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Subsurface Drip Lateral Line Depths to Protect against Root Intrusion

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Abstract: Root intrusion into emitters poses a threat to the lifespan of subsurface drip irrigation systems. In an attempt to address this problem, an experiment was conducted on spring wheat (Mengmai 30) grown in soil columns installed in a greenhouse to study the effects of lateral line depths to reduce root intrusion into emitters. The soil columns are rectangular containers, and the dimensions were 15 cm, 60 cm, 100 cm. The soil matric potential at a 20 cm depth immediately over (lateral line depth <20 cm), under (lateral line depth >20 cm), or next to (lateral line depth = 20 cm) the drip emitters was used to schedule the subsurface drip irrigation regime. Five different lateral line depths, with depths of 10, 20, 30, 40, and 50 cm, were maintained. The lateral line depths influenced the spring wheat root distribution, emitter flow rate, root intrusion, and spring wheat yield and quality. Results indicated that the shallower the lateral line depth, the more root was distributed in the surface layer. Root density values increased with soil depth. The emitter flow rate (eventual flow rate divided by the initial flow rate) increased as the lateral line depth decreased. All the treatments had root intrusion except 50 cm treatment. Root intrusion increased as the lateral line depth decreased. The lowest root intrusion rate (0%) was achieved with a lateral line depth of 50 cm. The greatest relative yield was achieved with a lateral line depth of 30 cm. After root intrusion and yield were both considered, the lateral line depth of 30–40 cm was a better choice.

Keywords: emitter clogging; root distribution; root density; soil matric potential; emitter flow rate

1. Introduction

Subsurface drip irrigation (SDI) has been a form of irrigation-driven agriculture for more than 50 years. In the last 20 years, the adoption of SDI has grown dramatically, owing to increasing pressure on water resources and the availability of reliable system components. The advantages of SDI include more efficient water use, high yield, good quality, and delayed pipeline aging [1,2]. In addition, reclaimed municipal wastewaters can be applied through SDI [2,3]. At present, SDI is regarded as the most efficient form of micro-irrigation [4,5].

However, there are some challenges to the successful use of SDI, such as root intrusion (roots growing into the emitters' flow paths). Suarez-Rey et al. [6] found that Bermuda grass roots intrude into some emitters after only one year of SDI use. Rubens et al. [7] measured the intrusion of coffee and citrus roots into 14 different emitter models placed in containers and found that all the tested emitters experienced root intrusion. Root intrusion is an important factor that affects SDI system uniformity and life span, as well as crop yields [2,8,9].

Burt and Styles [10] found that grapevine roots grew around and pinched SDI driplines, either greatly reducing or halting the water flow. Clogging from root intrusion has historically been the major hurdle to SDI use in landscaping. When SDI was used to irrigate turf, 10% of untreated SDI emitters blocked by roots during the first three years, 60% in four years, and 95% in six years [11]. Lamm [12] reported that serious tomato root intrusion occurred under SDI conditions in the mid-growing season, which decreased tomato yields compared with drip irrigation. Drip lines of SDI were buried underground. Once roots penetrate emitters, it is impossible to replace them. If root intrusion could be avoided, SDI would be a more acceptable and common irrigation practice [2].

Citrus and coffee were planted by Rubens et al. [7] inside a greenhouse to study root intrusion. The result illustrated that root tip entered emitters by chance. High-density roots system in the soil, where drippers are positioned, can promote root intrusion into emitters [7,13]. The probability of root tip entering drippers increases as root density increases where drippers are positioned. Previous studies have shown that root density is different with the different soil depth [14–19].

Miao et al. [20] studied the root distribution of 18 crops in North China. The results of Miao indicated the vertical distribution of the root system fits a reduction of the index. Kang et al. [21] and Wang et al. [22] indicated that under drip irrigation and different soil water conditions, potato roots were mainly distributed in 0–40 cm soil depth, and root density decreased mainly as the soil depth increased. The similar results were found with radish [23,24]. Under the SDI condition, Yu et al. [25] found that the root length density of wheat decreased as the soil depth increased.

In the SDI system, lateral line depth was an important parameter. Camp [1,9] and Ayars et al. [2] reported that in most cases, lateral line depths ranged from 0.02 to 0.7 m. The depth at which lateral lines were installed often depends on soil, crop, site conditions, and water characteristics. Conventional tillage methods, such as ripping, plowing, or disking, were used to eliminate compacted layers at a depth of 0.3 m. Where systems were used for multiple years, tillage was a consideration. Drip lateral line depths ranged from 0.3 to 0.7 m. Where tillage was not a consideration, drip lateral line depths ranged from 0.1 to 0.4 m. With the use of GPS guidance equipment, new tillage equipment, and approaches in cultivation, drip lateral lines could also be installed in depth of 0.1 to 0.4 m even considering tillage.

Hu et al. [26] found the soil water content at the 20 cm depth could be used as a predictor of the mean soil water storage of the watershed. This result also could be used to guide irrigation. Kang et al. [21,27] found that under drip irrigation, the variation of soil matric potential at a 20-cm depth immediately under the drip emitters was similar to the variation of average soil matric potential in the root zone. The soil matric potential in the root zone could be determined by controlling the soil matric potential at a 20 cm depth immediately under the drip emitters. The same results were found in our previous SDI experiment [28,29].

In this study, the soil matric potentials at 20 cm depth immediately over, under, or next to the drip emitters were used in scheduling the SDI regime, and a series of experiments with spring wheat was conducted to investigate the effects of different lateral line depth on root intrusion. The specific objectives of this study were to investigate the effect of different lateral line depth on the reduction of root intrusion.

2. Materials and Methods

2.1. Study Site, Soil Sampling, and Preparation

The experiments were carried out in a greenhouse at the Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing (40°0′ N, 116°22′ E). Sodium lamps were used as light sources, and the maximum illumination was 800 μmol·m^{-2}·s^{-1}. To increase the air circulation and regulate the temperature, four ventilators were installed in the greenhouse.

Soil samples were collected from a 0–30 cm depth from the Jinghai Experimental Station for Efficient Water Use of Agriculture in Coast Zone, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Tianjin. The soil at 0–30 cm was predominantly silt with a bulk density of 1.3 g/cm^3 and a soil organic matter of ~1.3%. The pH of the saturation paste extract was 8.0, and the electrical conductivity of the saturation paste extract was 0.7 dS/m. The soil samples were air-dried, crushed, and passed through a 2 mm sieve. Then, 5 cm depth increments of the soil samples were packed into columns with bulk densities of 1.3 g/cm^3.

2.2. Experimental Design

Five depths, 10 (D1), 20 (D2), 30 (D3), 40 (D4), and 50 cm (D5), were used in different lateral line depth treatments. Each treatment was replicated three times in a randomized complete block design (Figure 1). There were 15 soil columns in total.

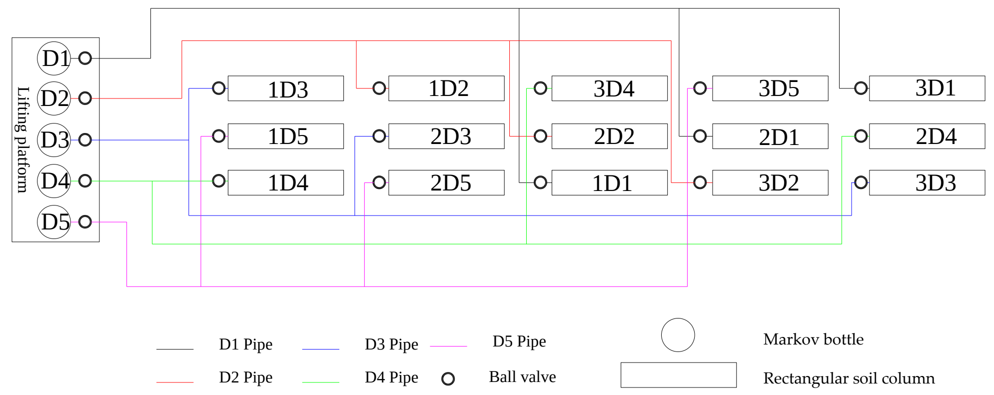

Figure 1. The layout of the SDI (subsurface drip irrigation) system.

Each rectangular soil column was 15 cm wide, 60 cm long, and 100 cm deep (Figure 2). To investigate the root growth, the rectangular soil column was made of tempered glass and was covered with shade cloth that could be opened. One drip tape with three emitters was installed in the center of each soil column at 10, 20, 30, 40, and 50 cm depth. The emitter spacing was 20 cm, and the emitter flow rate was 0.69 L/h at the operating pressure of 0.0245 MPa.

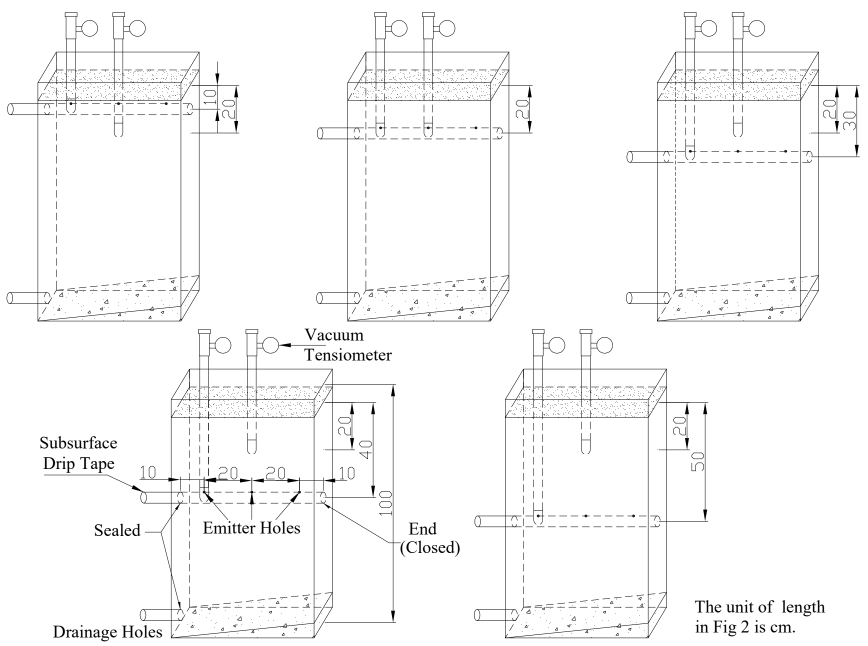

Figure 2. The layout of drip tape and tensiometers.

One Markov bottle with a scale was used to supply irrigation water for each treatment (three soil columns) (Figures 2 and 3). The Markov bottles were placed on a lifting platform 2.5 m above the ground. The Markov bottle and each soil column were connected with pipes and ball valves. When irrigation events occurred, the scale and a stopwatch were used to calculate the emitter flow.

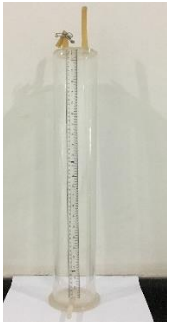

Figure 3. Markov bottle.

2.3. Agronomic Practices and Fertigation

Spring wheat cultivar Mengmai 30, which has a high-density root system, was chosen for this experiment. Seeds were planted in the center of the rectangular soil columns at a plant density of 330 kg/ha. The spring wheat was planted on 31 March, emerged about 6 d later, and was harvested on 30 June for total yield.

Before the seeds were planted, irrigation was applied for the five treatments. Irrigation began at the same time and stopped when the soil was moist. Initial irrigation amounts for D1, D2, D3, D4, and D5 were 10, 12, 24, 34, and 40 mm, respectively. No irrigation was applied before seedling emergence. After wheat emergence, irrigation was applied only when the soil matric potential values reached −40 kPa. Irrigation was stopped only when the soil matric potential values reached −10 kPa. Thus, the water depth of each irrigation event for each treatment during the growth period was different. Fertilizers were incorporated within the irrigation water using the SDI system and were applied to each treatment at rates of 157, 57, and 157 kg/ha N, P, and K, respectively.

2.4. Observations and Equipment

2.4.1. Soil Matric Potential

Two tensiometers were installed in the soil column of the second replication for each treatment (Figure 2). One tensiometer was installed in the center of the soil column at a 20 cm depth to schedule irrigation. Another tensiometer was installed at a 40 cm depth near the emitter to monitor the changes in the soil matric potential near the emitter during the winter wheat growth period. The tensiometers for each treatment were observed three times at 8:00, 12:00, and 17:00 daily during the growing period.

2.4.2. Root Growth and Root Intrusion Investigation

After the seedlings emerged, shade cloths were opened at 8:30 every day, and a high-definition camera was used to take pictures through the sidewalls of the transparent soil columns. The pictures whose resolution was 350 × 350 dpi were used to investigate the root growth.

Root sampling was performed just after harvest. In each soil column, all the roots were extracted at 5 cm intervals down to a depth of 80 cm. Dry root weight was determined using the oven-drying method, and root samplings were dried for 30 min at 105 °C and then for 10 h at 80 °C.

After the harvest, the drip tapes were extracted, and all the emitters were dissected to investigate root intrusion.

3. Results and Discussion

3.1. Irrigation Amount and Drainage Water

Figure 4 reveals that the irrigation amount and frequency changed during the growing season. The average irrigation amount per irrigation event occurred in the following order: D5 > D4 > D1 > D3 > D2. The average irrigation frequency occurred in the following order: D2 > D3 > D1 > D4 > D5. Seasonal total applied irrigation amounts for D1, D2, D3, D4, and D5 were 138, 82, 134, 98, and 109 mm, respectively.

No drainage water was found in any of the five treatments.

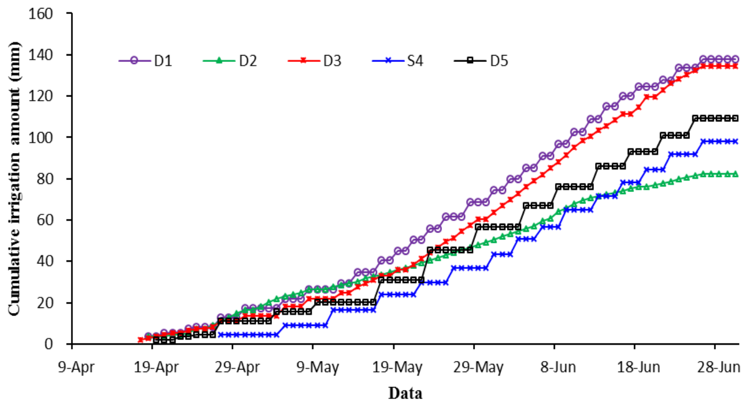

Figure 4. Cumulative irrigation levels for the five treatments.

3.2. Soil Matric Potential

3.2.1. Soil Matric Potential Distribution at a 20-cm Soil Depth

Figure 5 illustrates the soil matric potentials at a 20 cm depth during the wheat-growing period for the different treatments at 8:00. Soil matric potential values first decreased gradually and then increased immediately after the targeted values were reached, and irrigation was applied. Some values were not at the targeted values when they increased because the tensiometers for each treatment were observed at 8:00, 12:00, and 17:00 during a specific growing period. Although the targeted values had not been reached when they were observed, they might meet the targets at 12:00 or 17:00 when irrigation would also be applied. Accordingly, the values increased compared with the previous day.

Figure 5 shows that the soil matric potentials were well controlled at the targeted values.

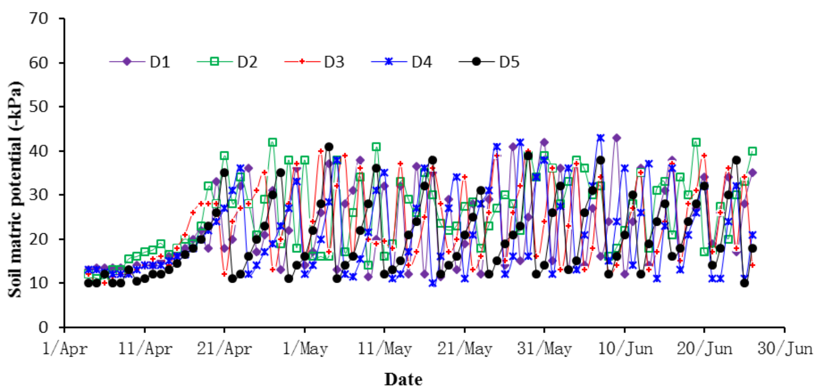

Figure 5. Soil matric potentials at a 20-cm depth for the five treatments.

3.2.2. Soil Matric Potentials Near Emitters

Figure 6 illustrates the soil matric potentials near the emitters for the five treatments. Soil matric potential values first decreased gradually and then increased immediately after the irrigation was applied. When the lateral line depth was different, the variations range of soil matric potentials near the emitters changed significantly. The variations range of the soil matric potentials increased as the lateral line depth decreased. After an irrigation event happened, soil matric potential values increased immediately. As the water absorbed by the root system, soil matric potential values decreased gradually. The water absorption capacity of the root system increased as the soil depth decreased [30]. Consequently, the variations range of the soil matric potentials increased as the lateral line depth decreased.

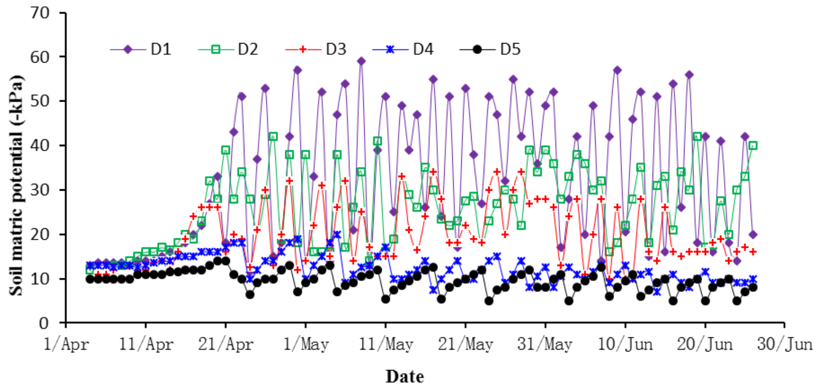

Figure 6. Soil matric potentials near the emitters for the five treatments.

3.3. *Crop Height*

The crop height growing process is illustrated in Figure 7. At the whole growth period, crop heights for the D3 and D4 treatments were very close. At the beginning of the growth period, crop heights for the D1 and D2 treatments were very close. At the later of the growth period, they varied from D1 > D2. For the five treatments, they varied from D3 > D4 > D5 > D1 > D2. Later in the growing period, crop height changed very slowly, and lateral line depths seemed to have little effect on crop height.

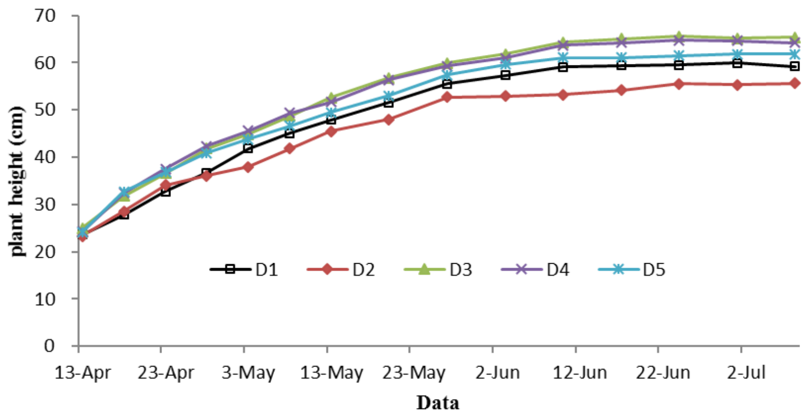

Figure 7. Plant height.

3.4. Root Distribution

Figure 8 shows the root growth depths that were surveyed from the sidewalls of the transparent soil columns. The root growth depth increased with time. Before the first irrigation happened (17 April), the root growth depth increased as the lateral line depth decreased. After the first irrigation was applied, the root growths of D1 and D2 treatment also differed, but no obvious regular pattern was discerned. For D3, D4, and D5 treatments, the result was similar. After 22 April, the root growth depths of the five treatments were greater than 40 cm. The depths of some roots that could not be visualized may have exceeded 40 cm prior to 22 April.

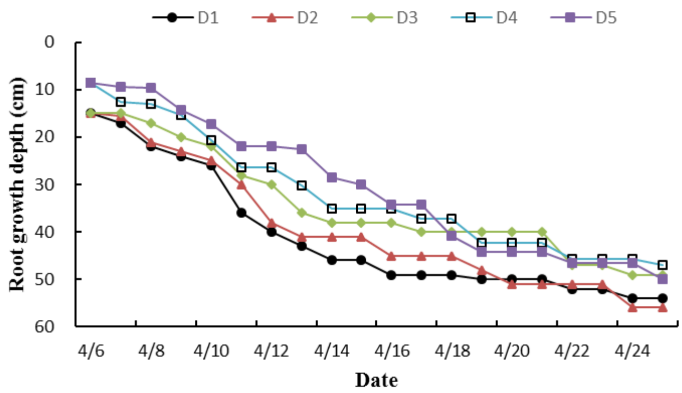

Figure 8. Changes in the root growth depth at different dates for the five treatments.

Before the first irrigation happened, root growth was affected by the initial irrigation. The initial irrigation amounts for D1, D2, D3, D4, and D5 were 10, 12, 24, 34, and 40 mm. The initial soil water content for the five treatments occurred in the following order: D5 > D4 > D3 > D2 > D1. Thus, low soil water content promotes root growth, in agreement with the earlier results of Plaut et al. [19] but contradictory to those of Rubens et al. [7]. According to Rubens et al. [7], low soil water content suppresses root growth. This result is largely the result of the dry treatment in the experiment, which was maintained until leaves had presented wilting symptoms in the morning before starting irrigation in Rubens' experiment. This showed that appropriate water stress could promote root growth, while excessive water stress could suppress root growth.

In Figure 9, the root distribution in soil depth of 0–80 cm is illustrated. At soil depths greater than 80 cm, very few roots were found. Root dry density weight values increased as the soil depth decreased. Among the five treatments, more than 79% of the roots occurred within a soil depth of 0–40 cm, and more than 50% of the roots occurred within a soil depth of 0–20 cm. This was consistent with the results of Plaut et al. [19], Li et al. [14], and Yu et al. [25].

At a depth of 0–80 cm, total root dry weight values for D1, D2, D3, D4, and D5 were 29.70, 32.01, 29.34, 26.34, and 26.38 g, respectively. Total root dry weight values for the five treatments followed the order D2 > D1 > D3 > D5 > D4. As shown in Figure 7, the root distribution was affected by the lateral line depth. The shallower the lateral line depth, the more nonuniform root distribution in a vertical direction. The root collection was found near the emitters for D1, D2, D3 treatments. Root dry weight density for the five treatments followed the order D1 > D2 > D3 > D5 > D4. This was consistent with the results of Shen [30].

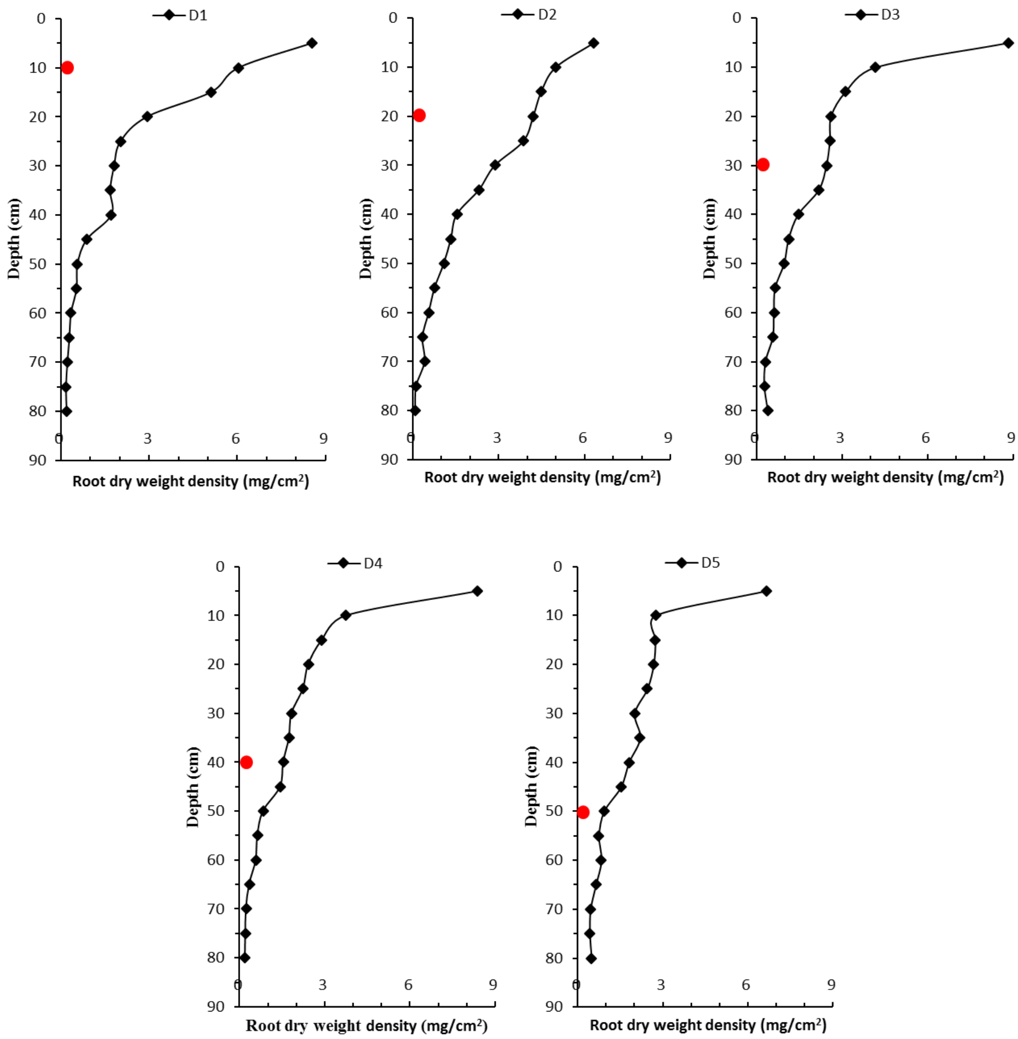

Figure 9. Changes in the root dry weight density with soil depth for the five treatments.

3.5. Root Intrusion

3.5.1. Changes in Emitter Flow Rate

Figure 10 shows the changes in the emitter flow with time for the different treatments. In the D1 treatment, the emitter flow decreased as time increased. The decrease in the flow mainly occurred before 17 June. After 17 June, the change in the emitter flow was limited. In the D2 treatment, the emitter flow decreased as time increased. Additionally, the decrease before 6 June was greater than the decrease after 6 June. In the D3 treatment, the emitter flow decreased as time increased. The decrease in the flow mainly occurred after 1 June. Before 1 June, the change in the emitter flow was limited. In the D4 and D5 treatments, the emitter flow generally decreased as the time increased. In addition, the emitter flow changed little.

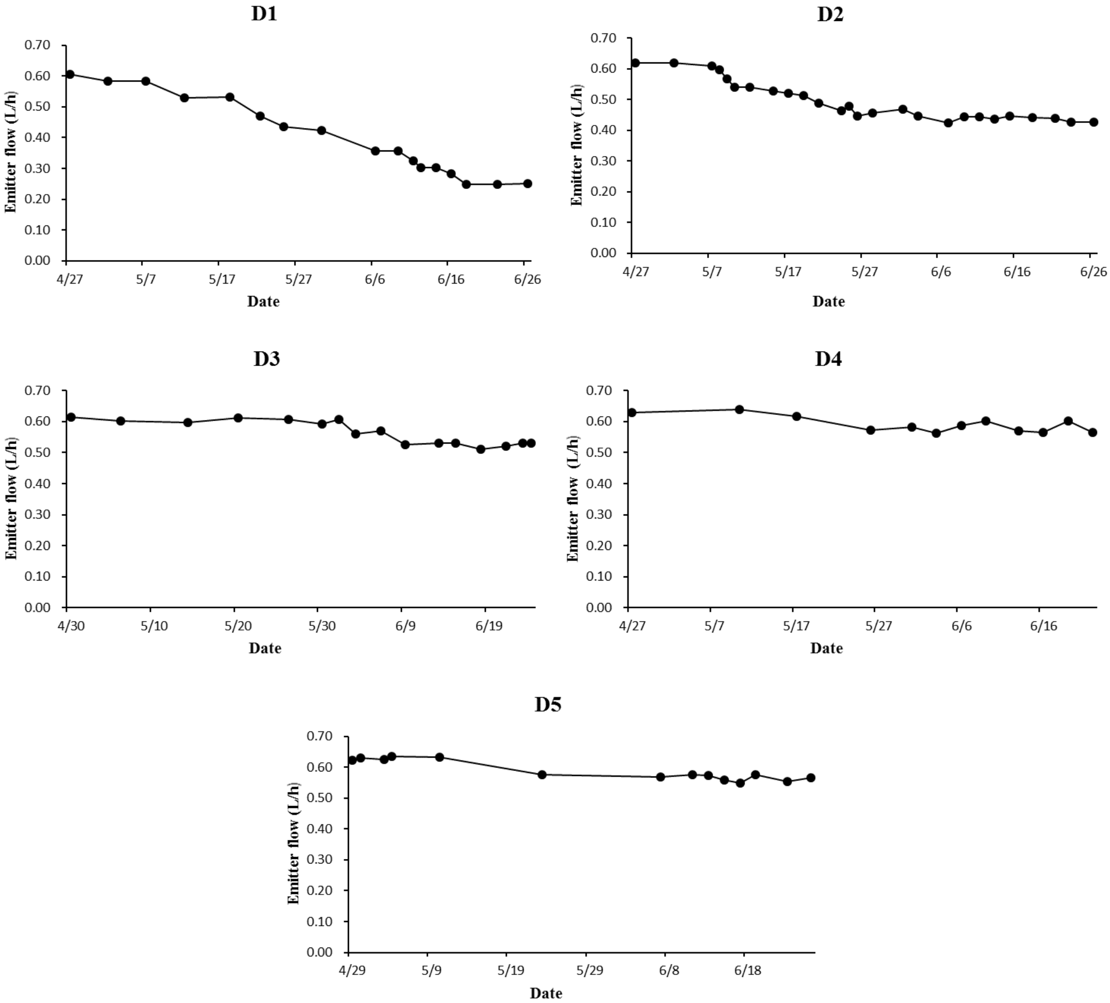

Figure 10. Emitter flow for different treatments.

Figure 11 indicates that the decrease in the emitter flow rate (eventual flow rate divided by the initial flow rate) for the five lateral line depths treatments occurred in the following order: D1 > D2 > D3 > D4 ≈ D5. The emitter flow rate increased as the lateral line depth decreased.

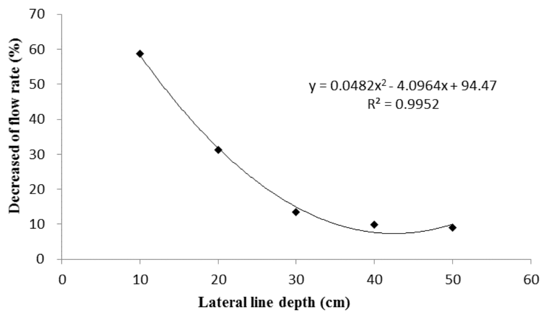

Figure 11. Decreased emitter flow rate for the five treatments.

3.5.2. Root Intrusion Investigating

After harvesting, all the emitters were extracted and dissected to investigate root intrusion. Figure 12 shows images of the three types of anatomical emitters. Figure 12a shows no root intrusion. Figure 12b shows roots that had entered into the water outlet of the emitter but had not entered into the channel, and Figure 12c shows roots that had entered into the emitter channel. Figure 12 reveals that there was some precipitate in the channels of the emitters and some silt in the water outlets of the emitters.

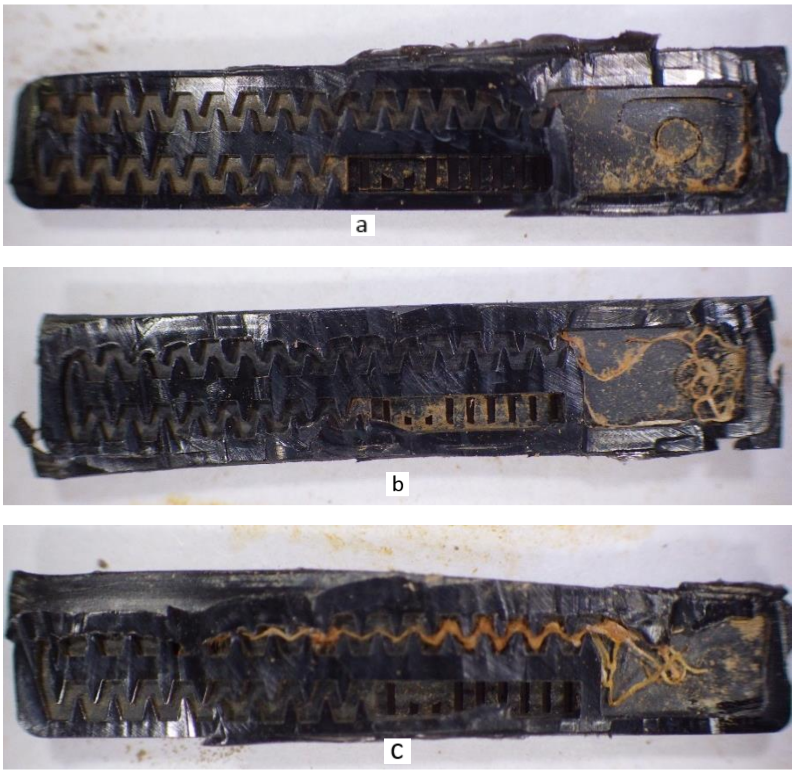

Figure 12. Photos of anatomical emitters: (**a**) no root intrusion; (**b**) roots that had entered into the water outlet of the emitter but had not entered into the channel; (**c**) roots that had entered into the emitter channel.

The results presented in Table 1 illustrate the data from the nine samplings for each treatment. The difference among different treatments was significant by F-test ($p < 0.05$). Values in a row with the same letter were statistically homogeneous by Duncan's test. Root intrusion occurred in all the treatments except D5, and the severity of intrusion was correlated with the lateral line depth. The number of intrusions, like those illustrated in Figure 12c, increased as the lateral line depth decreased. When the lateral line depth reached 40 cm, the number reached a minimum. The total number of events and the root intrusion rate for the five treatments were ordered as follows: D1 > D2 > D3 > D4 > D5. The minimum total number of root intrusion and root intrusion rates occurred in D5 treatment.

Table 1. Statistics for the anatomical emitters.

		D1	D2	D3	D4	D5
The number of sampling		9	9	9	9	9
The number of root intrusion	Type b	1	1	1	2	0
	Type c	7	6	3	0	0
	Total	8a	7a	4b	2b	0bc
Root intrusion rate (%)		88.88a	77.77a	44.44b	22.22b	0bc

It could be seen from the previous analysis that dry root weight density increased as the soil depth decreased. The initial soil water content for the five treatments occurred in the following order: D5 > D4 > D3 > D2 > D1. The low soil water content promoted the root growth. Those made the root weight density around the emitters different for the five treatments. The root weight density around the emitters for the five treatments occurred in the following order: D1 > D2 > D3 > D4 > D5. That made the root intrusion rate for the five treatments ordered as follows: D1 > D2 > D3 > D4 > D5. This was agreed by Sánchez [13] and Lamm [31].

The root intrusion led to the clogging of emitters. The anatomical emitters revealed that the decrease in the emitter flow rate was mainly owing to the intrusion of roots, as illustrated in Figure 12c. The emitter flow rate increased as the type number of clogged emitters decreased. This was similar to the results of Rubens et al. [7]. When the emitters were dissected to investigate root intrusion, in D4, the roots had just grown into the emitter channel exits. Consequently, the decreased emitter flow rates for D4 and D5 were similar. In this experiment, precipitate and silt found in the emitters also decreased the flow rate, but they were not the main reason.

3.6. Spring Wheat Yield and Quality

After harvest, two parameters, namely, relative yield (yield divided by the maximum yield) and relative thousand-grain weight (thousand-grain weight divided by the maximum thousand-grain weight), were selected as the indicators of spring wheat. These two parameters of spring wheat from all the treatments are listed in Table 2. In Table 2 the relative value for every dataset is the actual value divided by the maximum value and the difference among different treatments was significant by F-test ($p < 0.05$). Values in a row with the same letter were statistically homogeneous by Duncan's test.

Table 2. Effects of lateral line depth on spring wheat yield and quality.

	D1	D2	D3	D4	D5
Relative yield (%)	78.80a	41.74b	100a	80.85a	61.60ab
Relative thousand-grain weight (%)	93.17a	100a	90.49a	89.08a	76.01b

In the D1 treatment, severe root intrusion occurred in replications 1 and 3 (Figure 12c). The relative yields of replications 1 and 3 were just 42% and 58%, respectively. In the D2 treatment, the tensiometer, which was used to schedule irrigation, was installed next to the emitter. That made the irrigation amount of every irrigation event as 1~2 mm. So, the yield of D2 was significantly lower than other treatments. In the D3 treatment, the most severe root intrusion occurred in replication 3. The relative yields of replication 3 were just 33%. In the D5 treatment, the relative yields of replication 3 were just 16%. That was because the entrance of drip tape was crushed by the soil. That made the flow of replication 3 decreased a lot. Those results showed root intrusion affected the SDI system's uniformity and yield. This was agreed with Ferguson [11], Pizarro Cabello [8], and Ayars [2].

4. Conclusions

Root growth was affected by soil water content. Opportune water stress could promote root growth. Root distribution was affected by lateral line depth. Root dry density weight values increased as the soil depth decreased. The shallower the lateral line depth, the more nonuniform root distribution in the vertical direction, and the more root was distributed in the surface layer. When the lateral line depth was 10–30 cm, root collection was found near the emitters.

When the soil matric potential at a 20 cm depth, immediately over (lateral line depth <20 cm), under (lateral line depth >20 cm), or next to (lateral line depth = 20 cm) the drip emitters, was used to schedule the subsurface drip irrigation regime, the emitter flow rate and the root intrusion were affected by lateral line depth. The emitter flow rate increased as the lateral line depth decreased. Root intrusion increased as the lateral line depth decreased. When the lateral line depth was 30–40 cm, the decrease in the emitter flow rate and root intrusion were low, and the yield and quality of spring wheat were high. For spring wheat, when the soil matric potential at a 20 cm soil depth was used to determine the SDI regime, the lateral line depth of 30–40 cm was optimum.

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Conflicts of Interest: The author declares no conflict of interest.

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