Agriculture, Ecosystems and Environment 251 (2018) 149–157

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Direct-seeded rice increases nitrogen runoff losses in southeastern China

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ARTICLE INFO

Keywords:
Rice production
Nitrogen losses
Runoff
Direct seeding
Transplanting

ABSTRACT

recent years, alternative rice cultivation methods have been widely developed in Asia, and the environmental consequences of these practices on nitrogen (N) runoff losses from intensively cultivated rice fields deserve attention. A two-year field experiment (2013–2014) was conducted in a rice field in southeastern China to evaluate the N losses in runoff resulting from four rice cultivation

methods: (1) conventional, manually transplanted seedling rice (CTSR); (2) mechanically transplanted seedling rice (MTSR); (3) dry direct-seeded rice (DDSR); and (4) wet direct-seeded rice (WDSR). Runoff volumes; runoff concentrations of NH_4^+-N, NO_3^--N, and total N (TN); N uptake; and grain yield were measured. The seasonal runoff volumes varied from 775 to 2397 $m^3\ ha^{-1}$ in 2013 and 2014. Compared with CTSR, WDSR and DDSR significantly increased the total runoff volumes by 76% and 30%in 2013, and by 46% and 26% in 2014, respectively. The seasonal TN losses in runoff from the rice fields ranged from 1.99 to 10.18 kg N ha^{-1}, accounting for 0.74–3.77% of the seasonal N input during the two years. In contrast with CTSR, WDSR increased TN losses by 169% in 2013 and by 143% in 2014, while DDSR increased TN losses by 31% in 2013 and by 84% in 2014. Direct-seeded rice significantly increased runoff N losses during the early growth period largely by increasing runoff volumes and/or the N concentrations in runoff water. The main forms of N lost in runoff were NH_4^+-N for CTSR, MTSR and WDSR and NO_3^--N for DDSR. The grain yield, N uptake at mid-tillering and panicle initiation stages were similar in WDSR and DDSR and significantly lower than those under CTSR and MTSR. The results show that direct-seeded rice increased N runoff losses from intensively cultivated rice fields in southeastern China.

1. Introduction

Rice is a staple food crop worldwide, with an annual planting area of 158 million hectares (Mha), concentrated in Asia (FAO, 2009). In recent years, rice cultivation methods have changed greatly in China and South Asia due to the shortage of rural labor combined with an increase in labor costs (Farooq et al., 2011; Luo et al., 2016). For example, in China, rice was commonly grown by manually transplanting nursery seedlings into puddled soil prior to 2000 (Zhang, 2007), but in 2015, the areas using mechanically transplanted seedling rice (MTSR) and direct-seeded rice (both dry direct-seeded rice (DDSR) and wet direct-seeded rice (WDSR)) accounted for approximately 40% and 30% of the total 30.2-Mha rice-planting area, respectively (Luo et al., 2016). Meanwhile, algal blooms occur frequently in some lakes in southeastern China, and surface water eutrophication is becoming a serious environmental and social problem in both China and the rest of the world (Le et al., 2010). Nitrogen (N) runoff losses from rice fields have been identified as one of the main causes of the eutrophication of lakes in the lower reaches of the Yangtze River in southeastern China (Le et al., 2010; Liu and Qiu, 2007), which are dominated by rice production. Rice fields are intensively fertilized to achieve high grain yields in this region, where the application rates of N fertilizer have reached or exceeded 300 kg ha^{-1} (Lin et al., 2007; Peng et al., 2006; Zhu and Chen, 2002) and account for the largest proportion of the N load in the surrounding water systems (Linquist et al., 2014; Zhao et al., 2009). During a single rice growing season, the total N (TN) runoff from rice fields ranged from 0.12 to 65 kg N ha^{-1}, with an average of 12.7 kg N ha^{-1} (Chen et al., 2015; Guo et al., 2004; Liang et al., 2013; Qiao et al., 2012; Tian et al., 2007; Xue et al., 2014; Zhao et al., 2012, 2015), depending on the year and amount of N fertilizer applied (Kim et al., 2006; Linquist et al., 2014). As a result, some alternative agricultural practices have already been explored to reduce the N runoff

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http://dx.doi.org/10.1016/j.agee.2017.09.022
Received 14 February 2017; Received in revised form 22 September 2017; Accepted 23 September 2017
Available online 05 October 2017

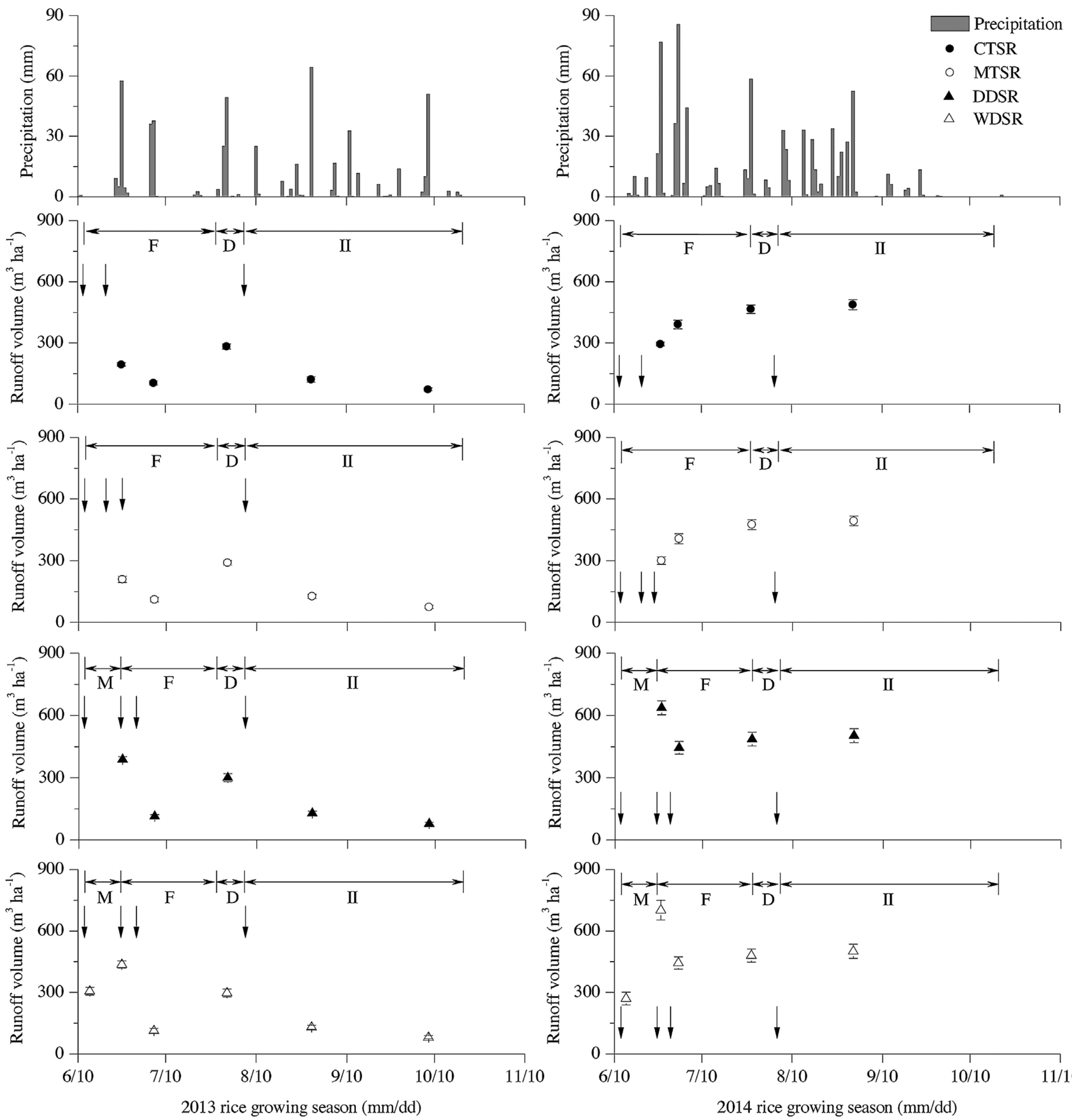

Fig. 1. Precipitation and runoff volume associated with conventional manually transplanted seedling rice (CTSR) and mechanically transplanted seedling rice (MTSR) under F-D-II (F, flooding; D, drainage; II, intermittent irrigation), dry direct-seeded rice (DDSR) and wet direct-seeded rice (WDSR) under M-F-D-II (M, moist but not saturated; F, flooding; D, drainage; II, intermittent irrigation) water regimes during the experimental period in 2013 and 2014. The vertical bars represent the standard deviation for each mean value (n = 4). Arrows denote fertilization.

losses to the environment while maintaining high rice production (Liang et al., 2013; Qiao et al., 2012; Wang et al., 2015; Xue et al., 2014; Zhao et al., 2015), but there has been limited research evaluating rice cultivation methods with the potential to mitigate N loss through surface runoff from rice fields (Farooq et al., 2011).

Rainfall and fertilizer application are the key factors that influence N runoff losses from rice fields (Guo et al., 2004; Yoshinaga et al., 2007; Chen et al., 2017a). In general, surface runoff occurs after heavy rainfall events or during the artificial drainage of fields (Kleinman et al., 2006; Zhao et al., 2012), and the N concentration in the surface water remains very high for 7–10 days after fertilizer application (Davis et al., 2016; Qiao et al., 2012; Zhao et al., 2012). Hence, previous studies related to the mitigation of N runoff losses from rice fields mainly focused on decreasing runoff volumes and/or the N concentration in runoff water. For example, replacing conventional flooding with water-saving practices can decrease the amount of N runoff losses (Gao et al., 2002), and Liang et al. (2013) reported that alternate wetting and drying irrigation reduced N runoff losses by 20–30% by lowering field water levels, which increased the field buffering capacity and decreased the number and volume of runoff events and the corresponding N losses. Using controlled-release fertilizer (Wang et al., 2015; Zhao et al., 2015) and adopting optimized N fertilization (Qiao et al., 2012; Xue et al., 2014) can also significantly decrease N runoff losses, as these agricultural practices can lower the concentration of N in surface runoff. Furthermore, the combination of water-saving practices and optimized N fertilization has been shown to reduce N runoff losses by 40–50% by decreasing both runoff volumes and N concentrations (Liang et al., 2013).

Each rice cultivation method requires a series of supporting agronomic techniques to maintain high yields, particularly the water regime