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Improvement of rice (*Oryza sativa* L.) growth in upland conditions with deep tillage and mulch

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Abstract

The productivity of upland rice in Japan as well as in the world is low and unstable owing to scarce and unpredictable rainfall. The objective of this study was to examine whether agronomic methods could enhance grain yield of upland rice. Four field experiments were conducted from 2001 to 2003 in Nishitokyo, Japan, under upland conditions with different water supplies, in order to quantify the effects of deep tillage combined with deep placement of manure (50-cm depth), straw mulch (6 t ha^{-1}), or their combinations on the growth and grain yield of rice. Mulch kept surface soil moisture higher than without mulch even at reproductive stage, and it increased yield to the greatest extent under the most favourable conditions with much rainfall before heading (i.e., 2003). Deep tillage with deep placement of manure induced deep root proliferation and higher nitrogen uptake, increasing biomass production, and panicle number, and consequently grain yield was enhanced under the two lowest yielding environments with less rainfall before heading. Rice plants with deep tillage with deep manure application without mulch tended to have lower leaf water potential and higher diffusion resistance during drought, and negative effects on grain filling and harvest index in some experiments compared with the control. When deep tillage with deep placement of manure was combined with mulching in two experiments in 2002 and 2003, grain yield always enhanced compared with the control ($P < 0.10$, 6.0 t ha^{-1} versus 5.4 t ha^{-1} on average), suggesting their synergetic mechanisms for yield increase and stabilization. The results showed that deep tillage or mulching can improve grain yield of rice under drought-prone rainfed upland conditions in a temperate climate on an Andosol, and their combination had more consistent and greater positive effects.

Keywords: Upland rice; Grain yield; Deep root; Nitrogen uptake

1. Introduction

Upland rice (*Oryza sativa* L.) is grown in Asia, Africa, and Latin America, and accounts for 13% of the total world rice area (IRRI, 2002). Annual rainfall in these areas ranges from 1200 to more than 3500 mm. But erratic rainfall frequently causes drought effects during times of growth, and results in low and unstable yields of upland rice (1–2 t ha^{-1}), compared with irrigated lowland rice (more than 5 t ha^{-1} on average). Rice is more susceptible to drought than other crops owing to its shallow root system (Angus et al., 1983;

Abbreviations: CT, conventional tillage; CTM, conventional tillage with mulch; DAS, days after sowing; DRL, deep root length; DRW, deep root weight; DT, deep tillage; DTM, deep tillage with mulch; LAI, leaf area index; N, nitrogen; RU, rainfed upland; TDM, total above ground dry matter; TRL, total root length; TRW, total root weight; WD, water deficit upland condition during panicle-formation stage

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Fukai and Inthapan, 1988a,b; Kondo et al., 2000). In rice production, soil water deficit reduces biomass not only through the decline in soil water extraction and transpiration (Puckridge and O'Toole, 1981; Lilley and Fukai, 1994), but also through a nitrogen (N) deficit associated with difficulty of access to nutrients due to low soil moisture (Prasertsak and Fukai, 1997; Khunthasuvon et al., 1998; Kato et al., 2006). Therefore, it is necessary for upland rice to maintain water and nutrient uptake under conditions of soil water deficit in order to maximize its productivity.

Many efforts have been made to genetically improve the ability of upland rice to capture water and nutrients, focusing on the role of the deep root system (Ekanayake et al., 1985; Price and Courtois, 1999; Price et al., 2002a). In comparison, fewer studies have examined yield improvements through agronomic manipulations (Kondo et al., 2000). The depth of a root system, whether it is defined by the absolute amount of deep roots or their proportion or distribution in the soil profile, is greatly affected by environmental factors (O'Toole and Bland, 1987; Hoad et al., 2001) such as soil moisture (Azhiri-Sigari et al., 2000; Price et al., 2002b; Kamoshita et al., 2004), nutrient (N and P) availability (Drew, 1975; Granato and Raper, 1989), and soil hardness (Atwell, 1990; Bushamuka and Zobel, 1998). Hence, simultaneous characterization of the rhizosphere environment and the root system in fields is needed, as root growth at one site is likely to differ from that at other sites or from that in pot experiments (Kondo et al., 2003).

The rhizosphere environment in a target field can be manipulated by various agronomic methods, so improvement of root and shoot growth should be achievable. Mulching (Gill et al., 1996; Tolk et al., 1999) and deep tillage (Unger, 1979; Varsa et al., 1997; Díaz-Zorita, 2000), for example, have been suggested to improve crop production through enhancing water and nutrient uptake under drought conditions. Mulch relieves water stress by reducing evaporation from the soil and keeping the surface soil moist during dry spells (Hillel, 1980; Ji and Unger, 2001). On the other hand, deep tillage can remove a hardpan with as much as 3 MPa of mechanical impedance, which often develops just below ploughing depth in upland rice fields (Price et al., 2002a). Hardpans prevent roots of many upland crops from penetrating into the deeper soil layer (Atwell, 1990; Unger and Kaspar, 1994). The positive effects of deep tillage on upland rice production might be enhanced during soil water deficits by maintaining both water uptake and nutrient uptake (when combined with deep placement of fertilizer).

The objective of this study was to assess agronomic methods that might enhance and stabilize upland rice production. Among the methods, we confirmed the effects of mulch and deep tillage with deep placement of manure, and their interactive effect on the growth of upland rice in a temperate climate in an Andosol field.

2. Materials and methods

2.1. Experimental site and climatic conditions

The experiments were conducted at the Field Production Science Center of The University of Tokyo at Nishitokyo, Japan (latitude 35°43′N, longitude 139°32′E) in three summer seasons (April–October) from 2001 to 2003. The soil was a volcanic ash soil of the Kanto loam type (Humic Andosol). The topsoil layer (0–35 cm) was a dark, humic silty loam, and the subsoil layer (below 35 cm) was a red-brown silty clay loam (Yamagishi et al., 2003). The soil chemical and physical properties of the experimental site were previously measured by Takai et al. (1982) and Imoto (unpublished data). Topsoil properties are: pH_{H_2O}, 5.83; total C, 58.8 g kg^{-1}; total N, 4.4 g kg^{-1} (Takai et al., 1982); volumetric soil water content at field capacity (pF 2.0), 0.55 cm^3 cm^{-3}; volumetric soil water content at permanent wilting point (pF 4.2), 0.26 cm^3 cm^{-3}; bulk density, 0.77 g cm^{-3} (H. Imoto, unpublished data). Subsoil properties are: pH_{H_2O}, 6.37; total C, 20.2 g kg^{-1}; total N, 1.4 g kg^{-1} (Takai et al., 1982); volumetric soil water content at field capacity (pF 2.0), 0.65 cm^3 cm^{-3}; volumetric soil water content at permanent wilting point (pF 4.2), 0.48 cm^3 cm^{-3}; bulk density, 0.50 g cm^{-3} (H. Imoto, unpublished data). The field was flat and run-off was not likely to occur.

Climatic data for the experimental periods at the experimental site are summarized in Table 1. Rainfall from July to mid-August was very scarce in 2001 (e.g., only 15 mm in July) and there were two dry spells (defined as more than 10 successive days with no rainfall) in July. In 2002, there were two dry spells in August. The year 2003 was the most favourable year in terms of rainfall distribution and volume, especially until heading (i.e., 431, 622, and 794 mm in 2001, 2002, and 2003, respectively), although there were two dry spells in September. Therefore, we can characterize water availability among 3 years in terms of timings of dry spells and the amount of monthly rainfall (Table 1); severe drought in July in 2001, mild drought in August in 2002, and mild drought in September in 2003. Mean air temperature and total solar radiation were low in July and August 2003.