment; ai: active ingredient. Means with different letters differ significantly at 5% probability level according to LSD test.

However, this herbicide poorly controlled (41-46%) crow foot grass. This confirms our previous findings (Khaliq *et al*., 2011a) where bispyribac-sodium failed to achieve a desirable level of crow foot grass suppression. Maximum suppression in individual and total weed density at 30 DAT was recorded for penoxsulam when used at its label dose.

Weed dry weight was reduced to a significant level ($P \leq 0.05$) by different weed control treatments (Table 2). Allelopathic plant water extracts alone recorded a weed dry weight reduction of 48 and 33% at 15 and 30 DAT, respectively. Tank mixing these water extracts with a reduced dose of bispyribac-sodium suppressed weed density by > 75% but was lower when the same doses were applied alone. Moreover, reduced herbicide doses applied either alone or as a tank mix with allelopathic plant water extracts were more effective against broad-leaf weed horse purslane (61-80%) than barnyard grass (9-38%), jungle rice (26-42%), and crow foot grass (39-62%) than the control. The label dose of bispyribac-sodium exhibited a dry weight reduction of > 80% at 15 and 30 DAT. Penoxsulam was higher with 91 and 87% reduction in weed dry weight, respectively, which can be attributed to the suppression of both narrow and broad-leaved weeds.

Data (Tables 1 and 2) revealed a pronounced negative influence of the eucalyptus+mango+mulberry water extracts mix against density and dry weight of different weed species. Such an inhibition can be attributed to the suppressive effect of phytotoxins present in these extracts. Nevertheless, using allelopathic plant water extracts as 'nature's own herbicide' is eye-catching as an eco-friendly weed management approach; this is contrary to bioassays carried out under controlled environments where the suppression achieved under field conditions is far below the level that can be referred to as acceptable for economical crop production. Limited activity and selectivity are still major drawbacks when working with natural herbicides (Duke *et al*., 2001). Bhowmik and Inderjit (2003) proposed that interaction between allelochemicals and herbicides can be exploited for weed management because of their complementary action. This can lead to reducing the use of herbicides as farm chemicals and simultaneously help enhance the efficacy of allelopathic agents (Khaliq *et al*., 2012c). The present experiments demonstrated a 75% reduction in weed dry weight with the tank mix of different allelopathic plant water extracts and 50% of the herbicide label dose. Suppression of weed germination and growth is believed to arise from the simultaneous and additive action of numerous allelochemicals (Einhellig, 1996). Duke and Lydon (1993) proposed that a synergistic interaction occurs between various allelochemicals since they can replace each other on the basis of their biological exchange rate and relative potency; thus, this adds to each one's herbicidal potential when mixed (Gerig and Blum, 1991). Khanh *et al*. (2005) further reported that the magnitude of suppression in the allelopathic interaction is directly proportional to the dose of the allelopathic product.

Both bispyribac-sodium and penoxsulam suppressed weeds at their label dose. Bispyribac-sodium acts as an acetolactate synthase (ALS) inhibitor that retards synthesis of branch chain amino acids, such as leucine, isoleucine, and valine (Darren and Stephen, 2006). Penoxsulam retards root growth by reducing photosynthate movement from leaves to root by interfering with an ALS enzyme (Devine, 1989). Effectiveness of these herbicides against rice weeds has been reported elsewhere (Mahajan *et al*., 2009). Our results also demonstrated that the magnitude of weed suppression is proportional to the herbicide dose whether it was applied alone or in combination with allelopathic plant water extracts, which was altered by the type of weed flora present. Broad-leaved weeds were susceptible to even the lowest herbicide dose so their density and dry weight were reduced to a greater extent than grasses when compared with the control. However, for grassy weeds, ≥ 75% of the label dose was required to keep weed count within an acceptable limit. Other authors (Iqbal and Cheema, 2007; Mushtaq *et al*., 2010) reported similar findings while working with tank mixes of a reduced herbicide dose with allelopathic plant water extracts in some other field crops under similar environments. The reduction in density and dry weight was presumably due to the decline in density of horse purslane, a dominant broad-leaved

Table 2. Influence of multipurpose tree water extracts applied alone and in combination with reduced herbicide doses on weed dry weight in direct seeded fine rice (mean of 2009 and 2010).

Treatments		Weed dry weight (g 0.25 m^{-2})									
		Horse purslane		Barnyard grass		Jungle rice		Crowfoot grass		Total weeds	
Extract/herbicide	Rate ha^{-1}	15 DAT	30 DAT	15 DAT	30 DAT	15 DAT	30 DAT	15 DAT	30 DAT	15 DAT	30 DAT
Control (weed control)	-	126.90a	54.51a	6.22a	7.86a	12.64a	11.66a	25.99a	7.28a	171.70a	81.30a
Eucalyptus+mulberry+mango leaf extracts	Each at 18 L	68.90b	35.67b	2.12de	5.82b	9.27bc	7.78b	9.10d	5.44b	89.40b	54.70b
Eucalyptus+mulberry+mango leaf extracts+bispyribac-sodium	Each at 18 L + 15 g ai	16.29f	7.40d	3.71bc	4.24cd	7.99cd	5.40d	14.57c	2.76ef	42.57f	19.81d
Eucalyptus+mulberry+mango leaf extracts+bispyribac-sodium	Each at 18 L + 7.5 g ai	27.40e	7.48d	2.50cd	3.82de	5.48e	5.50cd	20.06b	3.26de	55.44e	20.06d
Bispyribac-sodium	15 g ai	42.56d	11.23c	5.66a	4.88bc	9.39b	6.75bc	9.90d	4.47bc	67.52d	27.34c
Bispyribac-sodium	7.5 g ai	49.12c	10.70c	4.96ab	4.99bc	7.63d	7.06b	10.39d	3.88cd	72.12c	26.63c
Bispyribac-sodium	30 g ai	4.81g	3.64e	1.10de	3.18ef	3.38f	4.47de	8.41d	2.88e	17.71g	14.18e
Penoxsulam	15 g ai	5.56g	2.96e	1.02e	2.61f	2.97f	3.60e	5.32e	1.80f	14.87g	10.97e

DAT: Days after treatment; ai: active ingredient. Means with different letters differ significantly at 5% probability level according to LSD test.

weed of the experimental site. Control plots were initially taken over by this weed, and after it completed its life cycle in approximately one month it showed senescence and a decline in density. Such a decline can also be in part because of interspecific competition among weeds at later stages.

Rice yield and yield components

Weed management treatments significantly promoted rice grain yield components as compared to the control (Table 3). The highest number of productive tillers (345 m^{-2}) was recorded when penoxsulam was applied, while the lowest (122 m^{-2}) was found in the control plots. Tank mixing multipurpose tree water extracts with 50% reduced dose of bispyribac-sodium recorded a similar ($P \leq 0.05$) number of kernels per panicle, 1000-kernel weight, and grain yield to the results recorded when applying the label dose of this herbicide. Tank mixing allelopathic plant water extracts with a reduced (25 and 50%) dose of bispyribac-sodium achieved a significantly higher grain yield as compared to the sole application of these herbicide doses. However, the highest rice grain yield (2.80 t ha^{-1}) was achieved with penoxsulam.

Improvement in grain yield and related traits as compared to the control in the present study could be attributed to reduced weed-crop competition (Khaliq *et al*., 2011a), thereby attaining a higher number of productive tillers. A DSR crop does not have a head start over weeds and is a poor weed competitor, particularly during the initial establishment stage (Rao *et al*., 2007). Weeds usually emerge simultaneously or just after the emergence of rice and outcompete young rice seedlings due to their aggressive growth characteristics. The yield of DSR is particularly at risk due to weeds that establish early in the field. Delaying weeding beyond 20 DAS substantially reduces yield (Adigun *et al*., 2005; Khaliq and Matloob, 2011). Moody (1990) reported that weeds accomplish 20-30% of their growth as compared with 2-3% for the rice crop. Most of the weed flora encountered in the present study was comprised of highly competitive C_4 weed species (Caton *et al*., 2004). Uncontrolled weed growth accounted for 77% loss of rice grain yield in the present study. This level of yield reduction under season-long weed infestation corroborates previous work done by Khaliq and Matloob (2011).

Kernel quality attributes

Kernel quality was significantly improved under different weed control treatments (Tables 4). Kernel dimension is a principal determinant of kernel quality and thin long kernels are preferred. Tank mixing allelopathic plant water extracts with a reduced herbicide dose produced quality kernels as good as those harvested when using the label herbicide dose. Uncontrolled weed spread (control plots) recorded the lowest percentage (46.25%) of normal kernels. Nonetheless, a reverse trend was observed where weeds were controlled. Tank mixing allelopathic plant water extracts with a reduced herbicide dose recorded a similar percentage of normal kernels to that achieved with the label herbicide dose. Unmanaged weeds also reduced kernel-protein content (Table 4). It is worth mentioning that the increase in yield was accompanied with improved kernel protein content. Significantly lower amylose contents and higher water absorption ratios were recorded for all weed control treatments as compared to the control (Table 4).

Improved kernel length in the present study indicates a greater source capacity to produce photo-assimilates that were translocated and partitioned into sink. The increase in kernel quality attributes can be an outcome of better nutrient and water uptake under weed control treatments with improved fertilization and a lower number of abortive kernels (Khaliq *et al*., 2011a). Irshad *et al*. (2008) reported that reduced weed crop competition facilitates continuous translocation of carbohydrates to panicles. The improved kernel protein contents can be a result of the greater fraction of available N to rice plants in the absence of weeds.

Table 3. Influence of multipurpose tree water extracts applied alone and in combination with reduced herbicide doses on yield and yield components of direct seeded fine rice (mean of 2009 and 2010).

	Productive tillers	Kernels per panicle	1000 kernel weight	Grain yield
	m^{-2}		g	t ha^{-1}
T_1	122.00g	77.50d	19.18d	0.63f
T_2	161.25f	78.00cd	20.21cd	0.99e
T_3	261.25c	85.00abc	21.37ab	1.67bc
T_4	251.25d	80.75bcd	20.99abc	1.50cd
T_5	253.00d	78.25cd	20.95abc	1.27de
T_6	223.25e	78.25cd	20.45bc	0.99e
T_7	269.75b	86.25ab	21.44b	1.97b
T_8	345.00a	90.00a	21.94a	2.80a
LSD	7.75	7.37	1.11	0.34

Means with different letters differ significantly at 5% probability level according to LSD test. T_1: Control (weed control); T_2: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1}; T_3: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1} + bispyribac-sodium at 15 g ai ha^{-1}; T_4: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1} + bispyribac-sodium at 7.5 g ha^{-1}; T_5: Bispyribac-sodium at 15 g ai ha^{-1}; T_6: Bispyribac-sodium at 7.5 g ai ha^{-1}; T_7: Bispyribac-sodium at 30 g ai ha^{-1}; T_8: Penoxsulam at 15 g ai ha^{-1}.

Table 4. Influence of multipurpose tree water extracts applied alone and in combination with reduced herbicide rates on kernel quality attributes of direct seeded fine rice (mean of 2009 and 2010).

	Kernel length	Kernel width	Normal kernel	Kernel protein content	Kernel amylose content	Water absorption ratio
	mm		%			
T_1	6.86d	1.49c	46.25d	6.63e	22.81a	3.56c
T_2	8.15c	1.51bc	55.00c	7.35cd	22.23ab	3.89b
T_3	8.35bc	1.50bc	57.50bc	7.98b	20.28cd	4.04b
T_4	8.34bc	1.51bc	58.75bc	7.44c	20.12d	3.89b
T_5	8.35bc	1.49c	57.50bc	6.93de	21.78abc	4.06b
T_6	8.16c	1.51bc	55.00c	7.49c	20.72bcd	3.86b
T_7	8.80ab	1.55ab	61.25b	8.62a	20.12d	4.31a
T_8	9.17a	1.58a	66.25a	7.62bc	19.32d	3.93b
LSD	0.60	0.06	4.35	0.48	1.62	0.23

Means with different letters differ significantly at 5% probability level according to LSD test. T_1: Control (weed control); T_2: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1}; T_3: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1} + bispyribac-sodium at 15 g ai ha^{-1}; T_4: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1} + bispyribac-sodium at 7.5 g ha^{-1}; T_5: Bispyribac-sodium at 15 g ai ha^{-1}; T_6: Bispyribac-sodium at 7.5 g ai ha^{-1}; T_7: Bispyribac-sodium at 30 g ai ha^{-1}; T_8: Penoxsulam at 15 g ai ha^{-1}.

Economic and marginal returns

The economic evaluation of any weed management practice is of paramount significance for its acceptance at the farmer level. Weed control efficiency cannot be considered as the only criterion to determine the suitability of a particular treatment; cost effectiveness of a treatment is also very important (Jaya Suria *et al*., 2011; Khaliq *et al*., 2011a). Our data showed that the highest net benefit (Rs. 89650 ha^{-1}) achieved as compared to the control (Table 5) was obtained by applying penoxsulam followed by bispyribac-sodium (Rs. 63108 ha^{-1}) at their label doses. Marginal analyses give an additional insight by focusing on the relative outcome of per unit additional investment on any particular weed control treatment. Tank mixing allelopathic plant water extracts with 25% of the label dose of bispyribac-sodium was identified as the treatment achieving a 15 711% marginal rate of return (Table 6). It was closely followed by the penoxsulam (15 453%). Applying bispyribac-sodium at its label dose dominated due to lower net benefits and the higher variable costs involved. All other treatments reflected lower MRR.

CONCLUSIONS

The present work revealed a fairly acceptable level of weed suppression in a direct seeded fine rice field without a weed density increase in the following year; product quantity and quality was achieved when the reduced herbicide dose (50%) was tank mixed with multipurpose tree water extracts. It can be used as a cost-effective, economical, and environmentally friendly approach to minimize weed pressure and production costs.

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Table 6. Marginal and dominance analysis of different weed control treatments.

Treat-ments	Total variable costs	Net benefits	Change in variable costs	Change in net benefits	Marginal rate of return
	Rs. ha^{-1}				%
T_1	0	21 721	-	-	-
T_2	674.0	33 015	46.2	69	149
T_3	1229.7	53 829	277.9	5 082	1 829
T_4	951.8	48 747	46.1	7 243	15 711
T_5	905.7	41 504	231.7	8 489	3 664
T_6	627.8	32 946	627.8	11 225	1 788
T_7	1461.5	63 108	0	-	D
T_8	1461.5	89 650	231.8	35 821	15 453

T_1: Control (weed control); T_2: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1}; T_3: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1} + bispyribac-sodium at 15 g ai ha^{-1}; T_4: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1} + bispyribac-sodium at 7.5 g ha^{-1}; T_5: Bispyribac-sodium at 15 g ai ha^{-1}; T_6: Bispyribac-sodium at 7.5 g ai ha^{-1};T_7: Bispyribac-sodium at 30 g ai ha^{-1}; T_8: Penoxsulam at 15 g ai ha^{-1}, D: Dominated due to less benefits than preceding treatments (higher costs and lower net benefits); 1US$=91.10 Rs.

Impacto bioeconómico y cualitativo del uso reducido de herbicidas en arroz de siembra directa a través de extractos acuosos de árboles multipropósito. Los programas de control de malezas deben ser respetuosos del medio ambiente y rentables, y la reducción del uso de herbicidas puede ayudar a cumplir estas metas. Los ensayos de campo se llevaron a cabo para evaluar el impacto bioeconómico y cualitativo de dosis reducidas (25 y 50% de la dosis etiqueta) de un herbicida de post-emergencia pirimidiniloxi benzoico (bispiribac-sodio) aplicado solo o en combinación con extractos acuosos de árboles multipropósito [eucalipto (*Eucalyptus camaldulensis* Dehnh.), mango (*Mangifera indica* L.), morera (*Morus alba* L.)] en campos de arroz (*Oryza sativa* L.) de siembra directa. Se incluyó dosis recomendada en la etiqueta de bispiribac-sodio y penoxsulam y un control de malezas para comparación. Mezcla de estanque de los extractos acuosos de árboles multipropósito con dosis de herbicida reducida causó supresión de > 55% en densidad de malezas y > 75% en peso seco, lo que fue superior cuando estas dosis de herbicida se utilizaron solas. La combinación de estos extractos con un 50% de reducción de la dosis de bispiribac-sodio registró granos por panícula, peso 1000 granos y rendimiento de grano

Table 5. Economic analysis of different weed control treatments.

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	Remarks
Paddy yield	0.63	0.99	1.67	1.50	1.27	0.99	1.97	2.80	t ha^{-1}
10% loss (paddy)	0.063	0.099	0.167	0.150	0.127	0.099	0.197	0.280	To bring at farmer level
Adjusted paddy yield	0.567	0.891	1.503	1.35	1.143	0.891	1.773	2.52	10% discount
Income from paddy yield	19 136	30 071	50 726	45 562	38 576	30 071	59 838	85 050	Rs. 33750 t^{-1}
Straw yield	3.83	5.36	6.42	6.13	5.68	5.19	7.01	8.98	t ha^{-1}
10% loss (straw)	0.383	0.536	0.642	0.613	0.568	0.519	0.710	0.898	To bring at farmer level
Adjusted straw yield	3.447	4.824	5.778	5.517	5.112	4.671	6.309	8.082	10% discount
Income from straw yield	2 585	3 618	4 333	4 137	3 834	3 503	4 731	6 061	Rs. 750 t^{-1}
Gross income	21 721	33 689	55 059	49 699	42 410	33 574	64 569	91 111	Rs. ha^{-1}
Cost of extract	-	324	324	324	-	-	-	-	Rs.108 per 18 L of each extract
Cost of penoxsulam	-	-	-	-	-	-	-	1 111.5	Rs. 1111.5 ha^{-1}
Cost of bispyribac-sodium	-	-	555.7	277.8	555.7	277.8	1 111.5		Rs. 1111.5 ha^{-1}
Cost of spray application	-	250	250	250	250	250	250	250	Rs. 250 per man, one man d^{-1} ha^{-1}
Cost of spray rental		100	100	100	100	100	100	100	Rs. 100 per spray
Variable costs	0	674	1 229.7	951.8	905.7	627.8	1 461.5	1 461.5	Rs. ha^{-1}
Net benefits	21 721	33 015	53 829	48 747	41 504	32 946	63 108	89 650	Rs. ha^{-1}

T_1: Control (weed control); T_2: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1}; T_3: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1} + bispyribac-sodium at 15 g ai ha^{-1}; T_4: Eucalyptus+mulberry+mango leaf extracts each at 18 L ha^{-1} + bispyribac-sodium at 7.5 g ha^{-1}; T_5: Bispyribac-sodium at 15 g ai ha^{-1}; T_6: Bispyribac-sodium at 7.5 g ai ha^{-1};T_7: Bispyribac-sodium at 30 g ai ha^{-1}; T_8: Penoxsulam at 15 g ai ha^{-1}; 1US$=91.10 Rs.

similar a la dosis de etiqueta del herbicida superiores a la aplicación de dosis reducida de este herbicida. Este tratamiento también mejoró los atributos de calidad del grano sobre el control similar a la dosis de etiqueta del herbicida. A pesar de los mayores beneficios netos de la dosis de etiqueta del herbicida, la tasa máxima marginal de retorno se obtuvo con mezcla de estanque de 25% de la dosis herbicida sugerida con extractos acuosos vegetales multipropósito.

Palabras clave: dosis reducida, supresión de malezas, rendimiento, calidad de grano, *Oryza sativa*.

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