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Research Article

Optimization Study on the Space and Depth of Subsurface Drainage Tubes for Greenhouse Salty Soils: A 3-Year Field Experiment in South of China

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Abstract: A well-designed subsurface drainage system with reasonable drain space and depth contributes to large ratio of desalination and high crop yield. In order to find out the optimal space and depth of subsurface drainage tubes for tomato cultivation in greenhouse salty soils in south of China, drainage treatments with different buried methods were designed, the tomato quality, yield, Irrigation Water Use Efficiency (*IWUE*) and surface soil electricity conductivity in the treatments were observed during 2010 to 2012 growth seasons and the principle component analysis model and projection pursuit model were used to select the treatment with best comprehensive effects. Results showed that: (1) The tomato yield was increased by 14.21 to 50.29% during the growth seasons; (2) Surface soil EC decreased significantly, although in the process of experiments, surface soil EC of some treatments showed a temporary rise; (3) Under the same buried depth, the closer arrangement of subsurface drainage tubes appeared to be more effective for the yield gaining and topsoil desalination; (4) T7 was proved to be the optimal treatment according to the calculations of projection pursuit model, the comprehensive effects of which were the best, mainly embodying in improving the tomato quality, increasing the yield and *IWUE* and reducing salinity in topsoil. In this study, 0.8m depth combining with 4m space was selected as the optimized layout of subsurface drainage tubes for the tomato cultivation in greenhouse salty soils of south China.

Keywords: Projection pursuit, salty, subsurface drainage, tomato

INTRODUCTION

Saline soils are wide-spread and characterized by poor plant growth and low microbial activity (Asghar *et al*., 2012). In south of China, plastic greenhouses were the main facilities for vegetable production in winter and spring, but most of the greenhouses were in the semi-closed state lacking the leaching of rainfalls and the water and fertilizer management was lagging, this resulted in severer problems of salt salinity and blocked the sustainable development of the facility agricultural production (Jie *et al*., 2012).

Subsurface drainage had been proved to be an effective way in decreasing the soil salinity and controlling the underground water level (El-Sadany Salem *et al*., 1995; Mathew *et al*., 2001; Ritzema *et al*., 2008). Ritzema *et al*. (2008) and Ghumman (2010) suggested that in one period of crop growth, the utilization of subsurface drainage system can reduce the EC value by 50 and 17%. Nowadays, subsurface drainage systems have been installed to reclaim salt affected lands both in humid and arid areas (Mastrocicco *et al*., 2013). In Iowa, about 3.6 million ha of row crop area benefits from subsurface drainage during the crop growing season from April to October (Singh *et al*., 2007) and in Finland, 53% of cultivated fields (a total of 1.4×10^6 ha) are subsurface drained (Nuutinen *et al*., 2001). However, there were rare reports or studies about the application of subsurface drainage system on the improvement of greenhouse salty soils.

In this study, subsurface drainage systems with different space and depth were designed for greenhouse salty soils and the tomatoes were chosen as plant materials, the objectives were:

- Understanding how drainage systems affect the tomato quality.
- Exploring how the tomato quality, yield, *IWUE* and surface soil EC change under different subsurface drainage systems in the three years.
- Find out the optimized layout scheme of subsurface drainage tubes for the greenhouse salty soils of south China.

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Table 1: The depth and spacing of subsurface drainage tubes

Treatment	CK	T1	T2	T3	T4	T5	T6	T7	T8	T9
Depth (m)		0.4	0.4	0.4	0.6	0.6	0.6	0.8	0.8	0.8
Spacing (m)		4	6	8	4	6	8	4	6	8

MATERIALS AND METHODS

Experiment site: The experiments were carried out in film covered greenhouses at TongLi agricultural ecological park in Jingjiang, south of China. Jingjiang enjoys a moderate monsoonal climate in East Asia, which is warm and humid with four different seasons. Highest and lowest temperature appear in July and January separately, the mean annual temperature was about 14.4~15.1°C and the mean annual rainfalls were 1037.7mm. Soils of 0-20 cm were salt affected heavy clay loam with PH 5.13, EC 5.47 ms/cm, bulk density 1.36 g/cm^3 and K_{10} 0.85 10^{-4}cm/s.

Experimental design: The greenhouse salty soils were treated with 10 different subsurface drainage treatments and the depth and spacing of drainage tubes were shown in Table 1. The drainage tubes were all plastic corrugated pipes with diameter of 5cm, covered with non-woven fabrics. Material of leader drain pipes was PVC. Drainage ponds with enough capacity were excavated on the side of each treatment to collect the outflow from the subsurface drainage tubes and water pumps were used to debouch the water from the ponds.

Tomato cultivar "Xi Lan Ruby" was chosen as the plant material, seeds of tomato were sown in seedling trays each with 72 wells of 5×5 mm. Six weeks after seeds were sown, the young tomato plants with 6 expanded leaves were transplanted to the salty soils in greenhouses. Plant density was 4.2×10^4 plants hm^{-2}, with row spacing of 60cm and plant spacing of 40cm. During the whole growth period, conventional field management accorded with the local farming practices was conducted, which was kept the same among the treatments. The experiments lasted 3 years from 2010 season to 2012 season and the tomato cultivar remained unchanged in the three years.

Sampling and measurements: Surface soil EC (electricity conductivity) was measured by HH2/WET soil values electronic tachymeter (produced in England) and the monitoring point was right above the middle of two adjacent tubes.

Six representative tomato plants were chosen from one treatment and 3 ripe fruits in one plant were taken randomly at upper, middle and lower position for monitoring. Tomato volume was measured by the displacement method; tomato yield was calculated according to the observation of representative plants; soluble solid was measured by ACT-1E digital refractometer produced by ATAGO Company, Japan; total sugar was measured by fehling reagent titration method; total sugar was measured by NaOH titration method; V_c content was measured by 2, 6-dichloroindophenol titration method (Kahlon *et al*., 2008; Wang *et al*., 2011).

Irrigation water use efficiency (*IWUE*) was calculated by (Reina-Sánchez *et al*., 2005):

$$IWUE = \frac{Y}{I}$$

where,
Y = The tomato yield (kg hm^{-2})
I = The total irrigation amount (m^3 hm^{-2})

Data analysis: The Projection Pursuit (PP) model was used to select the optimum space and depth of subsurface drainage tubes. PP model was demonstrated to be an effective way in solving problems of high dimensional data (Hou *et al*., 2012), which reserved plentiful raw data information and data structure.

The essence of PP model is making use of computer technology to project high dimensional data to lower dimension, searching for the projection which could well reflect the characters of high dimensional data and studying data structures in low dimensional space, in order to achieve the aim of analyzing and disposing high dimensional data (Shao *et al*., 2012).

RESULTS AND DISCUSSION

Tomato quality: Tomato quality indexes and their values in 2010 season were shown in Fig. 1, fruit density (ρ), fruit density (V_F), soluble solid (D_S), total acid (G), vitamin C (V_C) and sugar/acid ratio (RSA) were selected to evaluate the comprehensive quality of tomato fruits. The depth of subsurface drainage tubes had no obvious effects on tomato quality, however, the space of which affected the values of quality indexes significantly: D_S, G, V_C and RSA value of T1, T4 and T7 was at a better level compared to that of other treatments, indicating a satisfactory effect on the balanced nutrient absorption of tomatoes. With the same irrigation, fertilization and field management supplied, CK detected a poor tomato quality with lower D_S, V_C and RSA value and higher G value. Generally, moderately saline condition improved tomato quality including the soluble solid content and fruit tastes (Cuartero and Fernández-Muñoz, 1998), while the situation was different in this experiment, salt concentration in soils of CK should be higher theoretically since which had no drainage treatments, but fruit quality of CK was no better than that of drainage treatments, hence other factors which had more significant effects on tomato fruits compared to

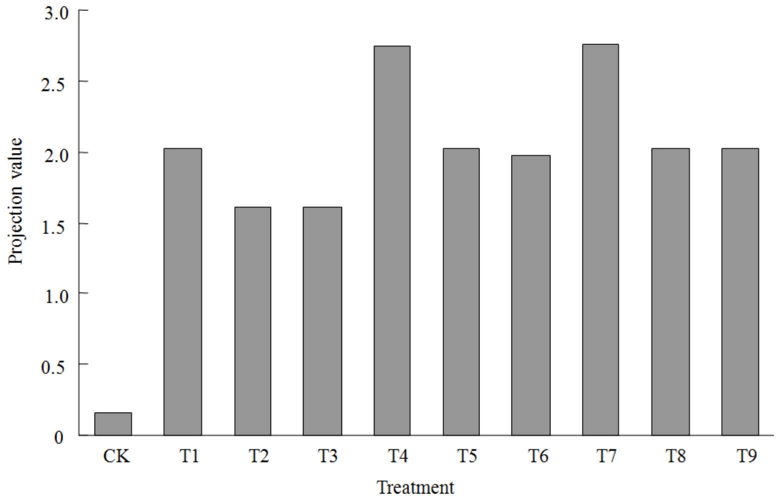

Fig. 1 Projection value of the treatments calculated by PP model

Table 2: Tomato quality indexes and their values in 2010 season (Values in the same column with same letters in the same test item show no significance (Duncan, 5 %), the same below.)

Treatment	ρ (g/cm^3)	V_F (cm^3)	D_S (%)	G (g/100g)	V_C (mg/100g^1)	*RSA*
CK	0.938a	119.880c	5.110c	0.7200a	10.280b	7.140c
T1	0.942a	138.68ab	7.280a	0.6230b	11.47ab	8.48ab
T2	0.951a	139.220a	6.72ab	0.6720a	11.12ab	8.110b
T3	0.948a	132.18bc	6.150b	0.6540a	11.87ab	7.96bc
T4	0.954a	144.250a	7.110a	0.5980b	13.370a	10.02a
T5	0.949a	134.260b	7.060a	0.6160b	12.890a	9.640a
T6	0.946a	125.440c	5.840bc	0.633ab	12.940a	9.22ab
T7	0.952a	141.220a	6.87ab	0.634ab	12.660a	9.400a
T8	0.955a	136.450b	7.320a	0.6860a	11.48ab	8.160b
T9	0.953a	137.88ab	6.73ab	0.7040a	10.99ab	7.420c

Table 3: Weight coefficient and contribution rate of main ingredients (2010 season)

	X_1	X_2	X_3	X_4	X_5	X_6	Eigenvalue	r_c/%	r_T/%
f_1	0.120	0.243	0.256	0.943	0.949	0.953	2.837	47.285	47.285
f_2	0.862	0.920	0.888	0.204	0.190	0.246	2.516	41.928	89.213

salinity were inferred to exist in the experimental soils and which needed a further study.

Main ingredient extraction of tomato quality indexes: The main ingredients of tomato quality indexes (Table 2, 2010 season) were extracted using principle component analysis method based on the principle of "eigenvalue>1, accumulative contribution rate>80%" (Babaoğlu *et al.*, 2010; Ul-Saufie *et al.*, 2013), the calculated weight coefficient and contribute rate of main ingredients were shown in Table 3.

The first principle component (f_1) mainly reflected the evolution information of total acid (X_4), vitamin C (X_5) and sugar/acid ratio (X_6), the second principle component (f_2) mainly reflected the evolution information of fruit density (X_1), fruit volume (X_2) and soluble solid (X_3). The cumulative contribution rate reached a high value of 89.213%, suggesting that vast quantities of the original information were remained during the calculations. The comprehensive quality index (M^a) of tomatoes with different treatments was shown in Table 4, tomatoes in the treatment with higher M^a value were proved to obtain better fruit quality. Analysis of tomato quality in 2011 and 2012 season was the same as that of 2010 season.

Evaluation indexes of subsurface drainage system: Table 4 collected the evaluation indexes of subsurface drainage system in different growth seasons, including the comprehensive quality (*M*), irrigation water use efficiency, tomato yield and surface soil EC. Tomatoes of T4 obtained best comprehensive quality in all growth seasons, but the yield seemed to have no direct relationship with fruit quality, T7 achieved the highest yield in 2011 and 2012 season, recording as 108.7 t/hm^2 and 128.2 t/hm^2 respectively. The tomato yield in all treatments presented obvious rising tendency with the increasing rate of 14.21~50.29%, by comparing the observation results of 2010 season and 2011 season.

Surface soil EC reflected the desalinization effects of subsurface drainage system, hence reducing EC value was one of the main tasks in this experiment. As was shown in Table 4, surface soil EC presented a decline trend during the growth seasons, overall. While

Table 4: Evaluation indexes of subsurface drainage system from 2010 to 2012 season

	2010 Season				2011 Season				2012 Season			
Treatment	M^a	$IWUE^a$ (kg/m^3)	Yield^a (t/hm^2)	EC^a (ms/cm)	M^b	$IWUE^b$ (kg/m^3)	Yield^b (t/hm^2)	EC^b (ms/cm)	M^c	$IWUE^c$ (kg/m^3)	Yield^c (t/hm^2)	EC^c (ms/cm)
CK	1.00	24.4	73.2	5.68	1.00	25.6	72.10	5.42	1.00	25.6	83.6	5.03
T1	2.50	29.3	87.8	4.02	2.18	35.0	98.70	4.15	2.39	34.6	112.8	3.53
T2	2.32	26.7	80.2	4.29	1.94	32.7	92.10	4.46	2.28	31.7	103.5	3.69
T3	2.17	29.8	89.3	4.58	2.25	32.0	90.10	4.63	2.16	32.7	106.6	3.74
T4	3.37	32.3	96.8	3.87	2.98	33.4	94.20	3.54	3.31	36.0	117.5	2.66
T5	2.90	28.5	85.6	4.06	2.75	28.5	80.30	3.78	2.27	34.8	113.4	2.87
T6	2.35	27.3	81.9	4.17	2.46	31.4	88.60	3.85	2.64	30.3	98.9	3.01
T7	2.92	28.4	85.3	3.92	2.77	38.5	108.7	3.16	2.74	39.3	128.2	2.48
T8	2.46	30.4	91.2	4.98	1.95	34.5	97.30	3.54	2.30	37.2	121.3	2.87
T9	2.11	27.6	82.8	4.42	2.24	32.8	92.6	3.28	2.05	35.4	115.3	2.64

Superscript a, b, c represented the growth season of 2010, 2011, 2012, respectively, for example, M^a, M^b and M^c represented the comprehensive quality of tomatoes in 2010, 2011 and 2012 season, respectively

EC of T1, T2 and T3 increased during 2010 season to 2011 season, this might relate to the shallower depth of drainage tubes and salt in the deeper soil layer went up with the effects of evaporation or underground water level. EC value of T7, T8 and T9 appeared to decrease most steeply, although in 2011 season, which had no remarkable difference with other treatments, indicating that 0.8m depth of subsurface drainage tubes were more conductive for topsoil desalination in the longer term. Under the same burial depth, the closer arrangement of drainage tubes was more efficient in reducing the EC value and in the treatments of 4m space, T7 was discovered to possess the best desalination effect, surface soil EC value of which was reduced to 2.48 ms/cm in the 2012 season.

Selection of optimal subsurface drainage system based on PP model: Model creation method is shown as follows (Zhang and Dong, 2009; Zhao and Atkeson, 1996):

- **Establish the evaluation matrix:** Suppose the sample size is *n*, number of evaluation indexes is *p*, the j^{th} index of i^{th} sample is x_{ij}^*, then the evaluation indexes could be expressed by an $n \times p$ matrix X^*:

$$X^* = \begin{bmatrix} x_{11}^* & x_{12}^* & \cdots & x_{1p}^* \\ x_{21}^* & x_{22}^* & \cdots & x_{2p}^* \\ \vdots & \vdots & & \vdots \\ x_{n1}^* & x_{n2}^* & \cdots & x_{np}^* \end{bmatrix}$$

- **Quantify the evaluation indexes:** In order to eliminate the differences of dimension, following measures are taken:

For the "the larger the better" index:

$$x_{ij} = \frac{x_{ij}^* - \min(x_j^*)}{\max(x_j^*) - \min(x_j^*)}$$

For the "the smaller the better" index:

$$x_{ij} = \frac{\max(x_j^*) - x_{ij}^*}{\max(x_j^*) - \min(x_j^*)}$$

A new $n \times p$ matrix X can be obtained:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix}$$

where max (x_j^*) is the maximum of j^{th} index, min (x_j^*) is the minimum value of j^{th} index.

- **Linear projection:** The essence of linear projection is to observe the data from different angles, to search for the best projective direction which could well reflect the characters of the data, therefore, suppose the unit vector $a = \{a_1, a_2, \ldots a_p\}$ as the one dimensional projective direction and z_i as the one dimensional projective eigenvalue:

$$z_i = \sum_{j=1}^{p} a_j \cdot x_{ij} \qquad (i = 1,2,3\cdots,n;\ j = 1,2,3\cdots p)$$

- **Constructs an object function of projection:** Express the object function as the product of distances between classes and density between classes:

$$Q_{(a)} = S_z \cdot D_z$$

where,

S_z = The standard value of projective eigenvalue z_i, also named distances between classes
D_z = The density between classes of z_i:

$$S_z = \sqrt{\frac{\sum_{i=1}^{n}(z_i - E(z))^2}{n-1}}$$

where, *E(z)* is the average of the array $\{z_i \,|i=1\sim n|\}$:

$$D_Z = \sum_{i=1}^{n}\sum_{k=1}^{n}(R - r_{ik})\cdot f(R - r_{ik})$$

where, *R* is window radius of local density:

$$r_{ik} = \left| r_i - r_k \right|$$

$$f(t) = \begin{cases} 0 & t \ge 0 \\ 1 & t \le 0 \end{cases}$$

$i, k = 1, 2,3.....n.$

- Optimize the object function. Optimize the projective object function by maximization:

$$\max Q_{(a)} = S_z \cdot D_z$$

$$s.t. \sum_{j=1}^{p} a^2(j) = 1,$$

$$\left| a(j) \right| \le 1$$

- **Evaluation:** The contribution of evaluation index can be obtained according to the best projective direction, the stand or fall of the samples can be also obtained on the basis of z_i value.

Projection Pursuit classification model (PP) was calculated by Matlab 7.1 based on the indexes in Table 4 and RAGA was used to optimize the PP method. In the course of optimization, the main parameters were set as: the original population size n = 400; the probabilities of crossover P_c= 0.8; the probabilities of mutation P_m = 0.8; number of excellent individuals was 20; α = 0.05; accelerating 20 times. According to the model's calculations, the best projection direction was $a_{(j)}^*$ = (0.2066, 0.1758, 0.0618, 0.3687, 0.3462, 0.2941, 0.2009, 0.4042, 0.4543, 0.0653, 0.1005, 0.3947) and the projection value of CK to T9 was ordered to be $z_{(i)}^*$= (0.2500, 2.0243, 1.6085, 1.6065, 2.7416, 2.0249, 1.9636, 2.7580, 2.0244, 2.0206), shown as Fig. 1. T7 was proved to be the optimum subsurface drainage system on account of the highest projection value, followed closely by T4.

CONCLUSION

In the third year after the operation of subsurface drainage systems, the tomato yield gained ranging from 14.21 to 50.29%. Meanwhile, the surface soil EC decreased significantly, although in the process of experiments, surface soil EC of some treatments showed a temporary rise.

Under the same buried depth, the closer arrangement of subsurface drainage tubes seemed to be more effective for the yield gaining and topsoil desalination. Among the treatments of 4m space, T4 obtained better fruit quality in the all growth seasons; while T7 was the optimal treatment according to the calculations of projection pursuit model, the comprehensive effects of which were the best, embodying in improving the tomato quality, increasing the yield and irrigation water use efficiency and reducing salinity in topsoil. In the practical cultivation of tomatoes in salt affected greenhouse soils, a modest increase of drainage tubes was beneficial for the topsoil desalination and the space of drainage tubes could be determined by the actual situation of soils; however, when designing the buried depth of subsurface drainage tubes, factors such as the salt movement from deeper layer and the underground water level should be fully considered. In this experiment, subsurface drainage system with 0.8m depth and 4m spacing was recommended as the optimal design for tomato cultivation in greenhouse salty soils of south China.

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