A sowing method for SDI to increase emergence rate in corn

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As a result of driplines being buried below the plow layer, it is hard for crop germination by using subsurface drip irrigation. This study were conducted from 2015 to 2016, including two sowing methods, namely alternate row/ bed planting (AP) with a 10 cm deep trapezoidal furrow; seeds were then sown in 5 cm deep soil below the furrow bottom and flat planting (FP), at two dripline burial depths (30 and 35 cm) with pre-emergence irrigation amounts from 15 mm to 75 mm. The following results were obtained: AP significantly increased the 5 cm soil depth moisture content below the seeds. The emergence rate, yield, water use efficiency and nitrogen partial factor productivity under AP increased by an average of 24.0%, 10.0%, 8.1% and 9.6%, respectively, compared with FP. Overall, AP for subsurface drip irrigation can considerably promote spring corn germination.
alternate row/ bed planting, flat planting, soil moisture content, emergence rate, yield, water use efficiency

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 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 while the effective precipitation in 2016 was 23.9 mm. 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 and May 5, 2016, germinated on May 30, 2015 and May 25, 2016, 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 21cm (see Fig. 1a). As a result of a furrow bottom depth of 10 cm relative to the original soil surface (i.e., the soil surface of the FP), the distance between the seed and the dripline was small: D_{APD30} (31 cm) $<$

D_{APD35} (33 cm) < D_{FPD30} (36 cm) < D_{FPD35} (40 cm). The image of AP is shown in Fig. 2. FP referred to the conventional method of sowing a seed in 5 cm deep soil on a flat field.

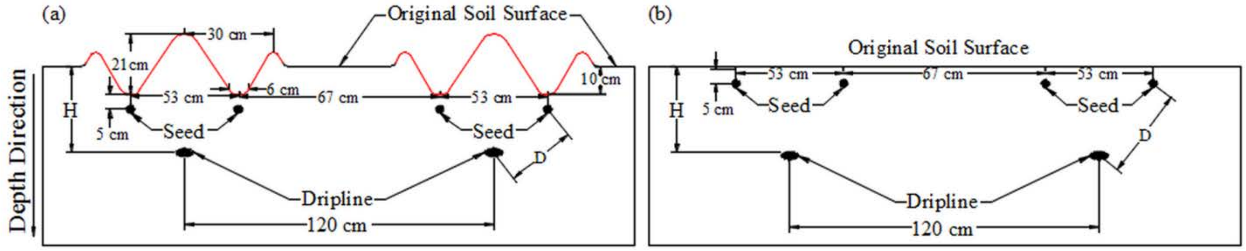

Fig. 1 Sectional drawing of alternate row/ bed planting (AP) (a) and flat planting (FP) (b) with a dripline depth of 30 and 35 cm H, dripline depth: 30 and 35 cm; D, distance between seed and dripline.

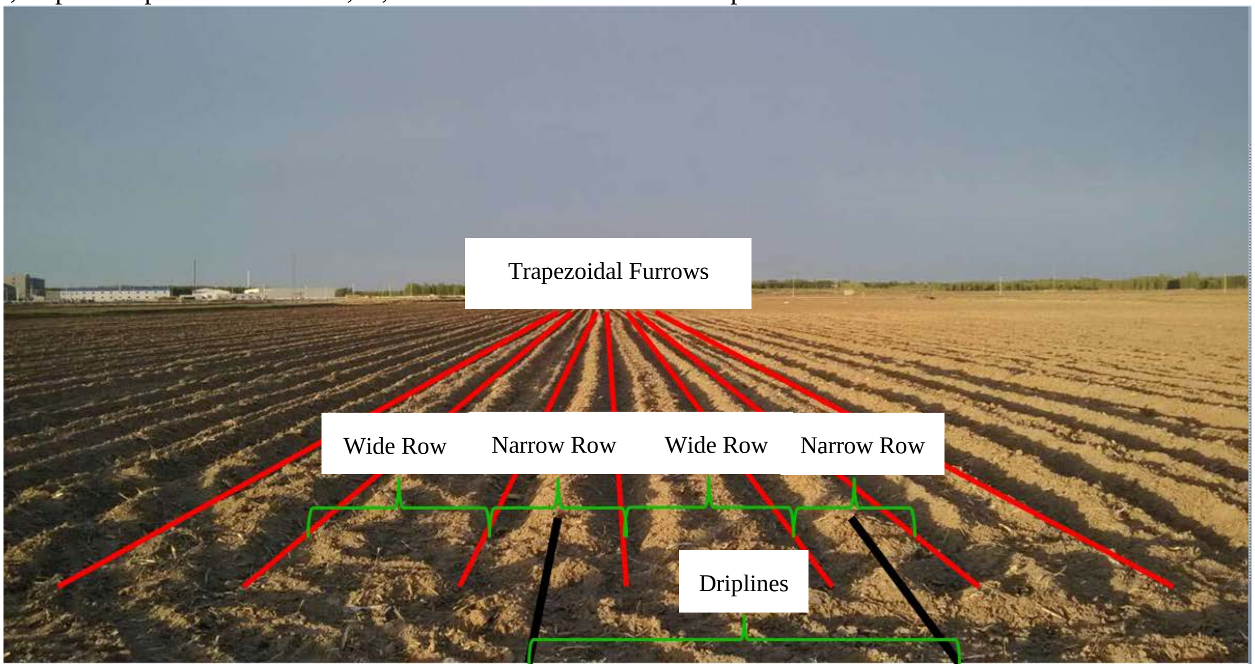

Fig. 2 Image of alternate row/ bed planting

As shown in Table 1, the pre-emergence irrigation amount in 2015 for all treatments was 25 mm. In 2016, the irrigation amount was increased by three levels for D30 and D35. This effect on corn emergence by alternate row/ bed planting will be further investigated to determine the appropriate pre-emergence irrigation amount. For all experiments, to prevent the influence of rainfall, the area was covered with tarpaulins during precipitation until the rain stopped.

Table 1. Pre-emergence irrigation amount of Year 2015 and 2016 for Spring Corn

Treatments	Pre-emergence irrigation amount (mm)	
	Year 2015	Year 2016
APD30	25	15
		25
FPD30		45
		60
APD35		25
		45
FPD35		60
		75

Each plot of 8.0 m × 50 m included six driplines with spacing of 1.2 m. The driplines were parallel to the corn planting ridges and in the middle of the narrow row. The driplines were provided by NATEFIM, with a wall thickness of 0.38 mm, a diameter of 16 mm, emitter spacing of 30 cm, and emitter rated flow of 1.05 L/ h. A complete set of pressure gauges, water meters, and valves were separately installed along the edge of a field to monitor the amount of water applied to the field and the flow rate of the subsurface drip irrigation system.

2.3 Irrigation and fertilization

After emergence, when the measured volumetric water content was between 70% and 75% of the field capacity, irrigation was necessary. The amount of water applied to the field was calculated by formula (1):

$$I' = 85\%\,\mathrm{ET}' - P' \quad (1)$$

where *I'* is irrigation amount (mm); ET' is evapotranspiration (mm), which can be calculated by formula (2); *P'* is effective precipitation (mm).

$$\mathrm{ET}' = K_c \times ET_0 \quad (2)$$

where ET_0 is reference evapotranspiration (mm/ d) calculated by the Penman-Monteith formula; and K_c is crop coefficient. Based on the results from several researchers in the same experimental plots, the corn planting process usually has a seedling stage $K_c = 0.7$, a jointing stage $K_c = 1.0$, a tasseling stage $K_c = 1.2$, a filling stage $K_c = 0.9$, and a milk stage $K_c = 0.5$ (Mi, 2013; Xu, 2014; Yuan, 2015).

The amount of nitrogen applied in the four treatments was identical (290 kg/ha; 20% applied as the base fertilizer and 80% applied with irrigation water). Self-priming pumps (H = 38 m, Q = 3 m^3/ h) and the pattern of "1/4 W-1/2 N-1/4 W" were used to ensure uniform fertilization, which consisted of clean water irrigation for 1/4 of the duration, fertilizer application for 1/2 of the duration, and flushing the pipework with clean water for the remaining 1/4 duration (Li *et al*., 2003). The details regarding the irrigation and fertilization systems in 2015 are provided in Table 2. The water applied on July 24 and

August 29 was minimal as it was used to fertilize. In 2016, the fertilization schedule was identical to that in 2015.

Table 2. Irrigation and Fertilization Schedule for Spring Corn of Year 2015

Sequence of Irrigation and Fertilization	Date	Irrigation Amount (mm)	Amount of Nitrogen Applied (kg ha^{-1})
Seed fertilizer			58
Pre-emergence irrigation	5/12	25	
1	7/9	25	58
2	7/24	7	72.5
3	8/7	45	43.5
4	8/18	10	
5	8/29	5	43.5
6	9/4	15	
7	9/11	30	14.5
Total		162	290

2.4 Monitoring indicators

2.4.1 Weather and soil moisture content

There was an automatic weather station (ET107; produced by Campbell Scientific, America) which was 100 meters from the experiment plot that could monitor and acquire the temperature, wind speed, wind direction, relative humidity, radiation, and other meteorological data within a time interval of one hour, continuously.

Three sets of EnviroSMART moisture sensors (produced by Sentek, Australia) were set between the wide row, narrow row and two corn plants, called A, B and C, respectively, and recorded once every one hour. As shown in Fig. 3, each of the sensors had four probes, numbered from 1# to 4#. Each probe recorded the volumetric water content (VWC) from a soil volume outside the access tube, which has a sphere of influence of 10 cm vertical height and 10 cm radial distance from the outer wall of the access tube and the precision of the sensor was 0.01cm^3/ cm^3. As shown in Fig. 3(a), the sensor B for AP was installed vertically downward at the bottom of the trapezoidal furrow, such that probes 1-4# could monitor the VWC at depths of 10, 20, 40, and 60 cm vertically below the furrow bottom. As shown in Fig. 3(b), the sensors for FP were installed with the flat field as a benchmark, such that probes 1-4# could monitor the VWC at depths of 10, 20, 40, and 60 cm vertically below the flat field (i.e., the original soil surface). Both sensors B for AP and FP could monitor the VWC at depths of 5, 15, 35, and 55 cm vertically below the seed. When calculating the seasonal change in soil water storage at 0-60 cm deep soil and then calculating the seasonal corn evapotranspiration, the average values from sensors A, B and C were used. When analyzing the soil moisture variation below the seed or corn, the values from sensor B were used. Moreover, augers were also used to measure the soil moisture content to correct the data gathered by the EnviroSMART moisture sensors.

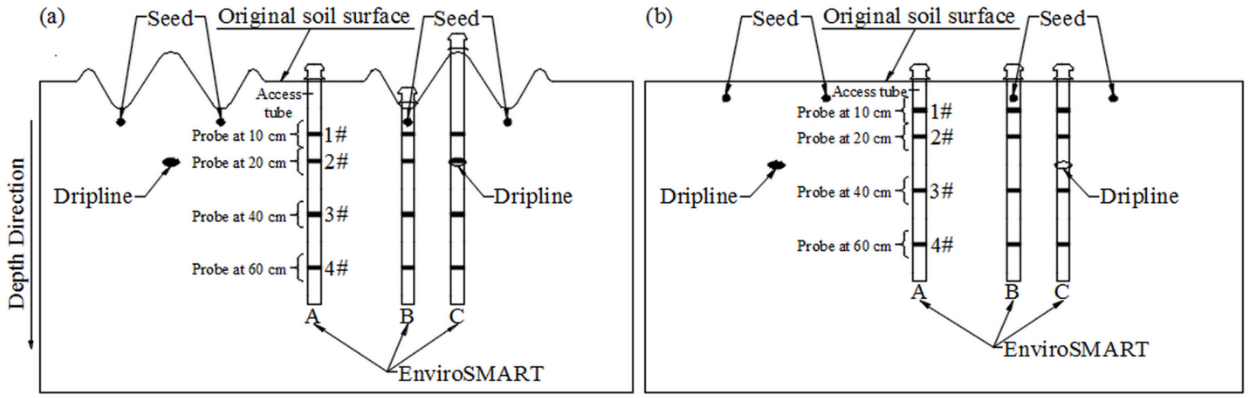

Fig. 3 EnviroSMART moisture sensor installations of alternate row/ bed planting (AP) (a) and flat planting (FP) (b)

2.4.2 Corn growth indexes at the seeding stage

The germination rate is the main indicator of the soil moisture content after sowing, and it is defined as the ratio between the emergence number and the sown seed number. The emergence number is determined under the condition in which corn plants have 2 cm of topsoil. Ten days after sowing (May 18, 2015 and May 15, 2016), the observation of the germination rate begins, and it ends after 2 weeks.

Five typical corn plants at the seedling stage were sampled on June 7, 2015 and June 5, 2016 to measure the plant height, stem diameter, and the width and length of all expanding leaves. Next, the leaf area index (LAI) was ascertained by using a correction coefficient of 0.75.

2.4.3 Seed and yield test

In year 2015, for the corn test, we eliminated the two rows outside of the plot and picked all of the plants in the mid-10 m of the four rows at the middle of every plot to measure their ear length, ear diameter, bare top length, kernels per ear, hundred-grain weight (after air-drying), ear weight, and yield (converted into the moisture content using 14% of the standard mass).

2.4.4 The index calculation and statistical methods

The seasonal crop evapotranspiration (ET_c) (mm) is calculated using the water balance equation (3), and the water use efficiency of corn (WUE_{ETc}) (kg ha^{-1} mm^{-1}) is calculated as follows:

$$\mathrm{ET_c} = P + I + U - R - \Delta S \quad (3)$$

$$\mathrm{WUE_{ETc}} = Y / \mathrm{ET_c} \quad (4)$$

where P is the seasonal effective precipitation (mm); I is the seasonal irrigation (mm); U is the seasonal upward capillary flow into the root zone (mm) (The capillary rise was negligible since the groundwater table was 20-30 m below the soil surface); R is the seasonal runoff (mm) (Runoff was never observed in the field); ΔS is the seasonal change in soil water storage at 0-60 cm (mm); and Y is the corn yield (kg ha^{-1}).

The nitrogen partial factor productivity (NPFP) (kg kg^{-1}) is calculated as follows:

$$\mathrm{NPFP} = Y / N \quad (5)$$

where N is the seasonal nitrogen applied amount (kg ha^{-1}).

All of the experimental data were statistically analyzed using SPSS17.0 and Microsoft Excel.

3. Results

3.1 Soil volumetric moisture content

3.1.1 Soil moisture change after sowing and after pre-emergence irrigation

In both year, after sowing, the AP soil moisture at a depth of 5 cm vertically below seed increased by 15.0%, on average, compared to FP. In 2015, forty-eight hours after a pre-emergence irrigation of 25 mm, only the soil moisture content of APD30 at 5 cm below seed increased by 10.9% while the soil moisture contents of the remaining three treatments decreased. Similarly, in 2016, only the soil moisture content of APD30 changed dramatically after pre-emergence irrigation of 15 mm and 25 mm. For the other three pre-emergence irrigation treatments, the AP soil moisture was larger than FP. (Table 3 and Table 4).

Table 3. Soil moisture content (Vol. %) 5 cm vertically below the seeds after sowing and after pre-emergence irrigation (year 2015)

Treatments	pre-emergence irrigation amount (mm)	After sowing	48 hours after pre-emergence irrigation
APD30	25	16.24	18.01
FPD30		14.47	14.39
APD35		16.82	15.98
FPD35		13.61	13.38

Table 4. Soil moisture content (Vol. %) 5 cm vertically below the seeds after sowing and after pre-emergence irrigation (year 2016)

Treatments	pre-emergence irrigation amount (mm)	After sowing	After pre-emergence irrigation	24 hours after pre-emergence irrigation
APD30	15	19.67	22.78	22.85
FPD30		17.80	14.44	20.70
APD30	25	19.67	29.96	25.01
FPD30		17.80	17.07	21.33
APD35		21.14	18.30	25.08
FPD35		18.62	15.25	18.47
APD30	45	19.67	34.22	30.12
FPD30		17.80	24.40	19.02
APD35		21.14	28.39	25.39
FPD35		18.62	26.86	22.48
APD30	60	19.67	33.33	32.94
FPD30		17.80	23.85	19.42
APD35		21.14	30.68	25.58
FPD35		18.62	27.27	22.89

APD35	75	21.14	32.05	23.22
FPD35		18.62	26.00	23.28

3.1.2 Other growth stages

The EnviroSMART moisture sensors were completely installed in early July and continuous recording of all soil volumetric moisture contents from July 5 to October 5 are shown in Fig. 4. The figures show that the moisture contents of soil at 10, 20, and 40 cm changed dramatically. The soil moisture content at 20 cm changed the most significantly, whereas the soil moisture content at 60 cm was relatively stable. Compared with topsoil (10 and 20 cm), the moisture content of deep soil (40 and 60 cm) increased by 54.2% on average.

In top soils of 10 and 20 cm, the mean soil moisture content of the two dripline depths under AP increased by 23.8% and 21.2%, respectively, compared with FP. Similarly, the mean soil moisture content of the two sowing methods under D30 increased by 13.8% and 13.9% compared with D35. For deep soils of 40 and 60 cm, the mean soil moisture content of the two dripline buried depths under FP increased by 9.1% and 0.6%, respectively, compared with AP. Similarly, the mean soil moisture content of the two sowing methods under D35 increased by 18.0% and 6.9% compared with D30.

After forty-eight hours of 30 mm irrigation on September 11, the soil moisture content in 10 cm soil under APD30 and APD35 increased by 8.9% and 6.0%, respectively, whereas FPD30 and FPD35 decreased by 3.5% and 0.2%, respectively. Forty-eight hours after 45 mm irrigation on August 7, the soil moisture content of 10 cm soil under APD30, APD35, and FPD30 increased by 4.1%, 5.5% and 1.4%, respectively, whereas FPD35 decreased by 3.7%.

Forty-eight hours after 29 mm precipitation on July 21, under a soil moisture content of 10 cm, AP and FP increased by 23.7% and 18.1%, respectively. Under a soil moisture content of 20 cm, AP and FP increased by 26.6% and 11.6%, respectively. Under a soil moisture content of 40 cm, AP and FP increased by 0.2% and 3.7%, respectively. Under a soil moisture content of 60 cm, AP decreased by 0.1% and FP increased by 1.5%, respectively. Forty-eight hours after 38 mm precipitation on July 29, for a soil moisture content of 10 cm, AP and FP increased by 40.3% and 24.0%, respectively. Under a soil moisture content of 20 cm, AP and FP increased by 28.1% and 19.5%, respectively. Under a soil moisture content of 40 cm, AP and FP increased by 3.7% and 10.8%, respectively. And under a soil moisture content of 60 cm, AP and FP increased by 0.9% and 3.5%, respectively.

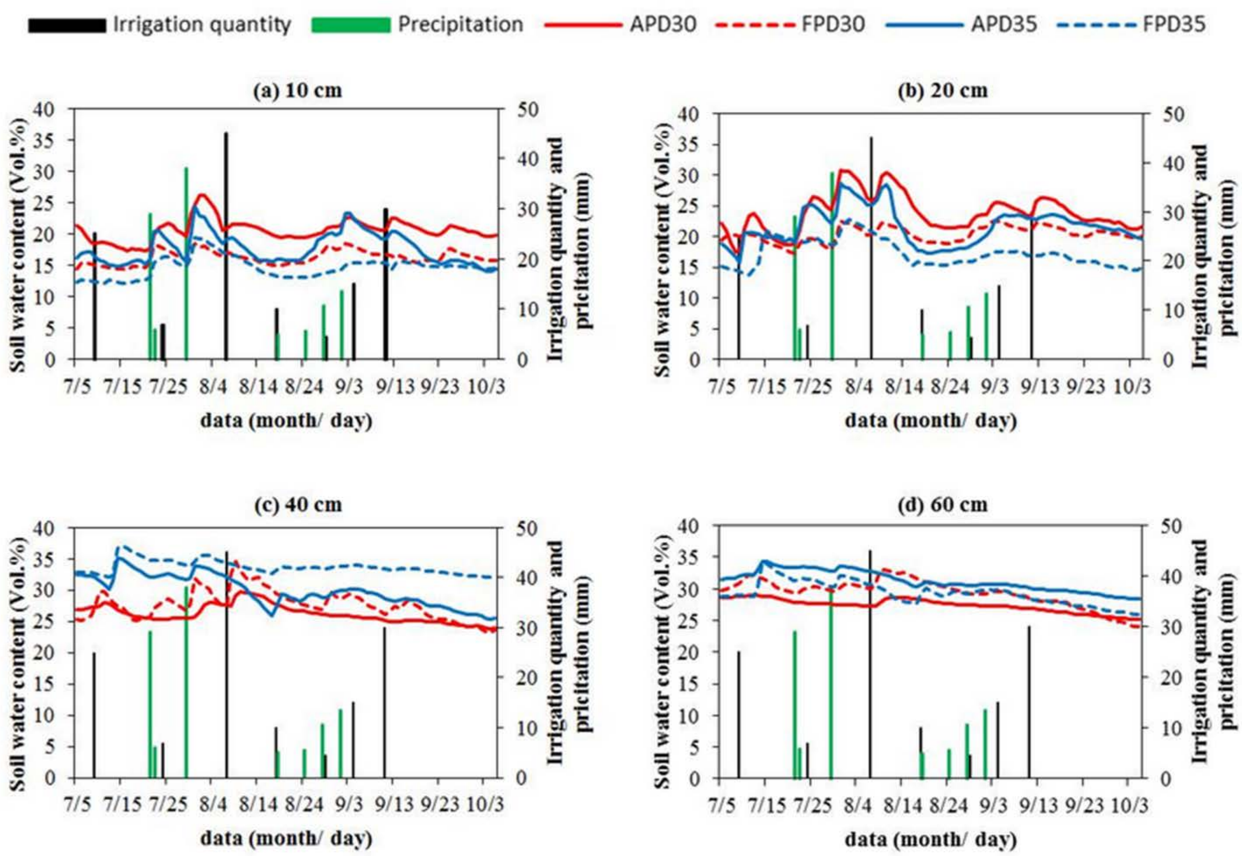

Fig. 4 Changes in the soil moisture content (Vol. %) of the four treatments at 10 (a), 20 (b), 40 (c), and 60 cm (d) from July 5 to October 5

APD30, alternative row/ bed planting with dripline depth of 30 cm; APD35, alternative row/ bed planting with dripline depth of 35 cm; FPD30, flat planting with dripline depth of 30 cm; FPD30, flat planting with dripline depth of 35 cm.

3.2 Emergence rate, plant height, stem diameter and LAI at the seedling stage

As the pre-emergence irrigation amount increased, the plant height, stem diameter, and LAI at the seedling stage of AP were initially increased and decreased later, whereas FP continued to increase (Table 5). For APD30, when the irrigation amount was 25 mm, the emergence rate was greater than 90% and later reached 100% with the irrigation amount approaching 45 mm. For APD35, when the irrigation amount was 25 mm, the emergence rate was greater than 90% and reached a maximum of 93%. Furthermore, for FPD30 and FPD35, the emergence rate was always less than 80%. Compared with FP, the mean emergence rate of AP increased by 23.3%. The larger the irrigation amount, the smaller emergence rate difference between APD30 and APD35. Under the same irrigation amount, there was a small emergence rate difference between FPD30 and FPD35. For D30, an irrigation rate of 15 mm had a substantial effect on the emergence rate, compared with irrigation amounts of 25, 45, and 60 mm. However, there was no significant difference for these three irrigation amounts. For D35, on the other hand, the irrigation amount had no significant impact on the emergence rate. For other physiological indicators, the pre-emergence irrigation amount mostly reached significant levels.

Table 5. Influences of pre-emergence irrigation amount on the emergence rate, plant height, stem diameter and LAI at the seedling stage

Pre-emergence irrigation amount (mm)	Emergence rate (%)	Plant height (cm)	Stem diameter (cm)	LAI
APD30				
15	81a	36.3a	1.10a	0.19a
25-Year 2016 (Year 2015)	93b (91)	39.3ab (41.8)	1.21ab (1.20)	0.26b (0.28)
45	100b	42.6b	1.29bc	0.38c
60	95b	42.1b	1.39c	0.33c
Mean	92	40.1	1.25	0.29
LSD ($p < 0.05$)	**	**	**	**
FPD30				
15	64a	26.0a	0.80	0.08a
25-Year 2016 (Year 2015)	74b (79)	31.9b (30.8)	0.94 (0.93)	0.13b (0.15)
45	75b	33.6b	0.91	0.15b
60	76b	31.1b	0.97	0.14b
Mean	72	30.6	0.90	0.13
LSD ($p < 0.05$)	**	**	NS	**
APD35				
25-Year 2016 (Year 2015)	82 (81)	36.6a (38.5)	1.13 (1.10)	0.21a (0.22)
45	92	39.8ab	1.17	0.27ab
60	93	41.7b	1.24	0.32ab
75	90	38.1b	1.17	0.28b
Mean	89	39.0	1.18	0.27
LSD ($p < 0.05$)	NS	*	NS	*
FPD35				
25-Year 2016 (Year 2015)	73 (74)	32.3a (30.1)	0.92a (0.97)	0.14a (0.12)
45	75	33.0ab	0.99ab	0.15a
60	74	35.8bc	1.12b	0.20b
75	77	34.5c	1.16b	0.22b
Mean	75	33.9	1.05	0.18
LSD ($p < 0.05$)	NS	**	*	**

Table 6 shows a significance analysis of the sowing methods, dripline depths, and their interaction on corn seedling physiology indicators under the same pre-emergence irrigation amount in 2015 and 2016. Sowing methods had a significant effect on the corn seedling physiological indicators under different irrigation amounts. With an increase in the irrigation amount, the dripline depth had a substantial impact on the emergence rate and plant height. Furthermore, for an irrigation amount of 60 mm, interaction of the planting method and dripline depth had a considerable effect on all indicators.

Table 6. Influences of sowing methods and dripline depths on the emergence rate, plant height, stem diameter, and LAI at the seedling stage for different pre-emergence irrigation amount

Treatment	Emergence rate (%)	Plant height (cm)	Stem diameter (cm)	LAI
Year 2015 25mm				
F value for dripline depth	7.683	3.858	0.364	5.878
LSD (p < 0.05)	*	NS	NS	*
F value for sowing method	12.444	86.684	13.091	40.209
LSD (p < 0.05)	**	**	**	**
F value dripline depth × sowing method	1.016	1.592	1.455	0.557
LSD (p < 0.05)	NS	NS	NS	NS
Year 2016 25mm				
F value for dripline depth	3.138	1.246	1.460	2.881
LSD (p < 0.05)	NS	NS	NS	NS
F value for sowing method	17.085	29.888	37.549	82.881
LSD (p < 0.05)	**	**	**	**
F value dripline depth × sowing method	1.898	2.165	0.365	6.881
LSD (p < 0.05)	NS	NS	NS	*
Year 2016 45mm				
F value for dripline depth	2.921	2.413	0.222	10.116
LSD (p < 0.05)	NS	NS	NS	*
F value for sowing method	73.014	53.593	62.720	116.053
LSD (p < 0.05)	**	**	**	**
F value dripline depth × sowing method	2.472	1.087	9.102	11.463
LSD (p < 0.05)	NS	NS	*	**
Year 2016 60mm				
F value for dripline depth	12.676	18.184	0.011	3.267
LSD (p < 0.05)	**	**	NS	NS
F value for sowing method	69.014	271.233	74.136	129.067
LSD (p < 0.05)	**	**	**	**
F value dripline depth × sowing method	24.845	25.021	24.960	8.067
LSD (p < 0.05)	**	**	**	*

APD30, alternative row/ bed planting with dripline depth of 30 cm; APD35, alternative row/ bed planting with dripline depth of 35 cm; FPD30, flat planting with dripline depth of 30 cm; FPD30, flat planting with dripline depth of 35 cm; LAI, leaf area index.

* indicates a significant differences (P<0.05), ** indicates extremely significant differences (p <0.01), and NS indicates insignificant differences.

3.3 Yield and its components

Table 7 shows the significance results for corn yield and its components. The yield of APD30 was the highest, at 14.7 t/ ha, and the yield of FPD35 was the lowest, at 11.6 t/ ha. For D30, the effective ears per ha and yield under AP increased by 12.6% and 14.8%, respectively, compared with those under FP. For D35, the effective ears per ha and yield under AP increased by 10.3% and 5.2%, respectively, compared with those under FP. For D30, the kernels per ear under AP increased by 6.9% compared with that under FP. However, insignificant differences were observed for the kernels per ear at a burial depth of 35 cm. For D30 and D35, the hundred-grain weights under FP increased by 4.5% and 8.5%, respectively, compared with those under AP, indicating significant differences. For D30, the ear diameter, effective ears per ha, kernels per ear, and yield increased by 2.4%, 11.0%, 3.5%, and 16.0%, respectively, compared with D35, indicating significant differences.

Table 7. Statistical analysis of spring corn yield and its components

Treatment	Ear Length (cm)	Ear diameter (cm)	Bare top length (cm)	Effective ears per ha	Kernels per ear	Hundred-grain weight (g)	Yield (t ha^{-1})
APD30	19.93	5.07	1.97	77617	635	30.16	14.7
FPD30	19.47	5.17	2.13	68930	594	31.52	12.8
Mean	19.70	5.12	2.05	73274	615	30.84	13.8
F value	0.925	4.5	0.205	17.026	9.145	1.857	53.14
APD35	19.00	5.00	1.87	69268	593	29.71	12.2
FPD35	19.30	5.00	1.83	62801	596	32.25	11.6
Mean	19.15	5.00	1.85	66035	594	30.98	11.9
F value	5.4	0	0.034	8.687	0.13	17.052	0.774
F value for dripline depth	4.797	9.8	0.954	22.668	6.314	0.055	29.515
LSD (p < 0.05)	NS	*	NS	**	*	NS	**
F value for sowing method	0.11	1.8	0.106	24.835	5.677	11.039	12.101
LSD (p < 0.05)	NS	NS	NS	**	*	*	**
F value for dripline depth × sowing method	2.33	1.8	0.238	0.533	7.629	1	3.386
LSD (p < 0.05)	NS	NS	NS	NS	*	NS	NS

APD30, alternative row/ bed planting with dripline buried depth of 30 cm; APD35, alternative row/ bed planting with dripline buried depth of 35 cm; FPD30, flat planting with dripline buried depth of 30 cm; FPD30, flat planting with dripline buried depth of 35 cm;

* indicates a significant differences (P<0.05), ** indicates extremely significant differences (p <0.01), and NS indicates insignificant differences.

3.4 Water use efficiency and nitrogen partial factor productivity

Table 8 shows that for D30 and D35, the ET_c under AP increased by 2.4% and 0.7%, respectively, compared with those under FP that had no significant difference. However, the dripline depth had a significant influence on the ET_c. For D30, the mean ET_c of the two sowing methods increased by 3.7%, compared with D35. Water use efficiency (WUE_{ETc}) is consisted by yield and ET_c and nitrogen partial factor productivity (NPFP) is consisted by yield and seasonal nitrogen applied amount (i.e., 290kg/ ha). The sowing methods and dripline depths significantly affected the WUE_{ETc} and NPFP. The WUE_{ETc} under AP increased by 8.2% on average compared with that under FP, and D30 increased by 11.8% on average compared with D35. The NPFP under AP increased by 9.8% on average compared with that under FP, and D30 increased by 15.6% on average compared with D35.

Table 8. Statistical analysis of ET_c, WUE_{ETc} and NPFP

Treatment	ET_c (mm)	WUE_{ETc} (kg ha^{-1} mm^{-1})	NPFP/ (kg kg^{-1})
APD30	409.4	35.9	50.6
FPD30	400.0	32.1	44.3
Mean	404.7	34.0	47.4
F value	1.270	10.758	52.933
APD35	391.6	31.1	42.0
FPD35	389.0	29.8	40.0
Mean	390.3	30.4	41.0
F value	0.098	0.407	0.759
F value for dripline depth	5.914	9.355	29.438
LSD (p < 0.05)	*	*	**
F value for sowing method	1.043	4.773	12.027
LSD (p < 0.05)	NS	**	**
F value for dripline depth × sowing method	0.338	1.162	3.407
LSD (p < 0.05)	NS	NS	NS

APD30, alternative row/ bed planting with dripline buried depth of 30 cm; APD35, alternative row/ bed planting with dripline buried depth of 35 cm; FPD30, flat planting with dripline buried depth of 30 cm; FPD30, flat planting with dripline buried depth of 35 cm; ET_c, seasonal crop evapotranspiration; WUE_{ETc}, water use efficiency. NPFP, nitrogen partial factor productivity.

* indicates a significant differences (P<0.05), ** indicates extremely significant differences (p <0.01), and NS indicates insignificant differences.

4. Discussion

When the subsurface dripline was buried below the plow layer, the moisture content of the soil under the dripline was higher than that of the soil above the dripline because of gravity (Cote et al., 2003; Schiavon *et al*., 2015), thereby causing the following problems: (1) neither the water nor fertilizer requirements at the seed germination and early growth stages of corn are met because of water deficiency in the moisture content of the soil around the seed; (2) deep percolation of water and fertilizer may result. The new sowing method of AP made a trapezoidal furrow with 10 cm depth, then seeds were sown in 5 cm deep soil below the furrow bottom which was similar to the method Lamm *et al*. (2012) recommended to move the dry and loose soil near the surface to the traffic furrow, and to sow into the wetter and firmer soil, it could provide a wetter soil environment for germination. Besides, AP could also shortened the distance between the seed and the dripline. Therefore, the soil water under AP would be easier to reach for seeds under the same irrigation amount. In both 2015 and 2016, only the APD30 soil water could reach up to 5 cm vertically below the seed after pre-emergence irrigation of 25 mm. The closer distance between the seeds and the dripline, the higher the soil moisture content around the seeds, the higher the rate of emergence rate and the better the growth for early corns. So the corn emergence rate, plant height, stem diameter and LAI at the seedling stage under AP were greater than FP.

From July 5 to October 5, the moisture contents of soil at 0-40 cm was affected by irrigation, rainfall, evaporation, and corn consumption changed dramatically. These results Liu and Li (2009) said that in the topsoil (10-20 cm), the moisture content significantly decreases with the increased dripline depth. However, in deep soil (20-70 cm), the moisture content increased with the increasing dripline depth. Due to the topsoil (10 and 20 cm) of AP was closer to dripline, while the deep soil (40 and 60 cm) was far away from the dripline, the average topsoil moisture content of AP was greater than that of FP, yet the deep soil moisture content of AP was smaller than that of FP.

The ridge and furrow rainfall harvesting system allows for collection and storage of rainwater and considerably increases the water storage capacity (Bu *et al*., 2013; Dahiya *et al*., 2007; Hu *et al*., 2014; Li *et al*., 2009). Similarly, the sowing method of AP enlarged the contact area between the soil surface and the rainwater, then storing the water in the soil below the furrow bottom where corn grows. This result was obtained by comparing the changes in soil moisture content after two precipitation events of 29 and 38 mm. The comparison showed that the mean moisture of soil at 0-60 cm of AP were 1.46 and 1.26 times bigger than FP, respectively.

Several scholars believe that if the burial depth of the dripline is too shallow, the topsoil will get readily wet, and the existing moisture will be prone to evaporation loss (Lamm *et al*., 2006). Lamm *et al*. (2010) noted that the evaporation under dripline depths of 40 cm was less than at buried depths of 20 and 30 cm. The result of the mean ET_c of two sowing methods for D30 significantly increased, by 3.7%, compared with D35, which agreed with the above conclusions. Due to the shortened distance between the seed and the dripline under AP, the water could more easily reach the soil surface and could accelerate evaporation. Besides, the corn under AP exhibited better outcomes than FP, the total actual water consumption of corn under AP would be higher than FP.

However, the proportion of the furrow bottom in the total area of the soil surface was small and the furrow in the present experiment was situated east-west and perpendicular to the direction of the locally common northerly wind. Therefore, a high evaporation resistance could reduce evaporation losses (Li *et al*., 2009). Furthermore, the poor corn cover of FP would increase evaporation. Although the ET_c under AP increased by 2.4% (D30) and 0.7% (D35), compared with FP, respectively, no statistically significant difference was observed.

When crop establishment is non-limiting (i.e., the emergence rate is uniform), the dripline depth, in most cases, has no remarkable direct influence on the yield or WUE_{ETc} (Lamm *et al*., 2010; Lamm and Trooien, 2005; Liu and Li, 2009; Machado *et al*., 2003). With respect to seed germination, a closer distance between the seed and the dripline implies a higher emergence rate, higher yield and improved water use efficiency (Charlesworth and Muirhead, 2003; Lamm *et al*., 2012; Pablo *et al*., 2007). Therefore, in the present experiment, AP was determined to be superior to FP in terms of the emergence rate and effective ears per ha. The yield under AP was significantly larger than FP for both dripline depths. The number of kernels per ear under D30 was considerably larger than that under D35, which is consistent with the findings of Lamm and Trooien (2005), who reported that, for the number of kernels per ear, the burial depth of the drip irrigation pipe at 20-30 cm was considerably higher than that at 41-61 cm. As a result, a low emergence rate can provide better air permeability and light transmittance, which can promote single corn growth and a change in the law of hundred-grain weights that was contrary to the emergence rate: FPD35＞FPD30＞APD30＞APD35.

Due to the no significant difference of ET_c between AP and FP, The WUE_{ETc} was principally determined by the yield and increased with yield and the WUE_{ETc} of AP was significant higher than FP. In addition, when the nitrogen applied amount in all treatments were the same, it could be concluded from formula (5) that NPFP also increased with the increase of Yield, so the NPFP of AP was higher than FP and the NPFP for D30 was higher than D35. The sowing methods and dripline depths had a significant effect on WUE_{ETc} and NPFP.

5. Conclusions

This study proposed a new sowing method for subsurface drip irrigation called alternate row/ bed planting (AP), which involved removal of the dry topsoil and then sowing seeds below the trapezoidal furrow bottom, which could also shorten the distance between the seed and the dripline. After sowing and irrigation, the soil moisture content vertically below the seed of alternate row/ bed planting (AP) was higher than flat planting (FP). Thus, the emergence rate of AP was significantly higher than FP under both dripline depths. As corn roots are shallow during the early growth stage, the growth of corn can be considerably fostered by AP. Furthermore, AP changed the geometry of the topsoil, allowing the collection and storage of rainwater after rain and increasing the topsoil moisture content. The mean yield, WUE_{ETc} and NPFP of two dripline depths under AP increased by 10.2%, 8.2% and 9.8%, respectively, compared with FP. Therefore, this sowing method is suitable for regions affected by spring droughts.

Acknowledgements

We are grateful for financial support from the National Science and Technology Project in the 12th Five-Year Plan of Chinese Ministry of Science and Technology (2014BAD12B00) and the Foundation for Innovative Research Groups of the National Natural Science Foundation of China (51321001).

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