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Weed suppressing ability and performance of common crop residues for sustainable weed management

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ABSTRACT

Application of crop residues can be a good option for organic and sustainable weed management in rice. Consequently, the use of crop residues can suppress weed emergence and weed biomass. A study was conducted in two consecutive seasons firstly to optimize the mixture ratio to soil (v/v) of different crop residues on inhibition of common weed species and secondly to evaluate their performance on rice growth and yield. Among the crop residues used in this study sorghum was the most effective followed by mustard, barley, soybean, rice, wheat, triticale, maize, lentil and grasspea. The 50:50 (crop: soil, v/v) treatments incorporation rate of all crop residues suppressed the growth of all weed species in maximum level. The result revealed that broadleaf weed species were more susceptible to crop residues than grass weed species. In this respect, the highest growth inhibition (54.49%) was observed in controlling *Monochoria vaginalis.* Variety and rate of sorghum residues application significantly influenced weed growth and inhibition. A maximum increment in terms of plant height, dry weight and yield was observed due to sorghum 2.0 t ha^{-1} residue applications. Considering yield and yield contributing characters, highest grain and straw yield was obtained from BRRI dhan29. All together, the result depicted that crop residues can effectively control weed along with enhancing growth and yield of rice and it can be successfully used in weed management program in rice.

Introduction

Current agriculture is productivity-oriented and depends mostly on artificial inputs to deal with weeds and other pest problems (Sadeghi et al. 2010). Extensive herbicide apply to manage weeds over the last few decades is posing rigorous ecological and environmental pressures to the globe and its inhabitants. Herbicide residues in produce, soil and ground water, shifts in weed populations, advancement of resistant weed biotypes, and related health hazards have diverted the

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attention of researchers to find out and commence alternative weed management strategies. There is an increasing strength for organically produced products worldwide (Jamil et al. 2009). Allelopathy, a fundamental natural phenomenon that clarifies interference among species through biochemical ways is a tool that can be operated to control weeds in agro ecosystems (Khanh et al. 2005). Use of allelopathic properties of native plant/crop species suggests promising opportunities for this purpose. Allelopathy can amend plant biodiversity through its impact on plant adaptation, survival, and community organization (Chou and Lee, 1991).

Crop residues are defined as crop or its parts left in field for decomposition after it has been thrashed or harvested (Kumar and Goh, 2000). In the past these were regarded simply as waste, but now because of their usefulness they are considered as principal resource that can bring significant physical, chemical, and biological changes in the agricultural soil after amendment. Weed multiplicity and community composition can be regulated by crop residue management through bringing changes in the qualitative and quantitative traits (Judice et al. 2007). In addition, residue management can alter soil properties which can also influence weed pressure level through their impact on weed seed survival, dormancy, predation, and long-term viability (Khaliq et al. 2015). Weeds can be suppressed through physical hindrance or by posing chemical (allelopathy) secreted by mulching of crop residues (Khaliq et al. 2015; Reddy, 2001). In the case of crop residues, there are two possible sources of allelochemicals; the compounds can be released directly from crop litter or they can be produced by microorganisms that use plant residues as a substrate (Kruidhof, 2008). Moreover, mulching of crop residues may decrease water loses through evapo-transpiration, preserve moisture and nutrient, reduce soil degradation, encourage rhizosphere biota, reduce farm inputs and greenhouse gases emissions (Malhi and Lemke, 2007; Sharma et al. 2011). Along with these, residue mulching also provides diverse supplementary benefits like slow release of nutrients, lighter soil color which reflects light, and cooler soil temperature (Bajgai et al. 2015).

There is limited information on the difference in crop residues application under different crop cultivation situation. However, the incidence of growth inhibition of certain weeds and the induction of phytotoxic symptoms by plants and their residues is documented for many crops, including all major grain crops such as rice (*Oryza sativa* L.), rye (*Secale cereale* L.), barley (*Hordeum vulgare*), sorghum (*Sorghum bicolor* L.) and wheat (Belz, 2004). Some residues are also known to enhance the efficiency of herbicides (Teasdale et al. 1991). However, much depends on crop residues, its placement, environmental conditions, and cropping patterns. Research regarding the application of crop residues in a mixture with soil with different ratio and its consequent finding application along with rice varieties is rare. Such information is vital for identifying the suitable crop residues to support the growth and yield of high yielding rice cultivars. It was hypothesized that crop residues mulching can be applied as organic and sustainable weed management approach in rice crop. Therefore, in this study, an attempt has been made to examine the influence of different crop residues (barley, sorghum, wheat, lentil, mustard, triticale, soybean, rice, maize and grass pea) ratio with soil and their subsequent effect on weed dynamics, crop growth, and yield performance of rice under irrigated conditions.

Materials and Methods

Site description

The experiments were carried out at Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, Bangladesh (latitude: 24° 42' 55'', longitude: 90° 25' 47'') at 2017 and 2018. During first year the pot experiment was conducted (using pots of 12.5 cm diameter) in a glasshouse under controlled conditions and the field experiment was conducted during second year. The experimental field was located at an elevation of 18 m above the sea level belonging to non calcareous dark grey floodplain soil under the Sonatala series of the Old Brahmaputra Floodplain which falls under agro-ecological region of the Old Brahmaputra Floodplain. The climate is humid subtropical monsoon. The physicochemical properties of the soil before the beginning of the experiment are shown in Table 1.

Table 1. Physicochemical properties of soil before start of the experiments.

Soil property	Values
Soil texture	Clay loam
pH–H_2O	5.83
Ec (µs/cm)	143
Organic carbon (%)	1.125
Total N (%)	0.145
Available P (ppm)	23.3
Available K (ppm)	88.64
Available S (ppm)	59.64

Plant materials for screening of crop residues

Barley, sorghum, wheat, lentil, mustard, triticale, soybean, rice, maize and grass pea crop residues were used in this study. All the crops were grown at the Agronomy Field Laboratory, Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh and were harvested at the time of ripening stage to collect crop residues.

Preparations of plant material

After collection, the crop residues were dried under shade in the cover threshing floor of Agronomy Field Laboratory of BAU. The studied crop residues were cut as small as possible and then send the samples to a flour mill to make them powder. After grinding, the ratio of each crop residues was mixed as a 0/100, 10/90, 20/80, 30/70, 40/60 and 50/50 of crop/soil by volume.

Weed control efficacy

The allelopathic potential of different crop residues against several weed species were evaluated. Assays were performed by impregnating rotation crop residues/rice grown soil mixture (0:100, 10:90, 20:80, 30:70, 40:60 and 50:50 v/v). Each pot was filled up with above mentioned ratio of crop residues and soil. Treatments were replicated four times and arranged as a completely randomized design. Pots were watered and maintained like a rice field condition to allow weed emergence and growth in the pots. Forty five days after treatment, weeds were collected and kept separately in brown paper bags and then placed in an electric oven at 72°C for 3 days. The samples were weighed separately. Efficacy of different rotation crop residues was measured based on dry matter of weed species. Percent inhibition as compared to the control was calculated for all data collected.

Experimental design and treatments

Three *boro* rice cultivars, BRRI dhan28, BRRI dhan29 and Binadhan-14 were supplied by the Bangladesh Rice Research Institute (BRRI) and Bangladesh Institute of Nuclear Agriculture (BINA). It should be noted that in the *boro* season farmers of Bangladesh are completely dependent on irrigation to grow their crops. The crop residue treatments include no crop residue application and sorghum crop residues (0.5, 1.0, 1.5 and 2.0 t ha^{-1}). The experiments were laid out in a randomized complete block design (RCBD) with three replications. The total number of plot was 45 having each plot size of 4 m × 2.5 m.

Pot preparation and fertilizer application

Each pot was filled with 8 kg of soil and placed in the glasshouse of the Department of Agronomy, BAU, Mymensingh. Extra water was applied to bring the soil moisture to a suitable level for seedlings because the pots were filled with dry soil. Two liters of water were added to saturate the soil. Fertilizer concentrations for pot experiments were applied as 0.8 g, 1.04 g, 0.9 g, and 0.03 g per pot in the form of Triple Super Phosphate (TSP), Muriate of Potash (MOP), gypsum, and zinc sulfate, respectively. Whole amounts of fertilizers were applied during the final pot preparation. The source of N was urea and was applied as per specified at 15 days after transplanting (DAT), 40 DAT, and 70 DAT.

Cultural Practices

The experimental plots were irrigated, ploughed and cross- ploughed followed by laddering for good puddled condition. At final land preparation, the experimental plots were fertilized with P, K, S and Zn at 25, 60, 18 and 3.5 kg ha^{-1}, respectively in the form of Triple Super Phosphate (TSP), Muriate of Potash (MOP), Gypsum and Zinc sulphate. Urea in the form of N at 115 kg ha^{-1} was applied in three equal installments at 10, 40 and 70 days after transplanting (DAT). Forty-one day old healthy seedlings were uprooted carefully from the seed bed and were transplanted at three seedlings $hill^{-1}$ in the unit plots on 19 January, 2015 with a spacing of 25 cm × 15 cm. The experimental plots were irrigated as and when it was necessary.

Measurement of weed control efficacy

The allelopathic potential of different crop residues against several weed species was evaluated. Forty five days after treatment, weeds were collected, counted and kept separately in brown paper bags and then placed in an electric oven at 72°C for 3 days. The samples were weighed separately. Efficacy of different crop residues was measured based on dry matter of weed species. Percent inhibition as compared to the control was calculated for all data collected.

Measurement of yield and yield components

Maturity date was identified when 90% of grains had matured. At maturity, the whole plant was cut at the ground level with a sickle. The harvested crop from each pot was bundled separately and tagged appropriately. After recording data for plant height and panicle length for each plant, plant materials were sun dried for grain collection. Finally, grain and straw yield and yield contributing parameters were recorded separately.

Data analysis

Data on weed growth, % inhibition, yield components, and yield of rice were compiled and tabulated for statistical analysis. Analysis of variance was conducted with the computer package MSTAT-C. Means were tested using Duncan's Multiple Range Test (Gomez and Gomez, 1984).

Results and Discussion

Weed dynamics under different crop residues application

Surface application of crop residues as mulch in different mixtures and rate is a new aspect for weed management in rice. A significant weed suppression capability of applied crop residue mulches is proved in our study. The emergence and growth of weeds are obstructed by crop residues. Besides, it may modify the frequency and distribution of weeds (Khaliq et al. 2015; Essien et al. 2009). Earlier it was reported that under the influence of canola residues, fresh and dry biomass of red root, amaranth, black nightshade, and curly docks were severely reduced (Zaji and Majd, 2011). In the present study, the suppression of *Echinochloa crusgalli, Scirpus juncoides, Monochoria vaginalis* and *Cyperus difformis* growth might have attained due to physical barrier by residue mulching and of released allelochemicals from these residues. Different factors like the family of the applied crop, amount and density of mulching, rate of decomposition and release of allelochemicals, soil moisture content, soil texture, and microflora may hamper the release of allelochemicals (Kamara et al. 2000; Khaliq et al. 2014). The weed species density and their biomass were counted and calculated. Four weed species belonging to three families infested in the pot culture. Local name, scientific name, family, morphological type and life cycle of the weed in the experimental plot have been presented in Table 2. All the crop residues significantly reduced weed density and dry biomass (Table 3). Generally it was noticed that broad leaf weeds were suppressed more than grasses and sedge weeds. Among the ten different crop residues, sorghum was the most effective to inhibit weeds followed by mustard, barley, soybean, rice, wheat, triticale, maize, lentil and grasspea. Sorghum crop residue ensured the lowest weed infestation (4.05) at 45 DAS in case of *Echinochloa crusgalli*. Similarly, among different crop residues ratio, 50:50, 40:60, 30:70, 20:80, 10:90 recorded 83, 63, 52, 24, 9% suppression in weed number respectively over nontreated (no crop residues application) plot at 45 DAS. The weed dry biomass illustrated almost a similar trend as weed density (Table 3). Significantly reductions (5–79%) in total weed dry biomass were observed under the influence of different ratio combinations in *Echinochloa crusgalli*. The highest suppression in weed dry biomass was observed in 50:50 ratio. Similar trend of results was detected for other weeds (*Scirpus juncoides, Monochoria vaginalis*, and *Cyperus difformis).*

Table 2. Infested weed species found growing in the pot culture and field condition in rice.

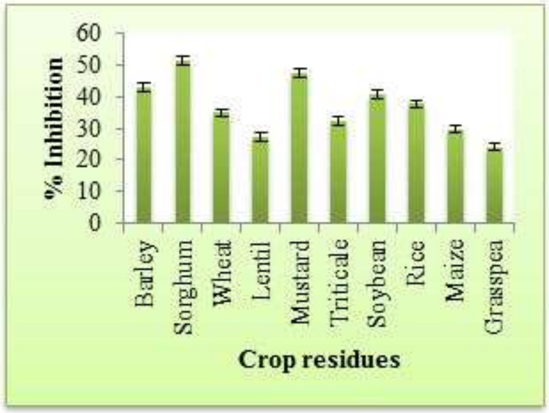
SL no.	Local name	Scientific name	Family	Morphological type	Life cycle
1.	Shama	*Echinochloa crusgalli*	Gramineae	Grass	Annual
2.	Chesra	*Scirpus juncoides*	Cyperaceae	Sedge	Annual
3.	Panikachu	*Monochoria vaginalis*	Pontederiaceae	Broad leaved	Perennial
4.	Sabujnakphul	*Cyperus difformis*	Cyperaceae	Sedge	Annual

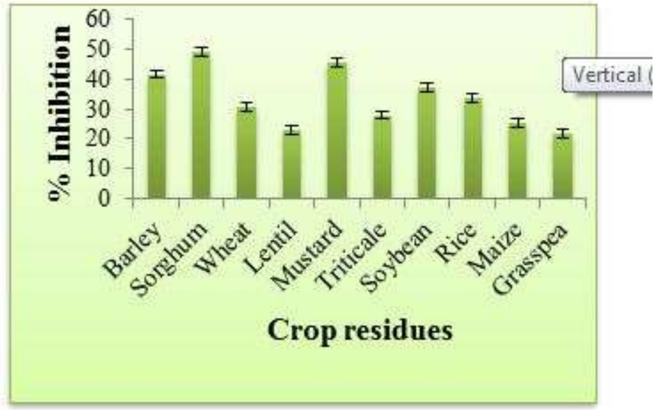
All the crop residues significantly reduced the growth of all tested weed species. The degree of inhibition increased with increasing mixture ratio of crop residues. The growth inhibition was highest (51.25%) in case of sorghum crop residues in controlling *Echinochloa crusgalli* (Figure. 1a). The second highest inhibition (47.48%) was obtained from mustard crop residues. On the other hand, it was 78.76%, 63.68% and 47.00% using the mixture ratio of 50:50, 40:60 and 30:70, respectively (Figure. 2a). *Scirpus juncoides* was inhibited by using crop residues. The highest inhibition was 49.09% in case of sorghum crop residues (Figure. 1b). The lowest inhibition (21.69%) was recorded in grasspea crop residues. In case of residues: soil (v/v), 50:50 ratio performed best and inhibition was 76.36% (Figure. 2b). Crop residues successfully controlled *Monochoria vaginalis* and inhibition was 50.00% when sorghum was used (Figure. 1c). The lowest % inhibition (22.59 %) was obtained from mustard crop residues. In case of mixture, 50:50 ratio showed the highest inhibition (Figure. 2c). The % inhibition was significant with application of crop residues for *Cyperus difformis*. It was 50.15% in case of sorghum residues application (Figure. 1d). Mixture of crop residues with soil significantly influenced % inhibition. The ratio 50:50 has highest % inhibition (Figure. 2d).

Table 3. Weed density and biomass as influenced by crop residues and crop residues: soil ratio

Treatments	*Echinochloa crusgalli*		*Scirpus juncoides*		*Monochoria vaginalis*		*Cyperus difformis*	
	Number	Dry weight (g)	Number	Dry weight (g)	Number	Dry weight (g)	Number	Dry weight (g)
Crop residues (C)								
Barley	4.77 a	1.33 h	7.44 a	1.83 g	1.44 a	0.17 fg	1.42 a	0.38 fg
Sorghum	4.05 c	1.10 j	6.61 b	1.55 i	1.05 c	0.15 h	1.07 c	0.35 g
Wheat	4.83 a	1.51 e	7.50 a	2.17 d	1.50 a	0.19 cde	1.50 a	0.46 cd
Lentil	4.83 a	1.69 b	7.50 a	2.41 a	1.50 a	0.22 ab	1.50 a	0.52 a
Mustard	4.38 b	1.23 i	6.83 b	1.73 h	1.22 b	0.15 gh	1.18 b	0.37 fg
Triticale	4.83 a	1.57d	7.50 a	2.26 c	1.50 a	0.20 bcd	1.50 a	0.48 bc
Soybean	4.83 a	1.38 g	7.50 a	1.97 f	1.44 a	0.18 ef	1.42 a	0.40 ef
Rice	4.83 a	1.45 f	7.50 a	2.08 e	1.50 a	0.18 def	1.50 a	0.43 de
Maize	4.83 a	1.63 c	7.50 a	2.34 b	1.50 a	0.21 abc	1.50 a	0.50 ab
Grasspea	4.83 a	1.76 a	7.50 a	2.46 a	1.50 a	0.23 a	1.50 a	0.53 a
Crop residues :Soil (R)								
0:100	7.63 a	2.32 a	11.63a	3.13 a	2.00 a	0.30 a	2.00 a	0.70 a
10:90	6.93 b	2.20 b	10.90 b	2.97 b	1.96 a	0.27 b	1.98 a	0.62 b
20:80	5.83 c	1.72 c	8.83c	2.54 c	1.83 b	0.24 c	1.81 b	0.54 c
30:70	3.66 d	1.23 d	5.66d	1.94 d	1.00 c	0.15 d	1.00 c	0.35d
40:60	2.83 e	0.84 e	4.86 e	1.15 e	0.96 c	0.10 e	0.95 c	0.26 e
50:50	1.33 f	0.49 f	2.13f	0.74 f	0.73 d	0.07f	0.71d	0.18 f
ANOVA								
Crop residues (C)	**	**	**	**	**	**	**	**
Crop residues :Soil (R)	**	**	**	**	**	**	**	**
C×R	NS	**	**	**	**	NS	**	**
CV (%)	9.64	4.73	7.04	4.83	11.76	15.26	8.44	12.62

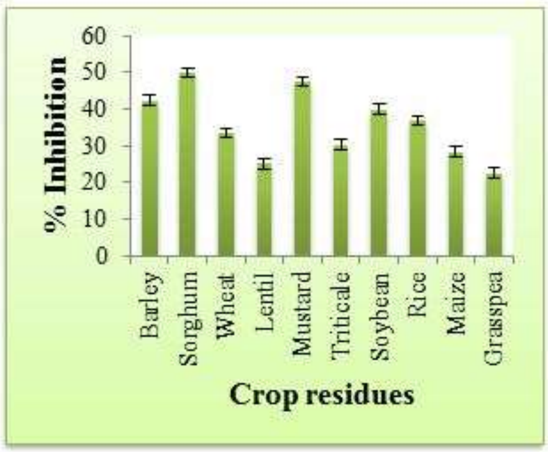
Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT). **: Significant difference at P ≤ 0.01, NS: Non significant.

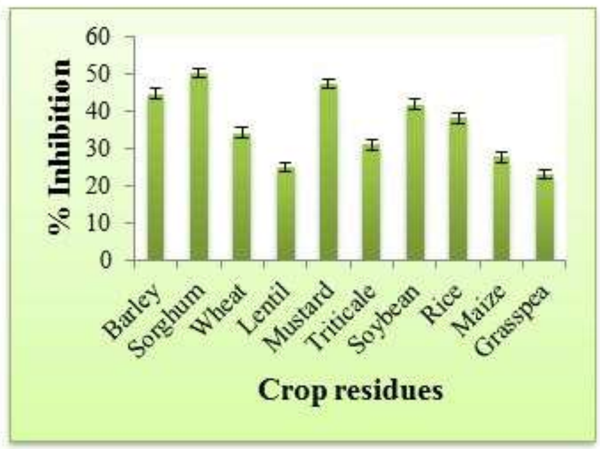




1a. *Echinochloa crusgalli*

1b. *Scirpus juncoides*





1c. *Monochoria vaginalis*

1d. *Cyperus difformis*

Figure 1. Effect of different crop residues on weed control in pot culture (a) *Echinochloa crusgalli*, (b) *Scirpus juncoides*, (c) *Monochoria vaginalis*, (d) *Cyperus difformis* (Bar represents standard error mean).

Weed control efficacy under different level of sorghum crop residues

The weed species density and dry weight were calculated for all varieties (Table 4 and Figure. 3a). The principal weeds were *Scirpus juncoides* and *Echinochloa crusgalli*. The lowest weed infestation (15.93) was observed for *Echinochloa crusgalli* at 45 DAS in Binadhan-14. Along with different crop residues rate, sorghum at 2.0 t ha^{-1} recorded 37% suppression in weed number over no crop residues application at 45 DAS. The weed dry biomass demonstrated almost a similar trend as weed density (Figure. 3a). In respect of *Scirpus juncoides,* Binadhan-14 showed best response in weed density compared to other varieties. *Monochoria vaginalis* was lowest in number in case of BRRI dhan28 plot. Sorghum at 2.0 t ha^{-1} crop residues showed 56% suppression in weed number compared to no crop residues application. The weed density and biomass of *Cyperus difformis* was similar to that of *Echinochloa crusgalli*. The efficacy of mulching materials is dependent on their nitrogen content, lignin, and polyphenol concentration which determine the rate of decomposition and release of plant toxins (Rathinasabapathi et al. 2005). Application of crop residues also show shading effect which can prevent weed germination as light and temperature control the seed dormancy in many annual weeds (Fahad et al. 2015; Gruber et al. 2008). The growth inhibition was highest (24.86%) in case of BRRI dhan28 in controlling *Echinochloa crusgalli*. The lowest inhibition (22.93%) was obtained from Binadhan-14. Among crop residues application, sorghum at 2.0 t ha^{-1} showed superior performance and inhibition was 54.67%. The lowest inhibition was recorded in no crop residues application. *Scirpus juncoides* was inhibited by using rotation crop residues and varieties. The highest inhibition was recorded (19.88%) in BRRI dhan28. In case of using crop residues, sorghum at 2.0 t ha^{-1} showed best performance and in that case inhibition was 44.48%. The inhibition of weed germination and growth may be due to the presence of several phytotoxins in sorghum 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, phydroxybenzaldehyde and sorgoleone (Netzly and Butler, 1986; Cheema et al. 2009). Allelochemicals from sorghum, their secretion mechanisms and genes regulating them have identified by several studies and also confirmed sorghum allelopathic potential under natural and controlled conditions (Weston and Duke, 2003). The suppressive effects of sorghum residues were reflective for germination dynamics. Phytochemicals during decomposition process (Thorne et al. 1990; Nelson, 1996) were released by sorghum (Cheema and Khaliq, 2000) residue that was stated to be inhibitory to germination of a number of species (Purvis et al. 1985; Norsworthy et al. 2005). Varieties had significant effect on weed inhibition in case of *Monochoria vaginalis*. The inhibition was 31.00% in case of BRRI dhan28. Regarding crop residues, sorghum at 2.0 t ha^{-1} showed superior performances in case of inhibition and it was 63.25%. The % inhibition for *Cyperus difformis* was significant when different varieties used. It was highest (25.24%) in case of BRRI dhan28. Crop residues also significantly influenced % inhibition. The highest % inhibition (52.10%) was observed in sorghum crop residues at 2.0 t ha^{-1}.

Crop growth

In case of crop residues effect on rice varieties a different scenario was found. The growth of rice tested did not hinder by crop residues. Rather crop residues enhanced plant height and plant dry weight through suppression of weed in the plot. Significant differences in plant height were observed due to variety at all sampling dates. The data revealed that BRRI dhan29 was tallest among varieties at all dates of sampling (Figure. 5a). The lowest plant height was observed in Binadhan-14. In case of application of crop residues, sorghum at 2.0 t ha^{-1} produced height plant at all sampling dates (Figure. 5c). Plant dry weight was also significant at all sampling dates except 25 DAT. At 50 DAT, highest dry weight was found in BRRI dhan29 (Figure. 5b). Similar trend was observed at dates onward. In case of application of crop residues, sorghum 2.0 t ha^{-1} produced height plant dry weight at all sampling dates (Figure. 5d). In that case, sorghum crop residues at 2.0 kg ha^{-1} produced higher plant and dry weight compared to others.

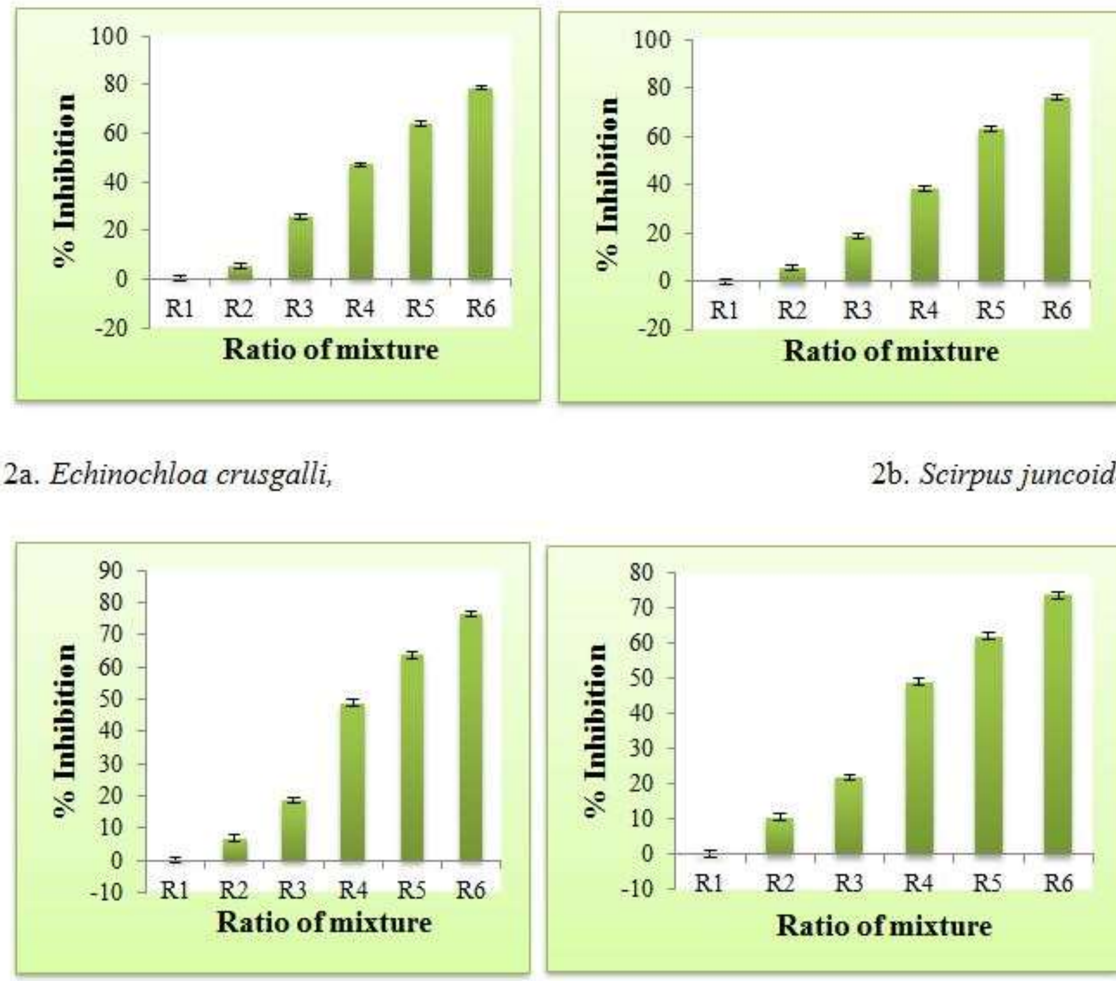
Table 4. Weed density (no. m-2) as influenced by variety and rate of sorghum crop residues.

Treatments	*Echinochloa crusgalli*	*Scirpus juncoides*	*Monochoria vaginalis*	*Cyperus difformis*
		Variety (V)		
BRRI dhan28	18.20 a	21.80 a	0.86 b	18.87 a
BRRI dhan29	19.40 a	22.73 a	1.26 a	20.20 a
Binadhan-14	15.93 b	15.93 b	1.20 a	16.07 b
Crop residues (C)				
No weeding	28.22 a	39.78 a	1.00 b	30.67 a
Sorghum at0.5 t ha^{-1}	12.89 c	12.89 c	1.66 a	13.22 c
Sorghum at1.0 t ha^{-1}	16.55 b	16.56 b	0.89 b	16.55 bc
Sorghum at1.5 t ha^{-1}	13.89 c	13.89 c	1.00 b	13.89 c
Sorghum at2.0 t ha^{-1}	17.67 b	17.67 b	1.00 b	17.56 b
		ANOVA		
Variety (V)	**	**	*	**
Crop residues (C)	**	**	**	**
V×C	**	**	**	**
CV (%)	10.25	10.78	22.09	18.39

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT). **: Significant difference at $P \leq 0.01$,*: Significant difference at $P \leq 0.05$.

Rice yield and agronomic traits

Significant variation in plant height was observed among the varieties at the time of harvest. Plant height was from 68.13 cm to 74.83 cm and highest plant height was observed in BRRI dhan29 (Table 5). Plant height due to application of crop residues also differed significantly. Maximum plant height (75.09 cm) was recorded in sorghum crop residues at 2.0 t ha^{-1} which was statistically similar to 2.0 t ha^{-1}. BRRI dhan29 produced highest number of effective tillers hill^{-1} closely followed by BRRI dhan28, whereas lowest number was noticed in Binadhan-14. Effective tiller hill^{-1} was significantly influenced by crop residues application. The highest number of effective tiller hill^{-1} (6.53) was obtained from sorghum crop residues at 2.0 t ha^{-1} (Table 5). Crop residues treated plots produced higher grains panicle^{-1} than in the non treated plots. Paddy straw incorporated treatment along with inorganic fertilizer increased significantly in number of panicle m^{-2} in over unincorporated treatments (Ali et al. 1995). The increased and sustained availability of nutrients due to the increased number of panicles and spikelets in the residue treated plots could be ascribed to harmonize better with crop uptake (Zhu et al. 1984), which finally reflected in higher grain yield. 1000-grain weight was significantly influenced by variety. Highest 1000 grain weight (22.30 g) was recorded in Binadhan-14. Application of crop residues did not differ significantly in respect of 1000 grain weight (Table 5).

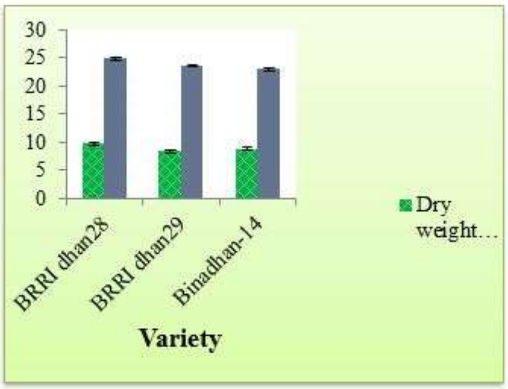


2a. *Echinochloa crusgalli,* 2b. *Scirpus juncoides,*

2c. *Monochoria vaginalis,* 2d. *Cyperus difformis*

Figure 2. Effect of mixture of crop residues with soil on weed control in the pot culture (a) Echinochloa crusgalli, (b) Scirpus juncoides, (c) Monochoria vaginalis, (d) Cyperus difformis (Bar represents standard error mean). Here, R_1=0:100; R_2=10:90; R_3=20:80; R_4=30:70; R_5=40:60; R_6=50:50.

Grain yield was significantly affected by variety and crop residues application treatments (Table 5). Highest grain yield (2.80 t ha^{-1}) was observed in BRRI dhan29. Crop residues application had also significant effect on grain yield. As expected, grain yield was always higher in the higher rate of crop residues treated plots than in the lower rate and non- treated plots. Grain yield in the highest when the plot was mulched with 2.0 t ha^{-1} of sorghum crop residues than all other treated plot. In the nontreated plots, grain yield was only 1.00 t ha^{-1}. In the present study, 75% increase in rice yield at sorghum crop residues at 2.0 t ha^{-1} was recorded over control.



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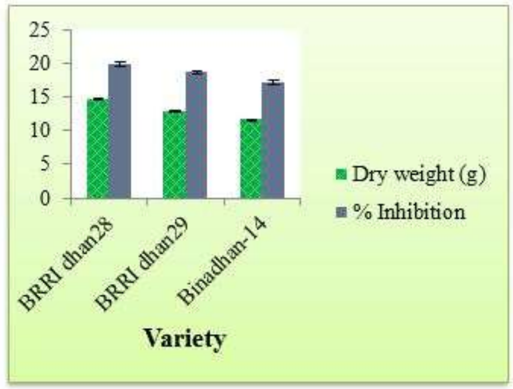
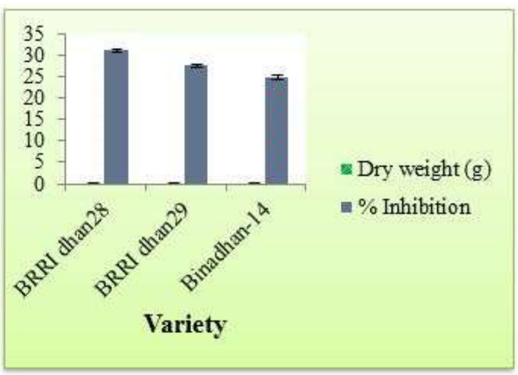
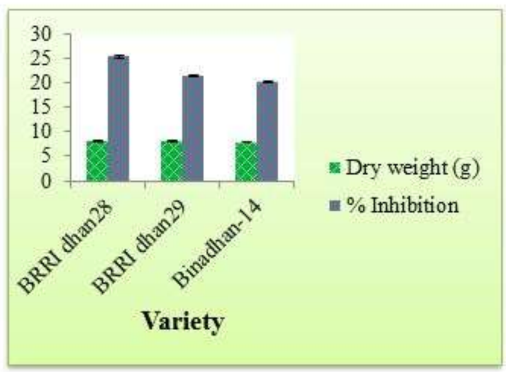


3b. *Scirpus juncoides,*



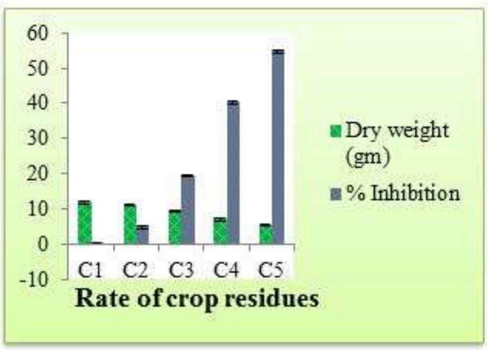
3c. *Monochoria vaginalis,*



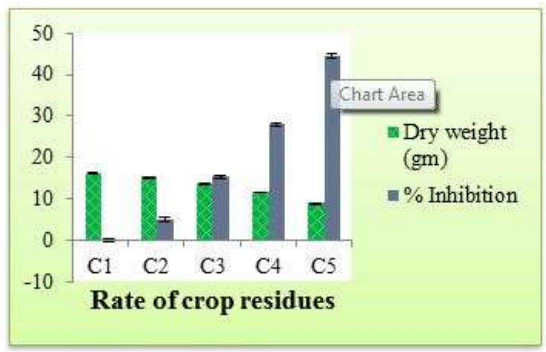
3d. *Cyperus difformis*

Figure 3. Effect of variety on weed control in the field condition (a) Echinochloa crusgalli, (b) Scirpus juncoides, (c) Monochoria vaginalis, (d) Cyperus difformis (Bar represents standard error mean).

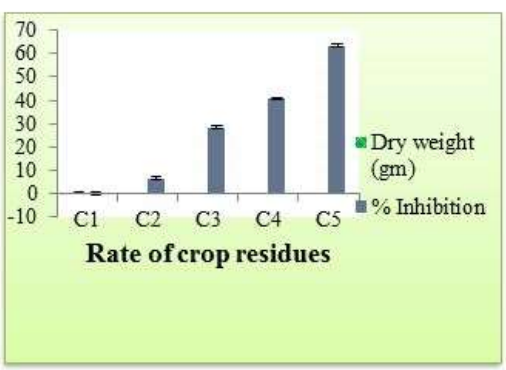
The improvement in yield might also be attributed to the weed suppression during the critical crop growth period. An effective inhibition of weeds enhanced the availability of resources, such as water, nutrients, light, and space (Kruidhof et al. 2008). Hence, grain yield increased by the crop residue application over a period of time by supplying the nutrients required by plants as well as by improving the soil properties. After several years of continued application of straw a similar increase in the grain yield was observed (Kun-Huang, 1982). Variety had significant effect on straw yield. BRRI dhan29 produced highest straw yield (3.28 t ha^{-1}) followed by BRRI dhan28 and Binadhan-14. In the crop residues treated plots, the higher amounts (2 t ha^{-1}) resulted in the highest straw yield, that is, 4.90 t ha^{-1}. Compared with the treatment in which no crop residues was applied resulted in 71% lower yield. This low yield was mainly due to high weed pressure. Our results support this observations as grain yield was negatively correlated ($p<0.001$) with weed biomass (Figure. 6a). Grain yield was also highly correlated with ($p<0.001$) with rice grains panicle^{-1} (Figure. 6b). There was a positive and linear relationship between grain yield and grains panicle^{-1}, with 83% variation in grain yield explained by the relationship. With regard to straw yields, the increase was significant in all the residue treated plots over control with maximum increase in sorghum crop residue 2.0 t ha^{-1}. The higher straw yields attained over no crop residue application (control) were ascribed to the factors already explained in case of grain yields.



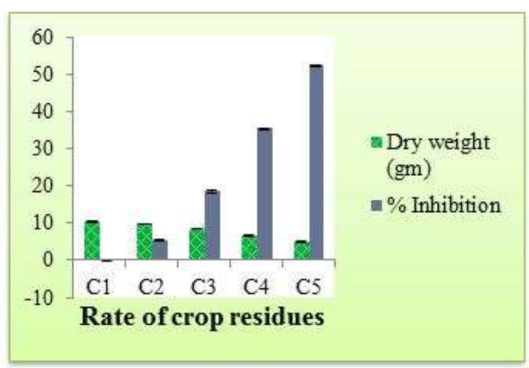
4a. *Echinochloa crusgalli*,



4b. *Scirpus juncoides*,



4c. *Monochoria vaginalis*,



4d. *Cyperus difformis*

Figure 4. Effect of rate of sorghum crop residues on weed control in the field condition (a) *Echinochloa crusgalli*, (b) *Scirpus juncoides*, (c) *Monochoria vaginalis*, (d) *Cyperus difformis* (Bar represents standard error mean). Here, C_1=No crop residues, C_2=Sorghum crop residues at 0.5 t ha^{-1}, C_3=Sorghum crop residues at 1.0 t ha^{-1}, C_4=Sorghum crop residues at 1.5 t ha^{-1}, C_5=Sorghum crop residues at 2.0 t ha^{-1}

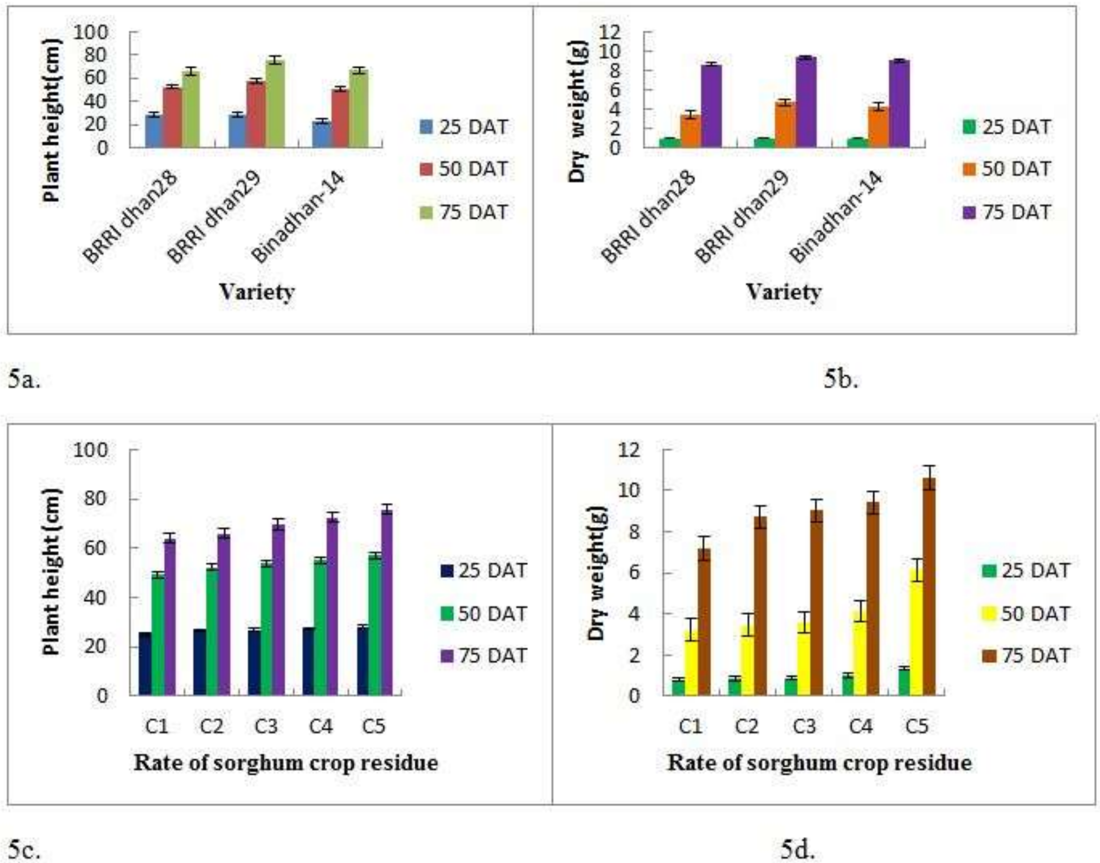


Figure 5. Effect of variety on (a) plant height, (b) dry weight and rate of sorghum crop residue on (c) plant height, d. dry weight in the field condition (Bar represents standard error mean).

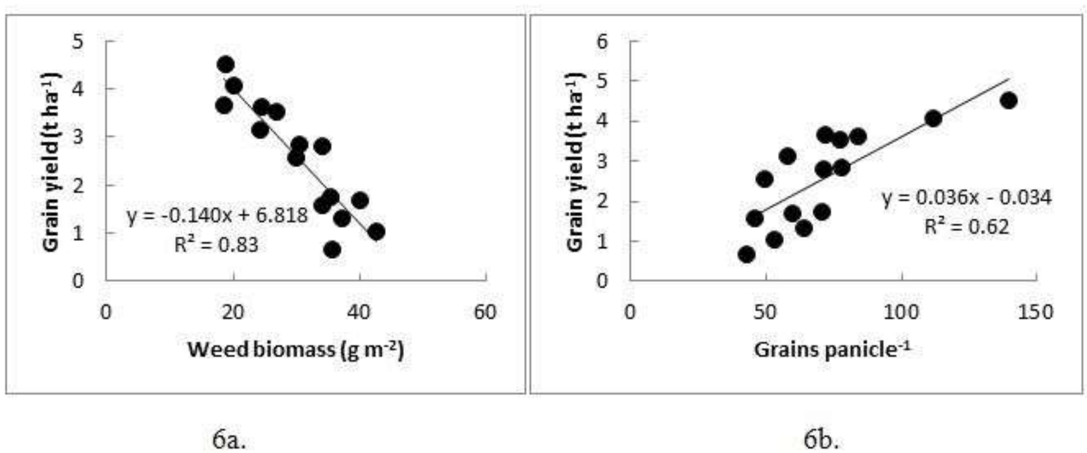


Figure 6. Relationships between (a) grain yield and weed biomass and (b) between grain yield and grains panicle^{-1}

Table 5. Yields attributes and yield of rice as influenced by variety and rate of sorghum crop residues.

Treatments	Plant height (cm)	Effective tillers hill^{-1}	Panicle length (cm)	Filled grains panicle^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
Variety(V)								
BRRI dhan28	72.89 b	5.620 b	18.02 b	74.47 b	21.49 b	2.62 b	2.96 b	46.37
BRRI dhan29	74.83 a	6.147 a	19.77 a	87.04 a	21.61 b	2.80 a	3.28 a	45.84
Binadhan-14	68.13 c	5.360 b	17.03 c	53.51 c	22.30 a	2.32 c	2.69 c	45.74
Crop residues (C)								
No weeding	69.10 b	5.056 d	17.53 b	53.13 e	21.69	1.00 e	1.43 e	41.11c
Sorghum at0.5 t ha^{-1}	71.00 b	5.367 cd	17.80 b	58.58 d	21.84	1.66 d	1.82d	47.77 a
Sorghum at1.0 t ha^{-1}	71.13 b	5.633 bc	18.14 b	66.10 c	21.71	2.73 c	2.92 c	48.31 a
Sorghum at1.5 t ha^{-1}	73.44 a	5.956 b	18.56 ab	72.90 b	22.01	3.43 b	3.82 b	47.29 a
Sorghum at2.0 t ha^{-1}	75.09 a	6.533 a	19.34 a	107.7 a	21.74	4.08 a	4.90 a	45.44 b
ANOVA								
V	**	**	**	**	*	**	**	NS
C	**	**	**	**	NS	**	**	**
V×C	NS	NS	NS	**	NS	**	**	NS
CV (%)	3.17	8.90	5.72	7.62	3.81	5.20	4.96	3.03

Within a column, means followed by same letters are not significantly different at 5 % probability level by Duncan's Multiple Range Test (DMRT).
**: Significant difference at P ≤ 0.01,*: Significant difference at P ≤ 0.05, NS: Non significant
[a] Grain yield and straw yield are at 14 % moisture content.

Conclusion

Crop residues are an important natural resource and their proficient management is vital for sustainable crop production. Application of field crops residues can be accepted as organic weed management option against challenging weeds in rice crop. In this study we found the inhibitory effect of different crop residues on different weeds especially sorghum residues was most effective to suppress weed growth. In addition, crop: soil at 50:50 ratio was found superior in controlling weed density and biomass. Our study also demonstrated significant weed suppression ability of sorghum crop residue at different rate. Among different rate, sorghum at 2.0 kg ha^{-1} recorded the highest reductions in density and dry biomass of weed growth as compared with no crop residues application. Mulching of sorghum crop residues at different rates has also significantly influenced plant height, total dry matter and grain yield of rice. Thus, sorghum at 2.0 kg ha^{-1} as cover mulch could be an alternate approach for weed management programs in rice.

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Conflicts of Interest

The authors have declared no potential conflicts of interest.

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