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A sowing method for subsurface drip irrigation that increases the emergence rate, yield, and water use efficiency in spring corn

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ABSTRACT

Subsurface drip irrigation is an advanced water-saving irrigation method. However, as a result of driplines being buried below the plow layer, sprinkler systems are usually used to ensure crop germination in arid and semi-arid regions. This study proposed a sowing method called alternate row/bed planting with a 10 cm deep trapezoidal furrow; seeds were then sown in 5 cm deep soil below the furrow bottom. A series of field experiments were conducted, including two sowing methods, namely alternate row/bed planting (AP) and flat planting (FP), at two dripline burial depths (30 (D30) and 35 cm (D35)). The following results were obtained: AP significantly increased the 5 cm soil depth moisture content below the seeds. The emergence rates at burial depths of 30 and 35 cm under AP increased by 15.2% and 9.5%, respectively, compared with those under FP. At the seedling stage, the plant height, leaf area index and dry biomass under AP were significantly higher than those under FP. At a burial depth of 30 cm, the effective ears number, yield, water use efficiency and nitrogen partial factor productivity under AP increased by 12.6%, 14.8%, 11.8% and 14.2%, respectively, compared with those under FP. At a burial depth of 35 cm, the above indexes under AP increased by 10.3%, 5.2%, 4.4% and 5.0%, respectively, compared with those under FP. Overall, alternate row/bed planting for subsurface drip irrigation can considerably increase the emergence rate of spring corn, promote growth at the seedling stage, and increase the yield, water use efficiency and nitrogen partial factor productivity, particularly in arid and semiarid regions where severe spring droughts frequently occur.

1. Introduction

The corn belt in Northeast China is one of the country's corn commodity production zones, with annual corn output of more than 42 million tons and corn-planted acreage covering more than 5.1 million ha (accounting for 70% of the total production of grain crops) (Ma et al., 2008). Under global warming conditions, the local limited rainfall from late April to mid-June cannot support the germination and seedling growth of spring corn, thus adversely affecting the germination and yield of this crop (Li et al., 2010).

Subsurface drip irrigation is currently the most advanced water-saving irrigation method. Compared with other irrigation methods, subsurface drip irrigation can maintain and even increase the yield of more than 30 types of crops, including corn, alfalfa, cotton, tomato, sweet corn, etc., by requiring less water in most cases (Adamsen, 1992; Alam et al., 2002; Bar-Yosef et al., 1989; Camp et al., 1989; Phene et al., 1987; Plaut et al., 1985; Wood and Finger, 2006). Considering the long-term use of the subsurface drip irrigation system, the dripline must be buried below the plow layer (Camp and Lamm, 2003). In a silt-loam experimental cornfield at Kansas State University, most of the driplines were buried at a depth of 40–45 cm, thereby remaining constantly in dry soil surface and avoiding moisture evaporation and weed growth (Lamm et al., 1997; Lamm and Trooien, 2003). However, the low soil moisture content of topsoil in the 0–10 cm layer results in germination difficulty because of gravity (Lamm and Trooien, 2005), particularly in the severe spring droughts of arid and semiarid regions. Germination using subsurface drip irrigation is primarily affected by the distance between the seed and the dripline, which is closely related to the depth at which the dripline is buried (Charlesworth and Muirhead, 2003; Pablo et al., 2007; Patel and Rajput, 2007). The relationship between the dripline depth and germination has been a matter of great concern among scholars around the world in recent years.

To ensure the uniformity of the emergence rate for different dripline depths, a large amount of water could be used to wet the soil around the seed (Bordovsky and Porter, 2003; Henggeler, 1995; Howell et al., 1997). During irrigation, a low limit of the soil matrix

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potential in the 20 cm soil layer was maintained at the same level. The emergence rates of potato with dripline depths of 10–50 cm reached 100%. The deeper the dripline is buried, the larger the quantity of irrigation that is needed, which will cause a slower increase in ground temperature. Lower temperatures result in a delay in germination (Liu et al., 2015). Excessive irrigation may also cause deep percolation, which affects the groundwater environment and results in soil compaction, thus affecting ventilation and leading to crop yield reductions (Colaizzi et al., 2004). A number of scholars have agreed that uniformity of the emergence rate can be maintained through not allowing irrigation during seed germination (Lamm et al., 2010; Lamm and Trooien, 2005) or transplanting during seedling stage (Leskovar et al., 2001; Machado et al., 2003). No significant effects were observed in the yield or water use efficiency of sunflower, soybean, sorghum (Lamm et al., 2010), corn (Lamm and Trooien, 2005), tomato or melon (Leskovar et al., 2001; Machado et al., 2003).

The low emergence rate caused by inadequate irrigation may appreciably affect the yield and WUE_{ETc}. The emergence rate, yield and WUE_{ETc} of corn was greater under a dripline depth of 15 cm than under burial depths of 20–30 cm, with only the surface of the 15 cm treatment wetted during the pre-emergence irrigation (Pablo et al., 2007). The dripline depth should similarly be no greater than 20 cm for tomato or seed germination, yield and WUE_{ETc} might be affected (Marouelli and Silva, 2002; Schwankl et al., 1990).

In California, less than 10% of farmers adopted subsurface drip irrigation for crop establishment, with dripline depths of no more than 10 cm (Burt and Styles, 1999). Other farmers used sprinkler irrigation systems to guarantee germination. To ensure the emergence rates of the Hami melon and broccoli, the pre-emergence water amount using subsurface drip irrigation was increased by 185 and 230 mm compared with the sprinkler irrigation (Roberts et al., 2008). When the pre-emergence irrigation amount was same, the emergence rate of turf grass with sprinkler irrigation increased by 25.6% compared with subsurface drip irrigation (Schiavon et al., 2015). Guaranteeing the germination rate with sprinkler irrigation costs an additional US\$ 400–800 ha^{-1} $crop^{-1}$, and the return on field crops, such as corn and cotton, is extremely low (Lamm et al., 2012). Several scholars recommend installing and recording subsurface driplines using Real-Time Kinematic-Global Positioning System-guided tractors, thus achieving shallow burial of drip irrigation pipes without damage from farm machinery (Bordovsky, 2006; Heidman et al., 2003; Lamm et al., 2012). However, for most Chinese farmers, equipment costs are exceedingly high (Ji and Zhou, 2014; Li and Lin, 2006). In addition, some researchers propose placing subsurface driplines above a V-shaped impermeable material to improve the wetted width, to decrease the deep percolation and, finally, to solve the problem of germination with subsurface drip irrigation (Barth, 1999; Welsh et al., 1995). While the effect was not obvious, the corresponding cost was higher, and the process involved more difficult construction (Brown et al., 1996; Charlesworth and Muirhead, 2003).

When soil tillage is used, the dripline must be put below the plow layer. The deeper the dripline is buried, the harder the emergence. There is no cheap and convenient method that can guarantee the crop emergence rate with little water. The objective of this article was to propose a new subsurface drip irrigation sowing method called alternate row/bed planting and by comparing the emergence rate, yield, water use efficiency and nitrogen partial factor productivity of spring corn under the same irrigation and fertilizer amount, to develop a proper sowing method for subsurface drip irrigation.

2. Materials and methods

2.1. Experimental site

The experimental plots are located in Chifeng City, in Eastern Inner Mongolia (42°57′ N, 119°19′ E, altitude 625 m), China. This location has a semiarid continental monsoon climate with a mean annual temperature of 11 °C and a mean annual precipitation of 343 mm (primarily from June to August). The effective precipitation for spring corn during the growth stage in 2015 was 180 mm, and no effective precipitation was observed during the beginning of May to the middle of June. The soil texture of the 0–40 cm layer of the experimental plots was classified as a sandy loam, whereas the 40–60 cm section was classified as loam. The mean dry bulk density was 1.51 g/cm^3, and the mean field volume capacity was 32.06%. The mean soil organic matter was 6.74 g/ kg, and the contents of total nitrogen, nitrate nitrogen, ammonium nitrogen, available potassium, and available phosphorus were 0.41 g/ kg, 94.15 mg/ kg, 24.92 mg/ kg, 289.7 mg/ kg and 18.3 mg/ kg, respectively.

2.2. Experimental design

The tested plants—"Xianyu 335" spring corn, which were sown on May 8, 2015, germinated on May 30, 2015, and were harvested on October 5, 2015. Wide/narrow planting rows were 67 cm × 53 cm, with row spacing of 20 cm and a planting density of 82,500 plants/ha.

Considering the long-term use of subsurface drip irrigation system, the locally popular rotary tillage depths (20–25 cm) and subsurface dripline should be buried as shallow as possible (Camp, 1998). The experimental plot had two different dripline depths (30 (D30) and 35 cm (D35)) and two sowing methods, namely alternate row/bed planting (AP) and flat planting (FP). This experiment had four treatments: (1) alternate row/bed planting with a dripline depth of 30 cm (APD30) (see Fig. 1a); (2) alternate row/bed planting with a dripline depth of 35 cm (APD35) (see Fig. 1a); (3) flat planting with a dripline depth of 30 cm (FPD30) (see Fig. 1b); and (4) flat planting with a dripline depth of 35 cm (FPD35) (see Fig. 1b). A total of 12 plots (3 replicates for each treatment) were randomly arranged.

As shown in Fig. 1a, AP refers to using a plough ahead of the seeding nozzle to make a trapezoidal furrow (east-west) (as shown in the red line) before sowing, then sowing the seeds in 5 cm deep soil below the furrow bottom. Four rows were sown once. The top edge of the trapezoidal trench was set at 30 cm; the bottom edge was set at 6 cm; the vertical distance between the top and the bottom edge was set at 21 cm (see Fig. 1a). As a result of a furrow bottom depth

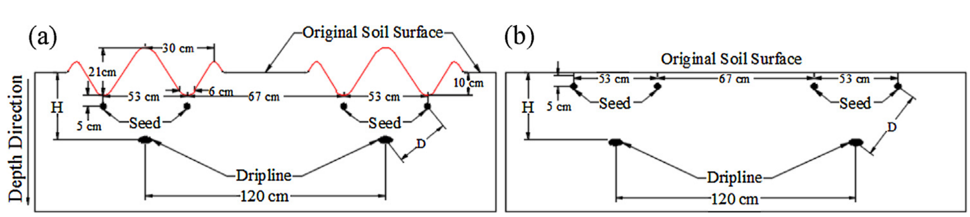

Fig. 1. Sectional drawing of alternate row/bed planting (AP) (a) and flat planting (FP) (b) with a dripline depth of 30 and 35 cm. H, dripline depth: 30 and 35 cm; D, distance between seed and dripline.

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