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Effects of crop establishment techniques on weeds and rice yield

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ABSTRACT

Field and pot studies were conducted to evaluate the effects of seven rice establishment techniques {puddling transplanting (PT), no tillage transplanting (NTT), puddling drum wet seeding (PDWS), no tillage drum wet seeding (NTDWS), conventional tillage dry drilling (CTDD), furrow irrigated raised beds system dry drilling (FIRBSDD), and no-tillage dry-drilling (NTDD)} and water submergence stress on weeds and rice yield. The highest yield and least weed abundance were in the PT treatment. The direct seeded rice (DSR), both dry and wet exhibited severe weed infestation, and compared to transplanting showed reduced yield both in the presence and absence of weeds. The yield losses due to weeds in the DSR treatments ranged from 91.4 to 99.0%, compared to 16.0 and 42.0% in the transplanting treatments (PT and NTT). Weeds, including *Cyperus rotundus* L., *Dactyloctenium aegyptium* (L.) Willd., *Digera arvensis* Forsk., *Phyllanthus niruri* L., and *Trianthema portulacastrum* L. which were found in the un-puddled DSR treatments were absent in the puddled plots, particularly the PT treatments. In pot studies, continuous water-submergence (2.5 cm) for 20 days reduced the emergence of *C. rotundus*, *D. aegyptium*, *T. portulacastrum*, and *Echinochloa crus-galli* (L.) Beauv. by 99.4, 100, 100, and 24.4%, respectively, compared to alternate wetting–drying. In farmer's field studies, when compared to the PT treatments, the DSR treatments exhibited lower yields (15.8%) with coarse varieties (HKR-47 & IR-64), but fine cultivars (Sharbati & PB-1) exhibited similar yields under both systems. In view of the shortage of labour for manual transplanting, there is a need to develop suitable cultivars for aerobic system conditions (unpuddled DSR and NT machine-transplanting).

1. Introduction

Rice (*Oryza sativa* L.), a staple food crop in India, is grown on 42.5 m ha, which is the largest area among rice growing countries and provides 29% of the caloric requirement in India (IRRI, 2014). Worldwide, it feeds about 50% of the population and provides 19% of the global calorie intake (IRRI, 2014). Therefore, sustaining and improving the production of rice is essential for global food security. In India, rice is mainly grown using a system known as puddling transplanting (PT). Puddling (wet tillage) is done to reduce water infiltration and to maintain the standing water in the field, which helps in weed management and facilitates easier transplanting (Sharma and De Datta, 1986). The depth of the water influences the type and density of the weed flora (Kent and Johnson, 2001; Kumar and Ladha, 2011). Besides water management, tillage can also influence weed emergence due to changes in the mechanical characteristics (bulk density, penetration resistance, aggregate mean weight diameter, and surface roughness) of the seedbed (Carman, 1996) as well as the vertical distribution of seeds in soil (Chauhan and Johnson, 2009). Puddled flooded soil has many other benefits such as neutralizing soil pH, improving the availability of plant nutrients (P, K, Ca, Mg, Mn, and Fe), and allowing for the accumulation of organic matter (Ponnamperuma, 1972; Sahrawat, 2005). Mainly, the indirect increase in the availability of nutrients by puddling is through the reduction of cation (e.g. NH^{4+}) leaching (Aggarwal et al., 1995). There is also the potential for biological nitrogen fixation through the use of blue-green algae (BGA) and Azolla in the PT system, which can save 20–30 kg N ha^{-1} (Singh and Bisoyi, 1989).

Some problems associated with puddling in rice are deterioration of the soil structure, creation of a hardpan (Sharma and De Datta, 1986), increased methane emissions, hydrogen sulphite

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formation (Ponnamperuma, 1972), increased bulk density, and soil compaction (Kirchhof et al., 2000). Moreover, puddling and transplanting also require large amounts of scarce water resources as well as labour (Kumar and Ladha, 2011). The puddling and rice transplanting operations consume about 25% of the total water required for rice during the growing season. The destruction of soil structure and formation of a hardpan during puddling may have adverse effects on the yield of subsequent non-rice crops in rotation, and these crops also require more energy for field preparation (Kumar and Ladha, 2011; Fujisaka et al., 1994). Based on a diagnostic survey in several rice-wheat system areas in South Asia, Fujisaka et al. (1994) observed low wheat yields in a rice-wheat system. Contrary to this, Singh et al. (2001) reported that puddling not only resulted in higher yields of rice, but also of subsequent wheat over non-puddling and saved 75 mm ha of irrigation water. The destruction of the soil structure due to puddling is not an irreversible process, and can be regenerated by alternate wetting and drying processes and tillage at optimum soil moisture conditions (Koenigs, 1961).

Low rice planting density (18–22 plants m^{-2}) in a manual random transplanting fashion against the recommended crop density of 33–35 plants m^{-2} is another major constraint encountered at the farmer level for achieving maximum rice yield potential. Considering the problems (low plant population, labour and water scarcity, as well as drudgery and cost) in manual transplanting, alternative rice establishment techniques are required. Direct seeded rice (DSR) can be an alternative to transplanting rice (TR) to offset the scarcity and drudgery of labour in manual transplanting (Kumar and Ladha, 2011). To resolve the problems associated with puddling, direct seeding or transplanting under unpuddled field conditions can be substituted. Under puddled conditions, if intense drought occurs shortly after transplanting, the puddled soil may shrink, crack, and impede rice root development, and these conditions do not arise in unpuddled fields (Mohanty et al., 2004). Also, dry DSR or transplanting under no tillage (NT) conditions may help in reducing the costs of rice production through reduction in tillage costs, and may be more environmentally sustainableFarooq et al., 2011). NT treatment has also been observed as a beneficial practice that conserves soil and water compared to conventional tillage treatment through improved infiltration and reduced evaporation (Kumar and Ladha, 2011).

In light of these facts, the present study was undertaken with the aims to evaluate the alternative crop establishment systems with respect to puddling transplanting, and also to determine the differences in weed flora as well as the extent of yield losses caused by weeds in different crop establishment systems.

2. Materials and methods

Studies were conducted at the Directorate of Wheat Research (DWR), Karnal (29° 43′N, 76° 58′E and 245 m above mean sea level), Haryana, India and at farmer's fields in the district of Karnal, Haryana, India during the *kharif* seasons (June to October) of 2004–2006. The soil of the DWR experimental field was a sandy loam with a pH of 8.2, organic carbon content of 0.41%, and bulk density of 1.57 Mg m^{-3}. The soil was low in N (165 kg ha^{-1}), contained intermediate levels of P (15.7 kg P_2O_5 ha^{-1}), and high levels of K (227 kg K_2O ha^{-1}). The details of the studies conducted are as follows.

2.1. Evaluation of crop establishment techniques in rice

An experiment involving seven crop establishment methods, [puddling transplanting (PT), no tillage transplanting (NTT), puddling drum wet seeding (PDWS), no tillage drum wet seeding (NTDWS), conventional tillage dry drilling (CTDD), furrow irrigated raised beds system-dry drilling (FIRBSDD), and no tillage dry drilling (NTDD)] in the main plots and two weed control treatments (weedy and weed free) in the subplots was conducted in split plot design for two *kharif* seasons of 2004 and 2006. In the weedy plots, weeds were allowed to grow till crop harvest. The weed free plots were maintained by hand weeding for direct seeding, and for the transplanted plots (either NT or puddled), butachlor @ 1250 g ha^{-1} was applied 1–2 days after transplanting to control weeds. The weeds which escaped the herbicide application were manually removed at weekly intervals. Each treatment was replicated thrice and the subplots were of 20 m^2, except for the FIRBS treatment which was 28 m^2. For the CTDD and the FIRBSDD treatments, the fields were prepared at optimum moisture conditions using two passes of harrow, one planking, two passes of rotary tillers, and one planking in a sequence. For the PT and the PDWS treatments, at optimum soil moisture conditions the plots were prepared using two passes of harrow and rotary tiller, followed by flooding to maintain about 10 cm of standing water, and thereafter puddling was done using two passes of cultivator followed by two passes of rotary tiller. A high yielding short duration coarse rice cultivar HKR 47 was grown in this experiment. In direct seeding, a seed rate of 40–45 kg/ha was sown using a zero-till seed-cum-fertilizer drill (flat seeding *i.e.* the NTDD and the CTDD treatments) and a DWR bed planter (FIRBSDD) at a depth of about 2–2.5 cm. The seeding was done in the 2nd–3rd week of June. The plots were irrigated immediately after seeding. In the FIRBDD treatment, three rows were sown on the beds (centre of furrow to centre of furrow, 70 cm apart and to the top of the bed around 40 cm wide). In the flat seeding treatments (NTDD and CTDD) the row to row (R × R) distance was 20 cm. In the drum seeding treatment, pre-sprouted seeds were dropped in lines using a drum seeder at a R × R spacing of 20 cm. In the NTT treatment the plots were irrigated twice, 2–3 days before transplanting to soften the soil for transplanting. In the transplanting treatments (NTT and PT), one month old seedlings were transplanted at a spacing of 20 × 15 cm. In no tillage (NT) plots, pre-seeding glyphosate at a concentration of 0.5% (350 lit ha^{-1} of spray solution) was applied 3–4 days before seeding/transplanting to control the germinated weeds.

Fertilizer (150 kg N, 60 kg P_2O_5, 40 kg K_2O, and 25 kg $ZnSO_4$ ha^{-1}) and flood irrigations (6–7 cm each) were applied according to standard rice production recommendations. The weed dry weight was recorded by placing a quadrat of 50 × 50 cm randomly at two places in each plot at 80–85 days after sowing (DAS)/days after transplanting (DAT). The crop was manually harvested and after threshing the grain yield was recorded. The data were subjected to analysis of variance (ANOVA) and analysed using the general linear model procedure of the Statistical Analysis System (SAS, version 9.2). Weed dry weight data were analysed in a randomized block design by considering only the weedy treatments, however the yield data were analysed using a split-plot design. The treatment mean values were separated by Fisher's protected least significant difference (LSD) test at $P \leq 0.05$.

2.2. Performance of the dry DSR at the farmer's field

The performance of dry DSR (CTDD) was compared with the PT rice at 8 field locations [Village Nidana ($n = 2$), Darar ($n = 1$), Kalron ($n = 2$), Chopri ($n = 1$), Narukheri ($n = 1$), and Arianpura ($n = 1$)] in the district of Karnal, Haryana, India. At each location, 0.4 ha area was divided into two parts. Direct seeding was done in an area of 1000–2000 m^2 and in the rest of the block the puddling transplanting treatment was imposed. The coarse rice cultivar HKR 47 or IR 64 ($n = 8$), and a fine to medium fine rice cv. Sharbati or PB-1 ($n = 3$) were used for comparing the performance under direct