Aerogation: Crop Root-zone Aeration through Subsurface Drip Irrigation System

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Abstract: - Subsurface drip irrigation as a source that provides the water directly to the root zone develops a saturated wetted front in the rhizosphere, particularly when the irrigation is close to 100% of evapotranspiration. Long duration irrigations collect root development around the drip emitters and relatively low hydraulic conductivity, mainly in heavy soils, lead to preservation of saturation in the root layer, resulting in lack of air, which is detrimental to the function of roots and directly influences crop development. The objective of this study is to examine whether the root zone aeration can improve the distribution of moisture in the soil thereby improving plant performance. For the investigation of this approach, a three-year experimental research was conducted, in a sugar beet crop, irrigated by a subsurface drip irrigation system. A technique for ventilating the root zone was developed, which comprises passing air in the irrigation water throughout the duration of irrigation using a venturi device and air supply under pressure after irrigation through a compressor. The air application (aerogation) affected the soil moisture in the root zone reducing the water content or repelled the water from the proximal environment of the emitter. Regarding the crop yield characteristics, the continuous air application gave a higher yield, although not statistically significant, than the conventional (without air) irrigation and aeration at the end of irrigation.

Key-Words: - Soil aeration, Drip irrigation, Soil wetting, Sugar beet

1 Introduction

Subsurface drip irrigation (SDI) has the potential to provide consistently high water use efficiency over traditional methods, including surface drip irrigation while conserving soil, water, and energy. The SDI systems have the capability of frequently supplying water to the root zone while reducing the risk of cyclic water stress that is typical of other irrigation systems. Various researchers have shown that crop yield and quality can be increased using SDI on major field crops including sugar beet [1,2,3].

Installing the drip tube up 30 to 50 cm below the soil surface places the water in the root zone where plants can use it efficiently. The drip tube is also deep enough that most surface tillage can be used without disturbing drip tube placement. Advantages of applying water by this method include: application of water at low operating pressure, minimal soil surface evaporation losses, maintenance of a uniform soil water content, and supplying the plant nutrients as needed during the growing season. These factors conserve energy and water and reduce the potential of polluting the environment while providing the plant-water needs [4].

The root zone of the plant must be well supplied with both water and oxygen. Water potential should be kept close to field capacity but if a low water tension is maintained, particularly in clay soil, plants will suffer most of the time from a sub-optimal level of oxygen supply in the root zone. The diffusion rate of gases in air is about 10,000 times greater than in water. Thus, it is obvious that the rate of gas diffusion decreases as the water content of the soil increases. These two requirements are apparently contradictory and the assessment of optimum level of soil aeration in the root environment is essential for better crop establishment and growth.

Subsurface drip irrigation (SDI) as a source that provides the water directly to the root zone develops a saturated wetting front in the rhizosphere, particular when irrigation depth is close to 100% of evapotranspiration or even lower [5]. Long duration irrigation events result in root development concentrated around the emitters and the relatively low hydraulic conductivity mainly in heavy soils retains the saturation in the root zone, resulting in lack of air, which is detrimental to the root functioning and directly influences crop development. Theoretical and experimental approaches [6,7] indicate that aeration of the root zone improves the yield of crops cultivated in both hydroponics and soil.

The idea of soil aeration probably belongs to M. Enyeart and the first experiments were conducted in the late 1970 as referred by Daigger (1979) and Busscher (1982) [8,9] with interesting results. In these experiments an air compressor was used to supply air via perforated pipes placed at some depth in the field and in pots.

Recent studies have shown that the ventilation of the root zone of crops via SDI increased growth and crop yield [10,11]. Goorahoo et al. (2001) [12] confirmed that crops irrigated with SDI are subject to lack of oxygen in their root zone and suggested the air supply in pepper cultivation.

Soil aeration by means of injection of atmospheric air into the soil via a subsurface drip irrigation system, is thought to accelerate the depletion of water from macropores and increase the oxygen concentration in the soil air.

Based on the foregoing, the present investigation proposes aerogation, a technique of root zone aeration that includes the injection of air in the irrigation water throughout the duration of irrigation and the forced air supply after irrigation. The basic infrastructure of SDI allows easy connection of air supply systems on irrigation line and thereby the direct air supply to the root zone of crops.

A sugar beet crop was subjected to aeration and the performance of these treatments is compared with a non-aerated control to quantify the effects of aeration on sugar beet yield.

2 Materials and Methods

2.1 Field experimental setup

The experiment was carried out during the growing seasons of years 2003-2005, in the farm of the University of Thessaly situated at central Greece. Sugar beet cultivar Arrieta was planted in a clay loam soil belonging to Typic Xerofluvent sub-group of Entisols, with a bulk density of 1.33 g/cm^3 and 125 mm Total Available Water (TAW).

The experimental design was developed in random blocks, with four replications for each of the three treatments tested. Treatments included aerated (continuous injection by venturi, AIRcont, and post irrigation delivering by compressor, AIRend) and non-aerated plots, SDIconv. Each elementary plot was 3 m x 12 m containing six plant rows.

Tops were hand harvested, the number of roots was counted and fresh roots were weighed for each plot. Subsamples of roots were analyzed by the Hellenic Sugar Industry's laboratory at Larissa, Greece, for sugar content determination.

Commercially available drip piping with 1.0-m lateral spacing was buried at a depth of 0.45 m corresponded to the middle of alternative plant rows. Pressure-compensated emitters discharging 2.3 l/h at a pressure range between 50 and 300 kPa were spaced 0.8 m apart along the lateral. The emitters were facing up in order to prevent clogging from soil sediments remaining in the lateral and to guide the air upwards.

2.2 Air supplying techniques

Air injection was accomplished by mixing air at the rate of 12% by volume of the irrigation water employing a Mazzei manufactured venture injector coupled in the pressurized irrigation line. The venturi injector gas inlet port was fitted with a throttling valve and set up to attach to an air flowmeter. An air compressor was connected to the post-irrigation treatment manifold, delivering air through the laterals, after irrigation seized, for a time period as much as needed to apply air in approximately 12% of the applied water.

2.3 Irrigation scheduling

Irrigation was scheduled using a water budget to calculate the root zone depletion with precipitation and irrigation water amounts as deposits and calculated crop evapotransiration as a withdrawal, according to the methodology formulated by Allen et al. [13]. The reference evapotranspiration, was calculated on a daily basis by means of Penman–Monteith's FAO-56 equation, using meteorological data from a meteorological station located within the farm.

Irrigation water amount was metered separately onto each treatment with commercial flow-meters with an accuracy of ±1.5%. The normal irrigation depth was about 24 mm, for a 4-days irrigation interval.

Soil moisture was monitored with a TDR system (Moisture Point, Environmental Sensors Inc.) to a depth of 1.2 m, approximately twice a week during each crop season. The irrigation schedule was not updated with respect to the measured soil water. Trime-FM instrumentation (Imko Gmbh) was used to take measurements of moisture in the soil profile, in trenches created perpendicular to the irrigation lines in order to record the spatial soil-moisture distribution around the emitter.

3 Results and Discussion

3.1 Effect on crop production

Table 1 presents the resulted root yield for each experimental year. In the first growing season the conventional irrigation (SDIconv) gave the highest fresh root weight, without statistically significant difference. In the second experimental year, continuously applying air (AIRcont) showed the highest production, followed by the conventional irrigation although without statistically significant differences between the treatments. At the third year's harvest, the continuous air application outweighed again the conventional, but not varying significantly. The difference between these two treatments and the application of air at the end of irrigation was strongest this year showing statistically significant difference.

Table 1. Root and sugar yields in T/ha.

Year	Yield			Sugar		
	SDI conv	AIR cont	AIR end	SDI conv	AIR cont	AIR end
1	84.58	82.87	81.36	13.51	13.12	12.69
2	75.63	76.06	72.40	12.30	12.21	11.71
3	83.46	86.81	72.86	12.27	12.29	10.07
Average	81.22	81.91	75.54	12.69	12.54	11.49

3.2 Effect on soil moisture

The temporal variation of moisture in the soil profile for each treatment is given in Fig. 1. At the surface layer, there is no significant difference between the air application treatments although AIRend ranged at slightly higher levels than the SDIconv. At this depth, low soil moisture values occur since the surface layer is not wetted because of the subsurface water application. In conventional application, the lower wetting of the surface layer occurs and soil moisture ranged in permanent wilting point level.

In 15-30 cm depth, in all cases, the soil moisture retained close or at field capacity level. Higher moisture levels compared with the other two treatments occurred in the AIRend treatment.

At the depth of 30-60 cm, an increased moisture level recorded in conventional irrigation, compared with the depth of 0-30 cm. In air handling applications, the trend observed in the previous two depths is maintained, with AIRend varying on systematically higher levels of soil moisture than AIRcont.

At the depth of 60-90 cm, there is high soil moisture, with no significant differences between treatments with AIRend having consistently higher levels than AIRcont.

Finally, at the last depth, that of 90-120 cm, the highest values of moisture were recorded, with no significant variation between treatments.

2.1.1 Soil moisture distribution

Figure 2 shows the distribution of soil moisture as measured in each treatment after application of irrigation. The distribution shown is representative of three series of measurements that carried out. The moisture content was measured with the Trime-FM (TDR) device and is expressed in volume percentage. The escalation of the color gradient and the moisture contour lines that created, give an image of the distribution of water to each treatment.

The continuous application of air (AIRcont) has shown better results than the air at the end of irrigation application, wherein the air supply seems to reduced moisture above the emitter, but below this level, moisture ranged at high levels.

Table 2 presents some parameters that can help in the evaluation of moisture distribution in each treatment. The table lists the maximum moisture measured by the Trime-FM device and the uniformity of moisture values, as calculated by Cristiansen's coefficient of uniformity (CU).

Finally, in the table is given the surface covered by the available soil moisture (TAW), calculated as the difference between the contour lines of field capacity and that of wilting point, as a percentage of total wetted surface.

Table 2. Soil moisture distribution evaluation parameters.

Treatment	θ_{max} (% vol)	CU_θ (%)	A_{TAW} (%)
SDI conv	41.09	49.5	46.6
AIR cont	40.52	42.2	50.9
AIR end	41.74	42.9	40.4

2.1.1 Soil wetted profile

In drip irrigation design the soil volume wetted by an emitter is quite important. This must be known in order to determine the total number of emitters needed to wet a large soil volume in order to meet the requirements of a crop.

Very little attention has been given to assessment of the distribution of water from the drip source under actual field conditions. The lack of understanding of how the distribution of soil water is influenced by the hydraulic properties of the unsaturated soil sometimes result in mishandling and consequently in low water use efficiency.

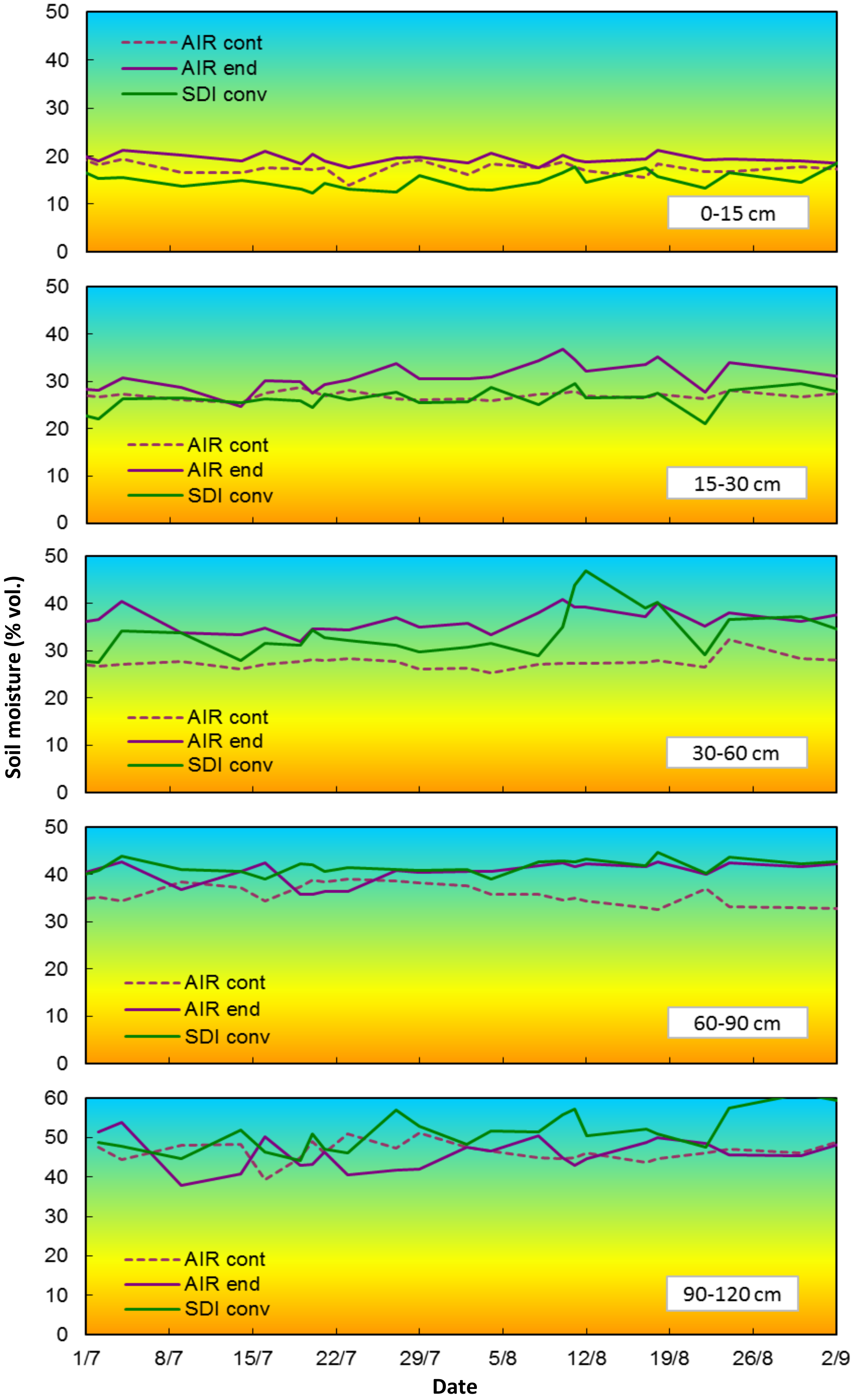

Figure 1. Temporal soil moisture variation in the soil profile for each treatment.

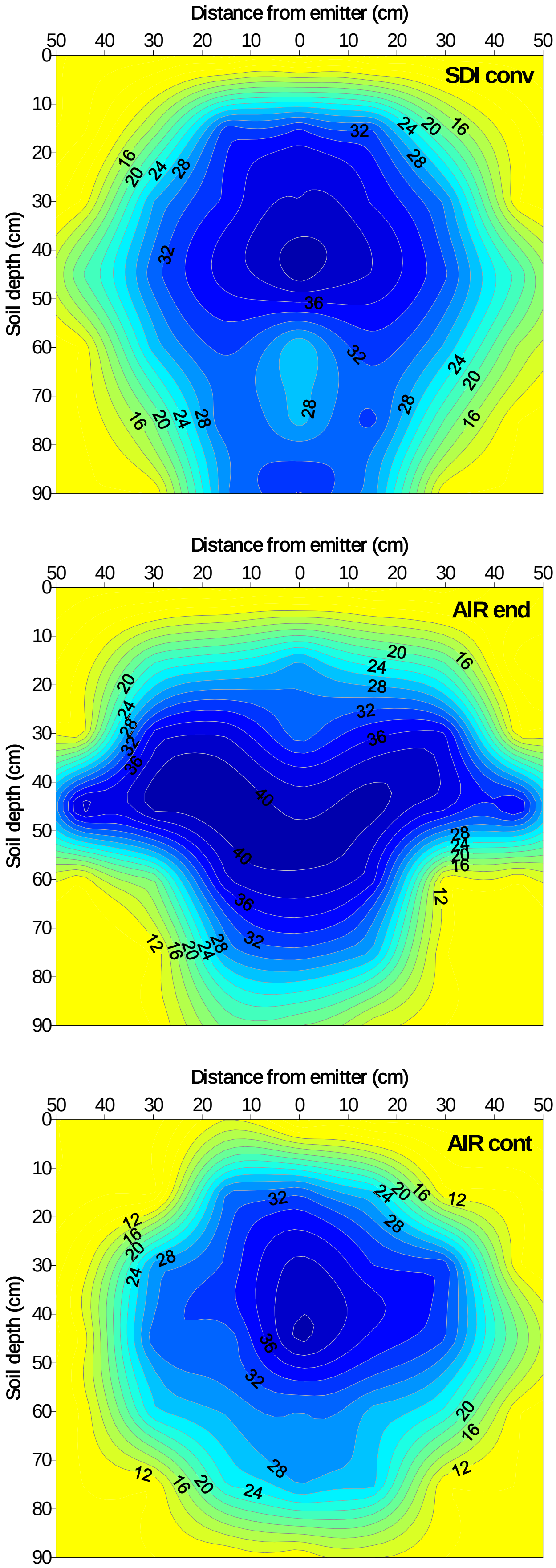

Figure 2. Profile of soil moisture (% by volume) as recorded after irrigation.

The form of wetting for each treatment was investigated in the experimental plot in a ditch excavated vertically to the drip laterals. The position of the wetting front was recorded by means of a 1 x 1 m grid with lattice dimensions of 0.1 x 0.1 m.

The term wetting front as used herein refers to recording of discrete visible boundaries between dry and moistened soil. This limit is clearly not the actual wetting front since it was not determined by measuring the soil moisture, but the process followed is a common practice among several researchers who studied the issue [14,15]. Despite the lack of accuracy in the determination of the wetting front, the visual recording indicates the shape variation of the water distribution under the different application techniques.

The measurements of wetting front to the soil depth presented in Fig. 3. In air application, the form of wetting front was similar to that of conventional SDI in downward and lateral directions but the shape of soil wetted varied clearly in upward direction where in aerogation treatments the air seemed to force the water towards the soil surface.

4 Conclusion

Typically when you irrigate, you displace a certain amount of air in the root zone. With “aerogation” we simply try to supplement the air that is displaced during irrigation. The air application influenced the soil moisture in the root zone reducing water content or repelled water from the nearest environment of the emitter.

Despite the lack of statistical significance, soil aeration tended to increase the root yield of sugar beet. These results and experience gained from this experiment will be the basis for more detailed investigations on the effect of soil aeration on the soil-plant system. The current findings justify follow-up fieldwork on larger plots approaching commercial scale.

However, any such work should include monitoring additional parameters such as soil oxygen content, soil and plant nutrient status, crop canopy, soil microbial activity and pressure and velocity measurements along the irrigation system. These additional measurements would allow for a more comprehensive investigation into any air-water mixture and soil-plant relationships.

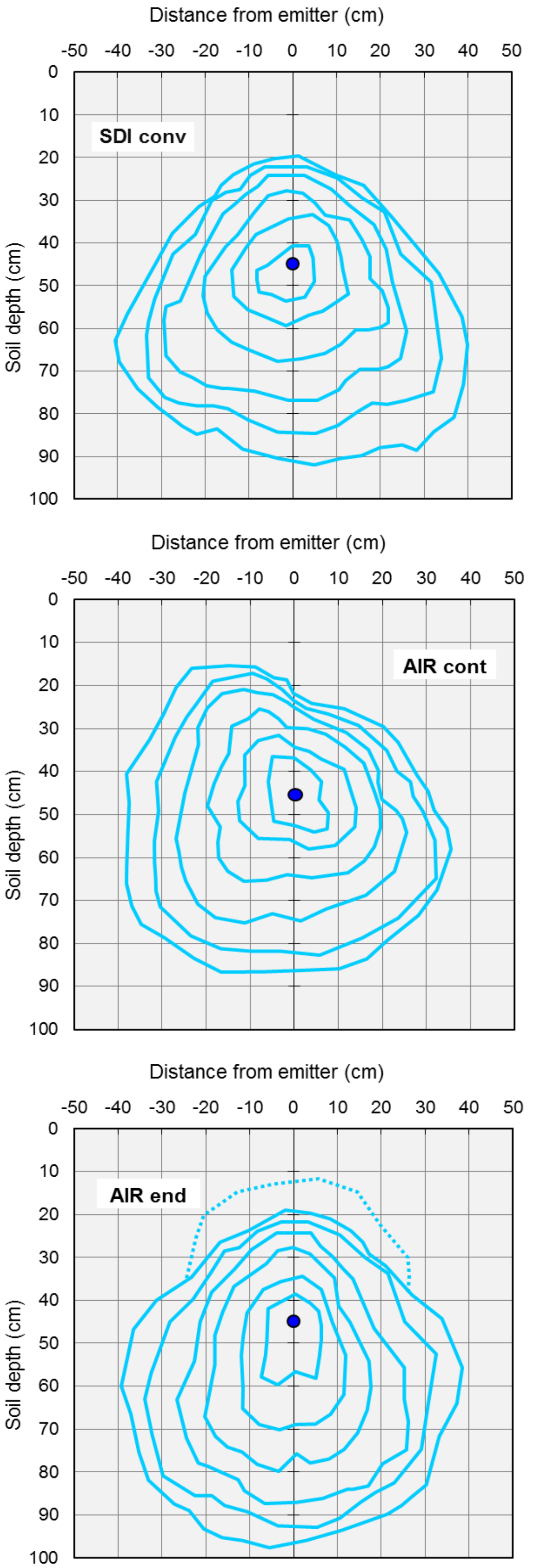

Figure 3. Wetting front as recorded in the three treatments.

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