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Influence of tillage, cover cropping, and herbicides on weeds and productivity of dry direct-seeded rice

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ABSTRACT

The adoption of dry direct seeding of rice in many Asian countries has resulted in increased interest among weed scientists to improve weed management strategies, because of the large and complex weed flora associated with dry-seeded rice (DSR). Tillage and cover cropping practices can be integrated into weed management strategies as these have been known to affect weed emergence for several ecological reasons. A study was conducted in the summer seasons of 2012 and 2013 at the Punjab Agricultural University, Ludhiana, India, to evaluate the effects of tillage, cover cropping, and herbicides on weed growth and grain yield of DSR. Most of the weed species (*Echinochloa crus-galli, Echinochloa colona, Eleusine indica*, and *Euphorbia hirta*) under study tended to populate the cover crop (CC) treatment more than the no-cover crop (no-CC) treatment. Zero tillage (ZT) resulted in higher weed densities of most of the weed species studied. The interaction effects of these treatments suggest that lesser herbicide efficacy in ZT and CC plots led to higher weed pressure and weed biomass. Grain yield was significantly higher in the conventional tillage system (2.40–3.32 t ha^{-1}), because of lesser weed pressure, than in ZT (2.08–2.73 t ha^{-1}). Almost all weed species increased in number and biomass production in the second year (2013) compared with the preceding year. Herbicide application (pendimethalin followed by bispyribac-sodium) alone, though significantly increased DSR grain yield over that of the unsprayed check, resulted in lesser grain yield compared with the weed-free check (5.07–5.12 t ha^{-1}) by 14% and 27% in 2012 and 2013, respectively. This was mainly due to the buildup of biomass by weeds that escaped from herbicide application. The study reveals that conservation practices such as ZT can form an important component of integrated weed management in DSR, provided that herbicide efficacy be improved by adjusting rate and time of herbicide application in such systems.

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1. Introduction

Rice is the world's most important crop, the staple food for more than half of the world's population. Worldwide, rice is grown on 161 million hectares (M ha), with an annual production of ~678.7 million tons (MT) of paddy (FAO, 2009). About 90% of the world's rice is grown and produced (143 M ha area with a production of 612 MT of paddy) in Asia (FAO, 2009). To meet global rice demand, it is estimated that about 114 MT of additional milled rice needs to be produced by 2035, which is equivalent to an overall increase of 26% in the next 25 years. The possibility of expanding the area under rice in the near future is limited. Therefore, the extra rice production has to come from productivity gain. The major challenge is to achieve this gain with less water, labor, and chemicals, thereby ensuring long-term sustainability.

The productivity and sustainability of rice-based systems are threatened by (1) the inefficient use of inputs (fertilizer, water, and labor); (2) increasing scarcity of resources, especially water and labor; (3) climate variability; (4) emerging energy crisis and rising fuel prices; (5) rising cost of cultivation; and (6) emerging socioeconomic changes such as urbanization, migration of labor, preference for non-agricultural work, and concerns about farm-related pollution (Ladha et al., 2009). Agronomic management and technological innovations are needed to address these issues in Asia.

In Asia, rice is commonly grown by transplanting seedlings into puddled soil (land preparation in ponded soil conditions). Puddling benefits rice by reducing water percolation losses, controlling weeds, facilitating easy seedling establishment, and creating anaerobic conditions to enhance nutrient availability (Sanchez, 1973). Repeated puddling, however, adversely affects the soil

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physical properties by destroying soil aggregates, reducing permeability in the subsurface layers, and forming hardpans at shallow depths (Aggarwal et al., 1995; Sharma and De Datta, 1985; Sharma et al., 2003), all of which can negatively affect the following non-rice upland crops in a rotation (Hobbs and Gupta, 2000; Tripathi et al., 2005). Moreover, puddling and transplanting require large amounts of water and labor, both of which are becoming increasingly scarce and expensive, making rice production less profitable. In the backdrop of declining water resources and reduced availability of labor, the conventionally flooded rice system is losing its sustainability and economic viability (Guerra et al., 1998; Bhushan et al., 2007). Declining water table, increasing costs of diesel and electricity, and climatic changes have further aggravated the problem (Vorosmarty et al., 2000; Rosegrant et al., 2002). Increasing labor cost and restricted supply of irrigation water have caused many Asian farmers to shift from manual transplanting of seedlings to direct seeding (Pandey and Velasco, 2005). Direct seeding of rice offers advantages such as faster and easier planting, reduced labor and drudgery, earlier crop maturity by 7–10 days, more efficient water use, higher tolerance for water deficit, lesser methane emissions, and often higher profit in areas with assured water supply (Balasubramanian and Hill, 2002). Direct seeding also eliminates the use of seedlings and related operations, such as seeding; nursery preparation; and care, pulling, bundling, transporting, and transplanting of seedlings (Serrano, 1975).

Weeds are a serious constraint to the productivity of dry-seeded rice (DSR) (Caton et al., 1999; Zhao et al., 2006; Singh et al., 2006; Rao et al., 2007; Sanusan et al., 2010) causing 100 per cent yield loss under uncontrolled conditions (Singh et al., 2014). There is an abundance of weeds of diverse nature in DSR fields (Sharma et al., 1977; Chin, 2001; Tomita et al., 2003; Singh et al., 2008; Kamoshita et al., 2010). Weeds grow more quickly in DSR than in transplanted-flooded rice and other crops (Karim et al., 2004; Begum et al., 2006; Chauhan and Johnson, 2009a; Kamoshita et al., 2010). These weeds severely disturb the growth of rice and sometimes result in crop failure (Phuong et al., 2005). The species composition of the accompanying weed flora may also change with management practices. Direct seeding of rice is known to be accompanied by a rapid shift in weed flora, with an increase in abundance of *E. crus-galli*,*E. colona*, *Ischaemum rugosum*, and *Leptochloa chinensis* and, on more freely draining soils, *Cyperus rotundus*. The ingression of annual grasses and perennial sedges presents particular weed management problems with continuous direct seeding. Different weed control practices have been evaluated to minimize weed pressure in DSR (Phuong et al., 2005; Chauhan et al., 2010). Application of herbicides effectively suppresses weeds and provides DSR a weed-free environment (Gitsopoulos and Froud-Williams, 2004). The use of only one method of weed control in a DSR crop, however, may not be enough to raise a successful crop.

In different production systems, DSR can be sown (direct-seeded) onto a prepared seedbed, after tillage or under zero-till (ZT) conditions (Rao et al., 2007). With dry direct seeding, fuel costs are further saved by sowing rice under ZT or reduced tillage conditions. In addition to reducing fuel and labor costs, these conservation tillage systems may reduce soil erosion, improve soil physical and chemical properties, and conserve soil moisture (Chauhan et al., 2006a). Changes in tillage practices, however, influence the vertical distribution of weed seeds in the soil (Chauhan et al., 2006b), and this may affect the relative abundance of weed species in the field (Froud-Williams et al., 1981). A large proportion of the weed seed bank remains on or close to the soil surface after crop planting in ZT systems (Chauhan et al., 2006b; Singh et al., 2015), which may promote greater emergence of weed species that require light to germinate. With conventional tillage (CONT), however, seedling emergence depends partly on the effect that tillage has on seed burial as deeply buried seeds may not be able to emerge. The soil disturbance caused by tillage systems places weed seeds at different depths, which differ in availability of moisture, diurnal temperature fluctuation, light exposure, and activity of predators. All these micro-environmental attributes have the potential to influence the behavior of weed seed banks. Further, cover crops that are usually not grown for harvest, serve many other benefits, such as enriching soil with organic matter, cycling of nutrients, and protecting the soil from wind and water erosion. Cover crops can also be a part of an integrated system to control weeds. Weed suppression varies with cover crop type and management, residue and tillage management, and weed populations. A particular combination of cover crop and management may suppress the emergence of particular weed species.

There is little research data available, however, in relation to the weed species occurring in rice under different tillage systems with cover crops. A trend toward reduced tillage is likely to continue and therefore research is needed to understand the effects of these factors on shifts in weed flora. This study was conducted to gather information on the performance of DSR under different tillage and cover crop conditions in association with chemical weed control through their effect on the occurrence of weed species and their competition with aerobic rice.

2. Materials and methods

2.1. Description of the experiment

A field study was conducted during the summer (kharif) seasons of 2012 and 2013 at the research farm of Punjab Agricultural University, Ludhiana, India. Soil at the site had a pH of 7.2, 80.5% sand, 8.6% silt, and 10.9% clay, with available N, P, and K of 251, 14, and 165 kg ha^{-1}, respectively. The study had two tillage systems: conventional tillage (CONT) and zero tillage (ZT) in combination with cover crop (CC) and without cover crop (no-CC) in the main plots, while six weed control treatments (WCT)–pendimethalin (0.75 kg ai ha^{-1}) as preemergence (PRE), followed by (fb) bispyribac-sodium (0.025 kg ai ha^{-1}) as postemergence (POST), oxadiargyl (0.09 kg ai ha^{-1}) as PRE fb bispyribac-sodium (0.025 kg ai ha^{-1}) as POST, oxadiargyl (0.09 kg ai ha^{-1}) as PRE fb fenoxaprop-*p*-ethyl with a safener (0.07 kg ai ha^{-1}) as POST and oxadiargyl (0.09 kg ai ha^{-1}) as PRE fb fenoxaprop-*p*-ethyl with a safener (0.07 kg ai ha^{-1}) as POST fb ethoxysulfuron (0.02 kg ai ha^{-1}) as POST along with unsprayed and weed-free checks in the subplots. The herbicides were applied using a knapsack sprayer that delivered around 500 L ha^{-1} spray solution for PRE and 375 L ha^{-1} for POST herbicides through a flat fan nozzle. The experiment was laid out in a split-plot design with three replications during both years. The size of the main plot was 15 m × 9 m, which was divided into six subplots, each of 2.4 m × 9 m. The cover crop of sesbania (*Sesbania aculeata*) was seeded at a rate of 50 kg ha^{-1} on May 7, 2012 and May 10, 2013, as per the treatment and was knocked down by a spray of paraquat at 300 g ai ha^{-1} 2 days before the sowing of rice. The field was prepared by giving four plowings (two with disc harrow and two with cultivator) and planking in CONT treatment. Sowing of rice was done with an inclined plate rice planter fitted with inverted blade-furrow openers. Rice (variety PR 115 with a duration of 125d) sowing was done on June 18, 2012 and June 22, 2013 at a seed rate of 25 kg ha^{-1}. P_2O_5, K_2O, and Zn were applied uniformly before the planking operation through diammonium phosphate (DAP), muriate of potash (MOP), and zinc sulphate ($ZnSO_4$) at 30, 30, and 13 kg ha^{-1}, respectively. Nitrogen was applied through urea in four equal splits of 37.5 kg N ha^{-1} each at 14, 28, 49, and 70 days after sowing (DAS). The field was surface-irrigated immediately

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