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Interaction of deep placed controlled-release urea and water retention agent on nitrogen and water use and maize yield

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ABSTRACT

Controlled-release urea has been widely adopted to increase nitrogen (N) use efficiency and crop production, and these effects can range widely depending on water availability in soil. However, limited information is available on the interaction of controlled-release urea placement depth with water retention agent (WRA) on N and water use and the yield of crops. The objectives of this study were to assess the consequences of this interaction on N and water use and the maize (*Zea mays* L.) yield by a split-plot design with WRA as the main plots and five application methods of urea as sub-plots. The five application methods consisted of inter-row side dressing of conventional urea at 5 cm and 10 cm depths, inter-row side dressing of controlled-release urea at 5 cm and 10 cm depths, and deep placement of the controlled-release urea at a 15 cm depth. Soil water stocks, dry matter accumulation, 1000-grain weight, grain-filling rate, N and water use efficiencies, and economic benefits were evaluated. The results revealed that the year, WRA, urea, and their interactions had significant effects on N and water use efficiencies, yield and benefits. When controlled-release urea was placed deep, soil water stocks were higher from the male tetrad stage to maturity and evapotranspiration (ETα) increased. Deep placement of controlled-release urea at a 15 cm depth without WRA enhanced the agronomic efficiency of N and water. The yield and net income were increased compared with controlled-release urea at a 5 cm depth. The combination of WRA and deep placement of controlled-release urea at a 15 cm depth had a significant effect on water use efficiency. However, this combination had no significant effects on N use efficiency, yield and benefits. WRA used with conventional urea can maintain higher soil water stocks, and increase the dry matter production, grain-filling rate, N and water use efficiencies. The differences were more significant during the dry season. Conventional urea at a 10 cm depth with WRA enhanced N and water use efficiencies, yield and net income by 6.5, 3.2, 6.5 and 4.2% respectively when compared with conventional urea without WRA. Thus, the best solution to obtain higher yield, water and N use efficiencies, and net income is placing controlled-release urea at 15-cm depth without WRA. When controlled-release urea is not available, placing conventional urea at a 10-cm depth combined with WRA is an interesting alternative for farmers.

1. Introduction

Increasing crop productivity and resource use efficiency, including nitrogen (N) and water, are globally pertinent for ensuring food security and improving environment quality (Al-Kaisi and Yin, 2003; Li et al., 2009; Lal, 2013). Increasing the use efficiency of N and water can reduce risks of soil and groundwater pollution by reducing transport of N (Li et al., 2009; Ferrant et al., 2013), while alleviating water shortage (Wallace 2000; Hu et al., 2013). Globally, fresh water resources are under pressure to reduce water consumption (Fereres and Evans, 2006; Zhang et al., 2014). The annual contribution of nonrenewable groundwater extraction to irrigation is largest in India (68 km^3) followed by Pakistan (35 km^3), the United States (30 km^3), Iran (20 km^3), China (20 km^3), Mexico (10 km^3), and Saudi Arabia (10 km^3), which has globally more than tripled from 1960 to 2000 (Wada et al., 2012). Thus, increasing the use efficiency of N and water is a global priority (Hvistendahl, 2010;

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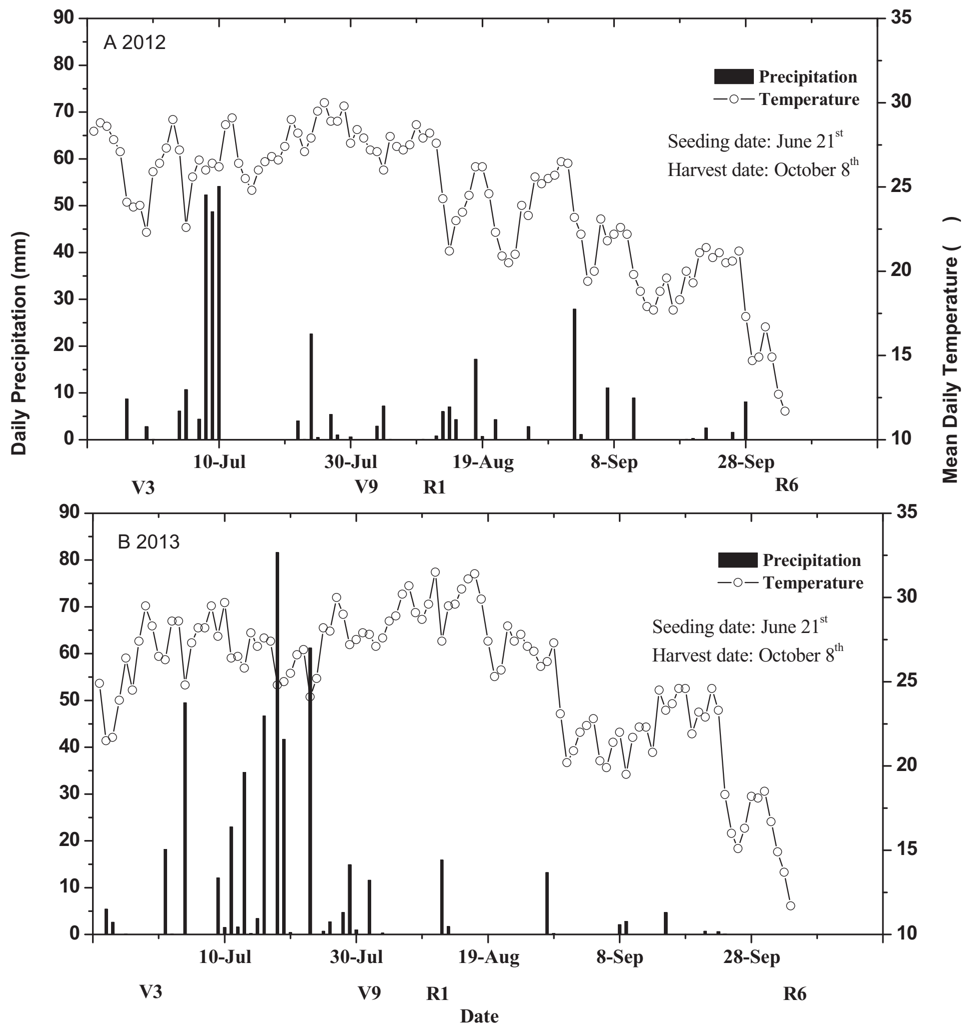

Fig. 1. Daily precipitation and mean temperature during the maize growth seasons in 2012 and 2013. V3, V9, R1, and R6 represent the 3-leaf, male tetrad, anthesis, and physiological maturity stages.

Ning et al., 2012). Moreover, water and N have significant coupling effects for producing high yields (Zhou et al., 2011; Ye et al., 2013). Thus, comprehensive management of water and N is essential for enhancing use efficiency of these precious resources.

Numerous studies have documented that the formulation of urea and their application methods can affect N use efficiency (NUE). The application of controlled-release urea, which occurs by coating urea pellets with a membrane that serves as a diffusion barrier, can release N gradually to coincide with the N demand of the crop (Kirda et al., 2005; Grant et al., 2012; Ye et al., 2013). This technique also reduces the risks of environmental pollution resulting from N losses (Shaviv 2001; Zhu et al., 2012), and significantly increases the yield and NUE of maize (Chu et al., 2007; Shao et al., 2013). The dry matter accumulation in maize with controlled-release urea is reduced before but increased after anthesis compared with that of conventional urea (Shao et al., 2013). Controlled-release urea can increase the maize yield by 5–15% compared with conventional urea (Hu et al., 2013). Deep placement of N fertilizer can strongly increase NUE by reducing losses from N runoff, and increase the yield (Zeng et al., 2008; Li et al., 2009). Larson et al. (1960) observed that fertilizer placed deep in the subsoiled channel was not as effective as conventional urea that is plowed under the soil. Using controlled-release urea in conjunction with subsoiling can increase N and water use as well as the grain yield of different varieties of maize (Hu et al., 2013).

Water retention agents (WRA) are structurally cross-linked hydrophilic polymers that have the ability to absorb considerable amounts of water or aqueous fluids (1000 times of their original weight or volume) in relatively short periods of time (Mikkelsen, 1994). These polymers can increase soil available water-holding capacity and improve crop yield (Busscher et al., 2009; Yu et al., 2012; Li et al., 2014). The use of hydrophilic polymer materials as carriers and regulators of nutrient release can minimize undesired fertilizer losses and sustain plant growth (Mikkelsen, 1994; Zheng et al., 2009). WRA can enhance efficient and eco-friendly production of crops because it will finally decompose to carbon dioxide, water, ammonia, and potassium ion, without any residue (Islam et al., 2011).

Synchronization of N and water application is important in improving N and water use efficiencies and minimizing the risks of environmental pollution (Al-Kaisi and Yin, 2003; Galloway et al., 2008; Hvistendahl, 2010; Ning et al., 2012). The interaction between WRA and ordinary N fertilizer can improve N uptake and minimize N loss (He et al., 2007; Eneji et al., 2013). Nonetheless, the interaction between placement methods of WRA and urea, especially those involving controlled-release urea, have not been widely studied. Therefore, the objectives of this study were to evaluate the combined effects of different urea placement methods, including controlled-release urea and conventional urea, and WRA on N and water use and maize yields. The study was specifically designed to