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Using *Sorghum* to suppress weeds in dry seeded aerobic and puddled transplanted rice

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ABSTRACT

Weed infestation is one of the major problems in dry seeded aerobic rice (DSAR). Modern agriculture primarily relies on the use of synthetic herbicides for weed control in field crops. Nevertheless, overuse of these herbicides can lead to numerous health and environmental issues and the evolution of herbicide-resistant weed biotypes. The phenomenon of allelopathy may be valuable for overcoming this problem. In this study, we evaluated the potential of *Sorghum* allelopathy for managing weeds in rice grown in rotation with wheat, under two rice production systems (puddled transplanted (PudTR) and DSAR). *Sorghum* was planted in the last week of April and harvested during the second week of June. After the *Sorghum* harvest, rice was raised either as PudTR or DSAR. In addition, other allelopathic strategies were included as treatments: (a) *Sorghum* water extract (SWE) (18 L ha^{-1}), (b) *Sorghum* mulch (SM) (8 t ha^{-1}) and (c) SWE (18 L ha^{-1}) + SM (8 t ha^{-1}). The combined use of SWE and SM in DSAR grown after *Sorghum* reduced the weed population and total weed dry weight by 77% and 78%, respectively, when compared with the fallow–DSAR treatment. Similarly, the SWE + SM treatment in PudTR grown after *Sorghum* reduced the weed population and total weed dry weight by 74% and 84%, respectively, compared with the fallow–PudTR treatment. The *Sorghum*–DSAR plus SWE + SM produced the highest grain yield (4 Mg ha^{-1}) while the fallow–DSAR with no SWE or SM produced the lowest grain yield (2.15 Mg ha^{-1}). The improved weed management and grain yield by combining allelopathic approaches enhanced the profitability of both DSAR and PudTR. In crux, the application of SWE + SM has remarkable potential for reducing weed infestations and improving the yield and profitability in DSAR and PudTR.

1. Introduction

Poor stand establishment and heavy weed infestation during early growth are major obstacles to the large-scale adoption of dry direct-seeded aerobic rice (DSAR). Several seed enhancements and priming techniques have been standardised to ensure better germination and uniform crop stands (Du and Tuong, 2002; Harris et al., 2002; Farooq et al., 2006a, 2006b), leaving weed management a key issue for the sustainability of DSAR (Rao et al., 2007; Nawaz and Farooq, 2016). Thus, selection of a suitable weed control method can ensure effective management of the diverse weed flora in DSAR (Matloob et al., 2015), as the rice and associated weeds grow at the same time in DSAR. When the weeds and crop emerge at the same time.yield losses generally increase several-fold (Aldrich, 1987). As such, the productivity and profitability of DSAR solely rely on weed management (Rao et al., 2007; Antralinaa et al., 2015).

Various studies have reported that application of herbicides is a useful strategy for managing weeds in DSAR systems (Mahajan and Chauhan, 2013, 2015; Singh et al., 2016). Aside from herbicide application, the weed spectrum is affected by factors including variety selection, seeding date, stand establishment, and the source, method and timing of fertiliser application. Many pre-emergence and post-emergence herbicides such as thiobencarb, pendimethalin, oxyfluorfen oxadiazon, butachlor, nitrofen, bispyribac sodium, ethoxysulfuron, acetochlor, butachlor, and 2, 4-D (ester) can effectively control the diverse weed biotypes in DSAR crops (Pellerin et al., 2004; Rao et al., 2007; Nawaz and Farooq, 2016). Heavy use of herbicides may also result in the evolution of herbicide-resistant weeds (Duke et al., 2001; Heap,

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2014), as reported in DSAR crops in Malaysia, Korea and Thailand (Kumar and Ladha, 2011). In these countries, the weeds such as globe fringerush (*Fimbristylis miliacea* (L.) Vahl.), dwarf water clover (*Marsilea minuta* L.) and Shorea spp. (*Shorea zeylanica* (Thwaites) P. Ashton) have evolved resistance due to the continuous use of phenoxy and sulfonylurea herbicides (Watanabe et al., 1997).

The evolution of resistance in weeds against the synthetic herbicides and the presence of miscellaneous weeds (flora) in DSAR (Freitas et al., 2008) has forced scientists to find ecofriendly alternatives to managing weeds in this rice production system (Kumar and Ladha, 2011; Juraimi et al., 2013; Nawaz and Farooq, 2016). During the last two decades, researchers have focused on organic and environmentally friendly approaches to weed management to replace synthetic herbicide application (Jabran et al., 2015) in various crops including rice. For this purpose, plant water extracts have been tested and found effective for weed control in several field crops (Cheema et al., 1997, 2001, 2002; Wazir et al., 2011) including rice (Irshad and Cheema, 2004). Other allelopathic weed management strategies for weed control in various crops may involve crop mulches (Cheema et al., 2000), soil incorporation of crop residues (Matloob et al., 2010), or the inclusion of crops with allelopathic potential in crop rotations (Einhellig and Rasmussen, 1989).

Of the potential allelopathic crops, *Sorghum* is an effective plant which has allelopathic effects on other plants and weeds (Cheema et al., 2000, 2003, 2004; Alsaadawi and Dayan, 2009). In addition to being a potent natural weed inhibitor in wheat, application of *Sorghum* allelopathic water extract is useful for reducing weed flora in other field crops, e.g. rice and maize (Cheema et al., 2004; Irshad and Cheema, 2004). For instance, *Sorghum* aqueous extracts at 12 and 15 L ha^{-1}, applied as a pre-emergence spray, suppressed the density of purple nutsedge (*Cyperus rotundus* L.) by 31–56 and 35–52%, respectively (Iqbal and Cheema, 2008). In another study, weed populations decreased in crops following *Sorghum* due to the release of various allelochemicals (Einhellig and Rasmussen, 1989).

While previous studies have indicated a differential effect of *Sorghum* allelopathy on subsequent crops and weeds (Cheema and Khaliq, 2000; Cheema et al., 2004; Irshad and Cheema, 2004), there is no available information regarding the integrated use of these approaches to control weed infestations in rice grown using PudTR or DSAR methods. For this study, we hypothesised that the inclusion of *Sorghum* in rice-based crop rotations, followed by the combined use of SWE and SM, will suppress weeds in DSAR and PudTR. An economic evaluation of the integrated use of weed management strategies in rice grown in PudTR and DSAR systems is also an important aspect of this study.

2. Materials and methods

2.1. Site, soil and climate

This experiment was carried out at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan during the summers of 2013 and 2014. Before initiating the experiment, the soil samples up to a depth of 0.20 m were collected from different locations within the experimental plot. The soil samples were analysed for various soil properties (Table 1). The soil at the experimental site is from the Lyallpur soil series and is classified as Haplic Yermosol in the FAO soil classification system (FAO, 2014) and an aridisol-fine-silty, hyperthermic Ustalfic, mixed, Haplagrid in the USDA soil classification system (USDA, 2014). The climate in Faisalabad (the study site) is subtropical with mean temperatures varying from 6 °C to 21 °C in winter and 27 °C to 39 °C in summer. The average annual rainfall is –300 mm. Weather data for the experimental period is in Table 2.

2.2. Plant material

The seeds of *Sorghum* cultivar Jawar-2002 and rice cultivar Basmati-515 came from the Fodder Research Institute, Sargodha and the Rice Research Institute, Kala Shah Kaku, Pakistan, respectively. The seeds of wheat cultivar Punjab-2011 were obtained from the Wheat Research Institute, Faisalabad, Pakistan.

Table 1
Physico-chemical properties of the experimental soil.

Characteristics	Units	Values	Status
Physical analysis			
Sand	%	58	
Silt	%	30	
Clay	%	12	
Texture			Sandy loam
Chemical analysis			
pH		7.9	Medium alkaline
EC	dS m^{-1}	0.4	Non-saline
Exchangeable sodium (Na)	mmolc 100 g^{-1}	0.4	Normal
Manganese (Mn)	mg kg^{-1}	4.5	Deficient
Zinc (Zn)	mg kg^{-1}	0.3	Deficient
Iron (Fe)	mg kg^{-1}	4	Deficient
Total nitrogen (N)	%	0.04	Low
Available phosphorus (P)	mg kg^{-1}	5	Low
Exchangeable potassium (K)	mg kg^{-1}	140	Medium
Organic matter	%	0.51	Low

2.3. Experimental details

2.3.1. Treatment details

The experimental treatments were randomised in a split–split plot arrangement within the field with three replicates. Two cropping systems (wheat–fallow and wheat–*Sorghum*) were the main plots. The two rice production systems (DSAR and PudTR) were the subplots, while the *Sorghum* treatments (control, SM, SWE, and SWE + SM) were the sub–sub plots. The gross plot and net plot sizes of the sub–sub plots were 8 m × 2.8 m and 7 m × 1.8 m, respectively.

2.3.2. Field preparation and sowing

The experimental field had been under a rice–wheat rotation for the last five years. To sow the wheat and *Sorghum*, the field was cultivated twice using a tractor-mounted cultivator followed by planking each year. In both years, wheat was sown in 22.5 cm spaced rows with the help of a manual drill at a seeding rate of 125 kg ha^{-1} on 12 November in both 2012 and 2013. After the wheat harvest, half of area was planted to *Sorghum*, while the other half was kept fallow. Forage *Sorghum* was planted at a seeding rate of 75 kg ha^{-1} on 24 April 2013 and 27 April 2014 using a hand drill. After harvesting the *Sorghum*, the rice was planted in wheat-fallow and wheat-*Sorghum* cropping systems under PudTR and DSAR systems. First, the field was cultivated three times using a tractor-mounted cultivator and then levelled. DSAR was sown in 22.5 cm spaced rows at a seeding rate of 20 kg ha^{-1} on 20 June 2013 and 26 June 2014 using a hand drill. At the same time, rice was sown for the PudTR treatment in a nursery at a seeding rate of 0.5 kg 25.2 m^{-2} and transplanted (22.5 cm × 22.5 cm) in the field on 22 July 2013 and 29 July 2014. For PudTR before transplanting, puddling was done before transplanting. Puddling was achieved by ploughing, with a tractor mounted plough, and planking in standing water.

2.3.3. Preparation of *Sorghum* mulch and *Sorghum* water extract

Mature, harvested whole plants of *Sorghum* were dried and chaffed into 2–3 cm pieces using a fodder cutter and stored in the shade. This chaffed herbage was used to prepare the SWE for foliar application, or to spread between crop rows at 8 t ha^{-1} to act as mulch one week after sowing. To prepare 18 L of SWE, 2.5 kg of chaffed *Sorghum* herbage was soaked in distilled water in a 1:10 (w/v) ratio for 24 h, after which the extract was filtered. The prepared water extract was concentrated twenty times (Cheema et al., 2001) Twenty days after seeding/