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Field Crops Research 95 (2006) 367–382
Field Crops Research
www.elsevier.com/locate/fcr

Water balance and rice growth responses to direct seeding, deep tillage, and landscape placement: Findings from a valley terrace in Nepal

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Received 1 November 2004; received in revised form 30 March 2005; accepted 16 April 2005

Abstract

For maximizing water retention and attaining high yields, transplanting into puddled soil (TPR) is often considered the optimal method of rice (*Orzya sativa* L.) establishment. Alternative management techniques like direct seeding (DSR) and deep tillage have been proposed as mechanisms to improve soil physical properties for subsequent dry-season crops, but the risks to rice are uncertain. In this full factorial study on a valley terrace in Nepal, the influence of tillage (shallow—T_1, deep chisel—T_2, deep chisel + moldboard plough—T_3) and establishment practice (TPR, DSR) on the field water balance and rice performance were evaluated in two adjacent landscape settings (terrace edge ''upland'', central terrace ''lowland''). Although deep tillage had only modest influences on seepage and percolation (SP) rates in both years (Y_1, Y_2), landscape placement and establishment practice had significant implications for the water balance (e.g. Y_2 SP cm day^{-1}: TPR-lowland = 1.6, DSR-lowland = 2.3, TPR-upland = 4.1, DSR-upland = 6.1). During low rainfall periods, however, soil water potential and drought vulnerability were governed solely by landscape placement. Despite water balance differences, there was little evidence that rice rooting behavior was substantially modified by landscape or establishment method. Weed biomass was higher in DSR, but was uncorrelated with water balance and productivity trends. In Y_1, lower SP rates and more days with continuous flooding were positively associated with rice productivity. DSR yields were significantly lower than TPR in both landscape positions, with the lowland outperforming the upland (Y_1 mt ha^{-1}: TPR-lowland = 6.4, DSR-lowland = 5.2, TPR-upland = 5.7, DSR-upland = 4.7). To determine if N dynamics were contributing to productivity differences, fertilizer nitrogen was increased from 120 to 150 kg N ha^{-1} in Y_2. Results suggest that DSR performance is comparable – and landscape less important – if nitrogen is non-limiting (Y_2 mt ha^{-1}: TPR-lowland = 6.9, DSR-lowland = 6.5, TPR-upland = 7.0, DSR-upland = 6.5); no aspect of the field water balance was associated with yield variability in Y_2. For direct seeding in N-deficient farming systems, landscape criteria may prove useful for minimizing production risks by identifying field areas with lower SP rates.

Keywords: Transplanted rice; Water relations; Water balance; Drought stress; Root distribution; Weed competition; Nitrogen dynamics

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doi:10.1016/j.fcr.2005.04.006

1. Introduction

In Nepal, Upadhyaya (1996) estimates that over 90% of the land area devoted to rice cultivation is seasonally inundated and the dominant establishment technique in these areas is transplanting into puddled soil (TPR). Most experimental evidence suggests that TPR is valuable for resource use efficiency, yield stability, and high productivity, primarily by conserving water and nutrient resources while reducing weed pressure (e.g. Sanchez, 1973; DeDatta and Barker, 1978; Naklang et al., 1996; Surendra et al., 2001). For areas with mono-modal precipitation distribution where dryland crops like wheat are cultivated after rice, direct seeded rice (DSR) may create favorable soil physical conditions for subsequent crops, thereby optimizing total system productivity (Hobbs et al., 1994; Timsina and Connor, 2001). DSR also can reduce the labor requirement for establishment by transferring field activities to periods when labor costs are comparatively low (Pandey and Velasco, 1999), providing additional impetus for adoption. The site-specific appeal of unconventional rice cultural practices is contingent not only on the growth benefit accrued to subsequent crops but also the risks posed to rice. Rice evolved as a semi-aquatic species with facultative root aerenchyma that facilitate aerobic respiration in flooded soils (Norman et al., 1995). Consequently, rice is significantly more sensitive to water deficit than other grain crops (e.g. Angus et al., 1983; Tanguilig et al., 1987; Inthapan and Fukai, 1988). During the summer monsoon, the confluence of shallow groundwater and surface flow elements periodically create the inundating conditions that define the prime rice growing areas in Nepal; less than a quarter of these areas are serviced by irrigation from assured sources, and drought stress during low rainfall periods is identified as a primary production constraint (Upadhyaya, 1996). Hence, water conservation is considered essential for yield stability and optimization.

In preparation for rice transplanting, wet tillage (i.e. soil puddling) reduces macropore volume in the upper portion of the soil profile while increasing bulk density in a compacted horizon that is alternately termed the plough sole or tillage pan (Ghildyal, 1978; Sharma and DeDatta, 1985; Adachi, 1990; Aggarwal et al., 1995; Bhagat et al., 1999). Tuong et al. (1994) demonstrated the importance of these changes to the soil's hydraulic properties by keeping small portions (ca. 1.5%) of a rice field unpuddled; uniformly puddled companion fields had lower seepage and percolation (SP) rates by a factor of five (2.7–15 mm day^{-1}). At a different site, DeDatta et al. (1973) report SP increases from 3.4 to 9.3 mm day^{-1} with the adoption of non-puddled establishment methods. On coarse textured soils, other findings suggest that wet tillage has less significant consequences, decreasing SP rates on the order of 50% (Kukal, 2002).

Limiting percolation losses and retaining a saturated soil profile may confer several advantages to rice. Ponding water increases in situ storage capacity, hedging against periods of limited rainfall. Consistent flooding also inhibits the establishment and growth of many weeds (DeDatta et al., 1973; Sahid and Hossain, 1995). Perhaps most importantly, consistent flooding can have substantial consequences for nutrient form, availability, and loss (Wade et al., 1998). Maintenance of reducing conditions prevents oxidation of ammonium (NH_4^+) and this form of N is largely retained against leaching (DeDatta, 1981; Kirk et al., 1994); although a fraction of this N pool can volatize as NH_3, especially when pH is high (Loomis and Connor, 1992). Some evidence suggests that chemical transformations in flooded soil increase phosphorous availability (Ponnamperuma, 1978; Neue and Bloom, 1987; Willet, 1991), but this may not hold beyond the first days after submergence (Kirk et al., 1998). Persistent flooding can also increase the plant-available stocks of potassium, calcium, silicon, and iron in the soil (DeDatta, 1981). Further, losses of soluble nutrients from the root zone are inhibited by the lowered floodwater export rates achieved with TPR (Kudeyarov et al., 1989).

Despite these advantages, TPR systems do entail uncertainty. If the main monsoon rains arrive late or fail altogether, timely crop establishment is often compromised and older seedlings demonstrate poor resilience to the stress of transplantation with reduced tillering and delayed maturation ((DeDatta, 1981; Torres and Liboon, 1994). Lagged development increases the damage probability from drought if anthesis and grain fill extend beyond the principal monsoon rains (Ekanayake et al., 1989; Boonjung and Fukai, 1996). Contributing to drought vulnerability,