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Full Length Research Paper

Spatial variability of soil quality and asparagus spear yield in an area of plastic-greenhouse cultivation on Chongming Island, China

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This study was undertaken to determine the spatial variability of pH, organic matter, soil salinity and spear yield of asparagus (*Asparagus officinalis* L.) in an area of plastic-greenhouse cultivation on Chongming Island, an alluvial island in the Yangtze River Delta and forming part of Shanghai City. Classical statistic and geostatistic analysis were applied. Results showed that, different soil properties were found to have different spatial heterogeneities as a result of agricultural practices and fertilization. Spatial dependences of the electrical conductivities of 1:5 soil:water extracts (EC), organic matter (OM), exchangeable sodium percentage (ESP) and total soluble salt (TSS) were moderate, while pH was high. Soil EC varied from 0.27 to 2.10 mS cm^{-1}, pH from 6.59 to 8.28, OM from 0.3 to 3.4%, ESP from 2.4 to 16.7 and TSS from 0.07 to 1.11%. In this study, Ca^{2+}, Mg^{2+} and K^{+} were the predominant soil cations, while the anions were Cl^{-}, NO_3^{-}, SO_4^{2-} and HCO_3^{-}. In addition, the *in situ* electrical conductivity of greenhouse soil had a significantly positive correlation (R2 = 0.97) with soil EC. Meanwhile, different fertilization management practices had significant effects on asparagus spear yield (P < 0.05).

Key words: Greenhouse cultivation, soil quality, asparagus, spatial variability, geostatistic.

INTRODUCTION

For best soil management in intensive agriculture, soil variability must be taken into account as a spatio-temporal continuum (Couto et al., 1997; Corwin et al., 2003; Casa and Castrignanò, 2008). In China, the area of intensive plastic-greenhouse cultivation is increasing (Yao et al., 2006; Liu et al., 2008) and fertilizer application rates have also increased dramatically in recent years because growers seem to believe that, high fertilizer inputs can result in high crop yields. However, improper practices, such as the application of very large amounts of fertilizer, can cause severe soil degradation and decreased crop production after several years (Ju et al., 2007). Soil secondary salinization is widely recognized as a challenge for sustainable high yield in greenhouse vegetable production systems with strongly salinized soil being detrimental to plant growth and resulting in low yields (Xue, 1994; Li et al., 1996; Lin et al., 2004). The soil's natural characteristics and different management practices, especially fertilization and irrigation, can have different effects on soil salinity and yield.

Therefore, in greenhouse vegetable production, evaluating the spatial variability of these properties and mapping spatial distribution patterns will enable better site-specific management decisions for soil fertilization and amendment (Ardahanlioglu et al., 2003). Meanwhile, understanding of the spatial variability of soil properties and of crop yield and also their interrelationships are important for successful crop and fertilizer management strategies to increase crop productivity and crop quality, as well as to reduce the risk of nutrient loss (Panagopoulos et al., 2006; Rüth and Lennartz, 2008; Sawchik and Mallarino, 2008). Nowadays, geostatistics has been extensively used as the basic analysis method for soil spatial variability and spatial interpolation, which

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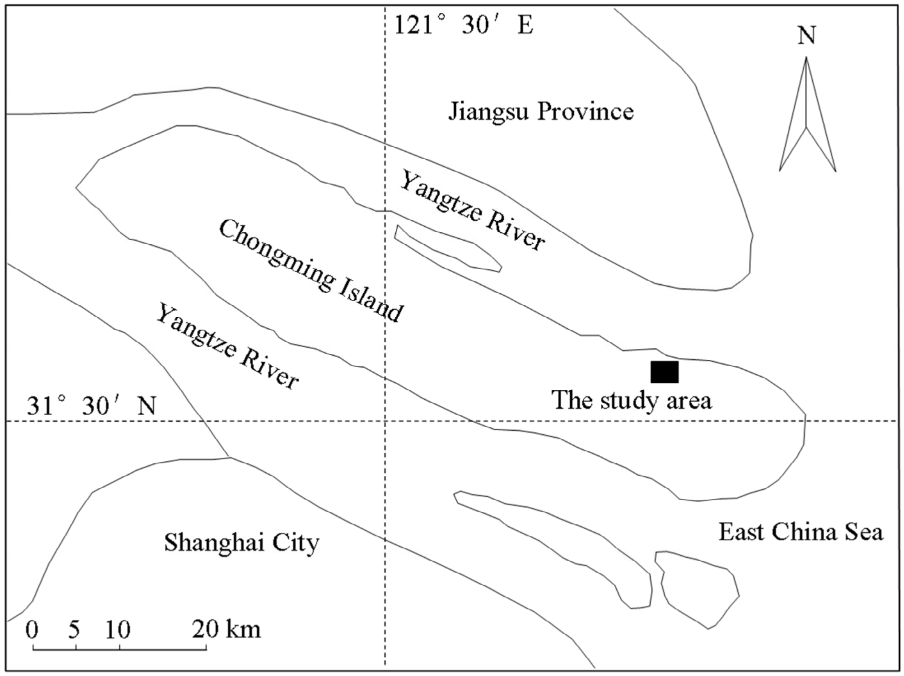

Figure 1. Geographic location of the study area (■).

can predict the values for un-measured points based on the values for the surrounding measured points. However, the geostatistical method is mainly used on farmland, the plains and hilly lands (Ardahanlioglu et al., 2003; Casa and Castrignanò, 2008; Han et al., 2010). Few geostatistical case studies have been reported in the evaluation of spatial changes of soil properties in the area of greenhouse cultivation.

This paper presents information on the spatial distribution of pH, organic matter (OM), soil salinity and spear yield of asparagus (*Asparagus Officinalis* L.) in an area of plastic-greenhouse vegetable production on Chongming Island. The aims were to determine the compositions of soil salinity under greenhouse cultivation, to show the effects of different management practices on soil pH, OM, salinity and crop yield under protected cultivation, and to evaluate the spatial variability of soil pH, OM and salinity to enable more effective site-specific management decisions for soil fertilization and amendment.

MATERIALS AND METHODS

Study-site description

Chongming Island is an alluvial island in the Yangtze River Delta (longitude 121°09′30″E to 121°54′00″E, latitude 31°27′00″N to 31°51′15″N) and forming part of Shanghai City. It has a subtropical oceanic climate, having average annual precipitation, sunshine hours, frostless days and temperatures of 1025 mm, 2094 h, 229 days and 15.2°C. With the elevation of Wusong being taken as 0 m above mean sea level (amsl), the elevation of over 90% of Chongming Island is between 3.21 and 4.20 m amsl. Mean groundwater level over the island is 85.7 cm below the undisturbed soil surface. The study site on Chongming Island is located in a modern market garden (Figure 1) which was formed between 1980 and 1986 on alluvial sediments from the Yangtze River. The study area is typical of greenhouse vegetable production on the island. The study site comprises 52 plastic greenhouses of 40 × 50 m and 1,660 of 6 × 40 m these being oriented approximately north-south. Figure 2 shows their distribution. The 40 × 50 m plastic greenhouses are in the 1# and 2# blocks. A road runs across the study site from east to west and auxiliary roads and irrigation/drainage canals run north to south at intervals. The study site is close to a water diversion trench on both north and south sides.

The study area is managed as a cooperative farm by 44 individual growers. Asparagus, watermelon (*Citrullus lanatus*), muskmelon (*Cucumis melo* L.) and cucumber (*Cucumis sativus* L.) are the main crops. However, because of serious soil salinization, many growers converted to grow asparagus (salt tolerant) in spring 2008. Two basal applications of fertilizer were made after the old stems were removed in January and July and furrow irrigation was implemented every 15 days. During the harvest of spears, split applications of fertilizer were made with irrigation every 15 days. Fertilizers were banded before furrow irrigation. Irrigation water was from the irrigation/drainage canal (Figure 2), which depended for its supply mainly on water diverted from the coast. The mean electrical conductivity (EC) of the irrigation water was 1.83 mS cm^{-1}, which is within the permissible range (0.75 mS cm^{-1} < EC < 2.0 mS cm^{-1}) for irrigation water quality based on EC according to Wilcox (1948).

Sample collection and *in situ* electrical conductivity measurements

Plant sampling employed a multistage technique (Figure 2). First, eight growers (U1 to U8) growing asparagus of the same cultivar (Apollo) and age (3 years) were selected from the initial 44 growers

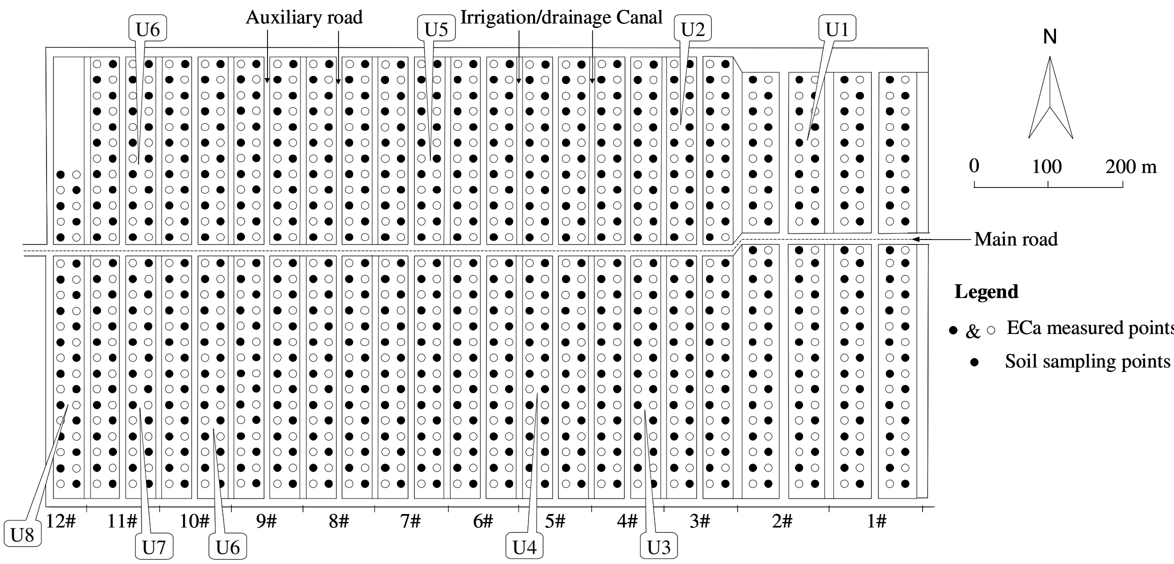

Figure 2. The design of *in situ* electrical conductivity (ECa) measuring points (● and ○) and soil sampling points (●). A main road runs across the study area from east to west and auxiliary roads and irrigation/drainage canals run at intervals from north to south. 1# to 12# represents the block of vegetable greenhouses. U1 to U8 represents the eight growers who grew asparagus of the same cultivar (Apollo) and age (3 years).

because cultivar and age are known to influence yield and quality of asparagus spears significantly (Heißner et al., 2006). Second, of the several greenhouses under the management control of each of these eight growers, four greenhouses were randomly selected for study. Third, during the main harvest period in 2007, asparagus spears were randomly sampled in each of the selected greenhouses for spear diameter and soluble solid content measurements. Meanwhile, the yield of asparagus spears in each greenhouse was calculated from the cumulative total. In addition, detailed records were made of agricultural practices when growers joined the cooperative farm. These included the number of greenhouses, the types and amounts of fertilizers applied, the applications of pesticide, irrigations etc.

Table 1 shows the fertilization practices of the eight growers selected and some characteristics of the fertilizers they used. Compound fertilizer was obtained from the China New Country Cooperation, with a nitrogen (N) content of 15% (NO_3^--N, 40%; NH_4^+-N, 60%), P_2O_5 15% (water soluble phosphorus (P) 70%) and K_2O 15% (potassium (K) from K_2SO_4). Commercial organic fertilizer (NPK, 4 to 7%; pH7.5 to 8.0; water content 20%) mainly comprising pig, cattle, chicken and duck manures, was obtained from Shanghai Jingke Bio-organic fertilizer Co. Ltd. Pig, cattle and duck manures were from the Chongming Modern Agricultural Zone, Shanghai. The manures were sampled when growers applied them. Manure samples were air-dried, ground and passed through a 2 mm sieve for analysis of organic carbon, pH and EC.

In situ electrical conductivity measurement (ECa) and soil sampling were performed in a regular 18 × 20 m grid pattern (Figure 2). The ECa of topsoil (10 cm depth) was measured at 1,220 points using a Field Scout® soil and water EC meter (Model 2265FS, Aozuo Ecology Instrumentation Ltd) after the removal of old stems (January, 2008). At each of the 1,220 points, ECa measurements were made three times within areas of size 20 × 20 cm. Meanwhile, soil samples within the same areas (20 × 20 cm and 0 to 15 cm depth) were collected at one point interval (that is 610 points) and taken to the laboratory where they were air-dried, ground and passed through a 2 mm sieve, pending later analysis.

Sample analysis

Soluble solid content in asparagus spears was measured 6 cm from the tip, using a portable saccharimeter (10 replicates) (Li et al., 2000). Spear diameter was measured 20 cm from the tip using a vernier caliper (20 replicates). The organic carbon content in manures was measured using the Walkley-Black method according to Bao (2005), and their pH and EC were determined in 1:5 manure: water extracts, using a pH meter (Model IQ150, Aozuo Ecology Instrumentation Ltd) and an EC meter (Model 2265FS, Aozuo Ecology Instrumentation Ltd).

Measurement of soil properties was performed as described by Bao (2005). Soil pH and EC were measured in 1:5 soil:water extracts using a pH meter (Model IQ150, Aozuo Ecology Instrumentation Ltd) and an EC meter (Model 2265FS, Aozuo Ecology Instrumentation Ltd). Samples were analysed for OM by the Walkley-Black method; HCO_3^- was measured using bromophenol blue indicator. The anions (F^-, Cl^-, NO_3^- and SO_4^{2-}) and the cations (Na^+, K^+, Mg^{2+} and Ca^{2+}) in 1:5 soil:water extracts were measured by ion chromatography using ICS-90 (Dionex corporation, US). Conditions for anion measurement were: suppressor AMMS®Ⅲ 4 mm, analytical column IonPac®AS12 4×250 mm, guard column IonPac®AG12 4×50 mm, effluent Na_2CO_3 1.8 mmol·L^{-1} and $NaHCO_3$ 1.7 mmol·L^{-1} and regenerator H_2SO_4 36.6 mmol·L^{-1}; and for cationic measurement: suppressor CMMS®Ⅲ 4 mm, analytical column IonPac®CS12 4×250 mm, guard column IonPac®CG12 4×50 mm, effluent methanesulfonic acid 32.6 mmol·L^{-1} and regenerator NaOH 160 mmol·L^{-1}. The sodium adsorption ratio (SAR) in each soil-sampling location was calculated by the equation:

$$SAR = \frac{[Na^+]}{([Mg^{2+}] + [Ca^{2+}])^{1/2}} \quad (1)$$

Where [Na^+], [Ca^{2+}] and [Mg^{2+}] represent the concentrations

Table 1. The fertilization practices of eight growers and characteristics of the fertilizers they used.

Growers	Fertilization pattern (t ha^{-1} $year^{-1}$)			OC (%)	pH	EC (mS cm^{-1})	SI
	Fertilizer types	BA	SA				
U1	Compound fertilizer	4.17	5.83				56.3
U2	Pig manure	68.5		36.5	6.4	10.9	
	Compound fertilizer		2.92				56.3
	Urea (N, 46%)		1.46				74.4
U3	Cattle manure	102.7		21.9	6.9	5.2	
	Compound fertilizer		5.83				56.3
U4	Pig manure	68.5		36.5	6.4	10.9	
	Compound fertilizer		5.83				56.3
U5	Commercial Organic Fertilizer	85.1		18.5a	7.5-8.0a		
U6	Commercial Organic Fertilizer	68.1		18.5a	7.5-8.0a		
	Compound fertilizer		2.50				56.3
	K2SO4		0.90				42.6
	Urea (N, 46%)		0.90				74.4
U7	Duck manure	131.5		16.9	7.5	7.2	
	Compound fertilizer		2.92				56.3
	Urea (N, 46%)		1.46				74.4
U8	Pig manure	81.2		31.5	6.4	10.9	
	Compound fertilizer		5.83				56.3

BA: basal application of fertilizers; SA: split application of fertilizers; OC: organic carbon; EC: electrical conductivity; SI: salt index of mineral fertilizers (for equal weights), data from Mortvedt (2001). a Data from Shanghai Jingke Bio-organic fertilizer Co. Ltd., Shanghai.

(mmol·L^{-1}) of Na^+, Ca^{2+} and Mg^{2+} in the soil-water extracts. Meanwhile, exchangeable sodium percentage (ESP) was estimated as (Levy, 1999):

$$ESP = 1.95 \times SAR + 1.8 \quad (2)$$

Data analysis

The data obtained from the eight selected growers was subjected to one-way analysis of variance (ANOVA) and Duncan's multiple range tests at P = 0.05 using SAS 9.1 software provided by SAS Inc. Spatial variability of soil properties was analyzed by geostatistical methods using ArcGIS9.1 software. The basic theory of geostatistics has been well established (Journel and Huijbregts, 1978). The degree of spatial dependence of a random variable Z(Xi) over a certain distance can be described by the following semivariogram function:

$$r(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(X_i + h) - Z(X_i)]^2 \quad (3)$$

Where r(h) is the semivariance for the interval distance h, Z(Xi) is the measured sample value at point Xi, Z(Xi + h) is the measured sample values at position (Xi + h), and N(h) is the number of pairs of the lag interval. Many models can be fitted to estimate semivariograms. In this study, we selected the anisotropic models including circular [Equation (4)], spherical [Equation (5)], tetraspherical [Equation (6)], pentaspherical [Equation (7)], exponential [Equation (8)] and Gaussian equation [Equation (9)].

$$r(h) = C_0 + C\left[\frac{2}{\pi} \times \arcsin\left(\frac{h}{a}\right) + \frac{2h}{\pi a}\sqrt{1 - \left(\frac{h}{a}\right)^2}\right] \quad 0 < h < a$$

$$= C_0 + C \quad h > a \ (4)$$

$$r(h) = C_0 + C\left[\frac{3h}{2a} - \frac{h^3}{2a^3}\right] \quad 0 < h < a$$

$$= C_0 + C \quad h > a \ (5)$$

$$r(h) = C_0 + C\left\{\frac{2}{\pi}\arcsin\left(\frac{h}{a}\right) + \frac{2}{\pi}\frac{h}{a}\sqrt{1 - \left(\frac{h}{a}\right)^2} + \frac{4}{3\pi}\frac{h}{a}\left[1 - \left(\frac{h}{a}\right)^2\right]^{\frac{3}{2}}\right\} \quad 0 < h < a$$

Table 2. Selected soil properties for the different growers.

Growers	n	ECa (mS cm^{-1})	EC (mS cm^{-1})	pH	OM (%)	TSS (%)	NO_3^- (mg L^{-1})
U1	10(20)	2.87b	0.98b	8.01a	1.84a	0.28bc	18.8c
U2	12(24)	2.22c	0.75c	6.98d	1.60b	0.26c	164.1b
U3	15(30)	1.68d	0.61cd	7.15cd	2.09a	0.20cd	55.4c
U4	15(30)	1.44d	0.49d	7.34c	2.04a	0.15d	18.7c
U5	10(20)	1.54d	0.44d	7.94a	0.75c	0.21cd	60.7c
U6	27(54)	3.45a	1.20a	7.25c	1.52b	0.43a	348.1a
U7	15(30)	3.07b	1.13ab	6.73e	2.07a	0.35b	276.1a
U8	10(20)	1.53d	0.45d	7.69b	1.87a	0.13d	28.7c

n: the number of soil-sampling points for each grower, the values in parentheses show the number of points for *in situ* electrical conductivity measurements; ECa: in situ electrical conductivity; EC: electrical conductivity in a 1:5 water:soil extract; OM: soil organic matter; TSS: the content of total soluble salt in the soil, which was equal to the sum of HCO_3^-, NO_3^-, SO_4^{2-}, Cl^-, F^-, Na^+, K^+, Mg^{2+} and Ca^{2+}. Values with the same letters in each column are not significantly different at the 5% level.

$$= C_0 + C \quad h > a \ (6)$$

$$r(h) = C_0 + C\left[\frac{15}{8}\frac{h}{a} - \frac{5}{4}\left(\frac{h}{a}\right)^3 + \frac{8}{3}\left(\frac{h}{a}\right)^5\right] \quad 0 < h < a$$

$$= C_0 + C \quad h > a \ (7)$$

$$r(h) = C_0 + C\left[1 - \exp(-\frac{3h}{a})\right] \quad h > 0 \ (8)$$

$$r(h) = C_0 + C\left\{1 - \exp\left[-3\left(\frac{h}{a}\right)^2\right]\right\} \quad h > 0 \ (9)$$

Where C0 is the nugget, and a is the range of spatial dependence to reach the sill (C0 + C). Proportion of nugget to sill (PNS) represents the extent of spatial dependence, which can be calculated as given in Equation (10):

$$PNS = \left[C_0 / (C_0 + C)\right] \times 100\% \quad (10)$$

PNS represents the spatial dependence as strong if, PNS < 25%, moderate for PNS ranging from 25 to 75%, and weak if PNS > 75% (Cambardella et al., 1994).

Earlier studies indicate that, different sampling methods and study aims, determine the most appropriate interpolation methods for mapping soil properties (Gotway et al., 1996; Kravchenko and Bullock, 1999; Corwin et al., 2003; Makarian et al., 2007). Here, universal kriging was selected because it is more accurate being based on the use of the mean squared error and root-mean-square prediction error as the main criteria when matching measured values to predicted values (Corwin et al., 2003; Shi, 2006; Zhao and Shi, 2007).

RESULTS AND ANALYSIS

Change of soil properties between growers U1 to U8

Table 2 shows the change of soil properties between the eight growers, each managing their greenhouses differently. Different fertilization practices significantly affected the soil properties (P < 0.05). EC values ranged from 0.44 to 1.20 mS cm^{-1}, pH from 6.73 to 8.01, OM from 0.75 to 2.09% and NO_3^- content from 18.7 to 348.1 mg L^{-1}. Table 2 indicates that the soil pH for grower U1 was 8.01 compared to 6.73 for U7. Also, soil NO_3^- contents for growers U2, U6 and U7 were significantly higher than for the others (P < 0.05), which was possibly due to the application of urea. Regression analysis revealed that, there was significant correlation between ECa, EC and total soluble salt (TSS), which indicates that EC and TSS may be able to be predicted by measuring just the ECa value. Their correlation equations were:

$EC = 0.3443 \times ECa$ (R2 = 0.97), $TSS = 0.0011 \times ECa$ (R2 = 0.90) and $TSS = 0.0033 \times EC$ (R2 = 0.88).

Asparagus spear yield for different growers

Asparagus spear yields differed significantly among growers (P < 0.05). Table 3 indicates that, the mean spear yield for grower U3 was 33.0 t ha^{-1} year^{-1}, which is significantly higher than for the others (P < 0.05). Spear yield for grower U3 was 1.63, 1.17, 1.10, 1.47, 1.73, 1.84 and 1.29 times more than for growers U1, U2, U4, U5, U6, U7 and U8, respectively. Tables 2 and 3 show that spear yield shows an increasing and then decreasing trend with increasing soil EC. This relationship can be fitted using a quadratic equation ($y = -44x^2 + 59x + 9$, R2 = 0.67). In addition, spear diameter and soluble solids showed similar trends to yield.

Spatial variability of pH, organic matter and soil salinity

Table 4 shows the descriptive statistics of selected soil

Table 3. Change of asparagus spear diameter, soluble solids and yields for different growers.

Growers	Spear diameter (cm)	Soluble solid (%)	Yield (t ha^{-1} $year^{-1}$)
U1	1.012c	5.0bc	20.2de
U2	1.241a	5.5a	28.3b
U3	1.284a	5.7a	33.0a
U4	1.209ab	5.6a	29.9b
U5	1.114bc	5.0bc	22.4d
U6	1.089c	4.7c	19.1de
U7	0.965c	4.8c	17.9e
U8	1.125b	5.3ab	25.5c

Values with the same letters in each column are not significantly different at the 5% level.

Table 4. Descriptive statistics of some soil properties under plastic-greenhouse cultivation.

Variable	n	Min	Max	Mean	Median	S.D.	CV (%)	Skewn	Kurt
ECa (mS cm^{-1})	1,220	0.57	6.06	2.47	2.29	0.98	39.5	0.83	3.36
EC (mS cm^{-1})	610	0.27	2.10	0.75	0.68	0.30	40.0	1.18	4.68
pH	610	6.59	8.28	7.49	7.58	0.39	5.2	-0.34	2.04
OM (%)	610	0.26	3.41	1.69	1.74	0.49	29.0	-0.26	3.24
HCO_3^- (mg kg^{-1})	610	91.5	732.0	383.5	366.0	84.2	21.9	0.70	4.14
F^- (mg L^{-1})	610	0.06	2.34	0.98	0.93	0.32	32.7	0.69	4.42
Cl^- (mg L^{-1})	610	1.6	597.8	117.1	97.2	75.2	64.2	1.92	8.66
NO_3^- (mg L^{-1})	610	0.5	1130.1	142.3	69.6	162.7	114.5	2.21	10.02
SO_4^{2-} (mg L^{-1})	610	0.9	411.8	66.2	56.9	44.0	66.5	3.60	21.15
Na^+ (mg L^{-1})	610	6.5	278.5	82.4	71.2	39.1	47.4	1.43	5.79
K^+ (mg L^{-1})	610	0.4	83.4	10.8	7.7	9.3	85.7	2.80	15.22
Mg^{2+} (mg L^{-1})	610	1.7	60.5	13.2	10.1	9.0	68.0	1.70	6.93
Ca^{2+} (mg L^{-1})	610	24.9	308.4	64.1	50.8	37.0	57.8	2.20	10.12
SAR	610	0.3	7.6	2.6	2.3	1.3	47.8	1.11	3.93
ESP	610	2.4	16.7	6.9	6.2	2.5	35.4	1.11	3.93
TSS (%)	610	0.07	1.11	0.29	0.25	1.43	50.0	1.70	7.24

n: the number of measured values; ECa: *in situ* electrical conductivity; EC: electrical conductivity; OM: soil organic matter; SAR: sodium adsorption rate; ESP: exchangeable sodium percentage; TSS: total soluble salt, which is equal to the sum of HCO_3^-, F^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+} and Ca^{2+}; Min: minimum; Max: maximum; S.D.: standard deviation; CV: coefficient of variation; Skewn: skewness; Kurt: kurtosis.

properties. Over the study area, different soil properties had different degrees of spatial heterogeneity, indicating that they were affected by the different agricultural practices and fertilization. Soil pH values ranged from 6.59 to 8.28 with 7.49 being the average. In open field systems on Chongming Island, soil pH ranges from 8.0 to 8.5 with 8.2 being the average (Zhou et al., 2009), indicating that there is an increasing trend for soil acidification under protected cultivation, due to the very large inputs of fertilizer and manure. The OM content in the soil was 1.69% on average, which is low under protected cultivation. ESP ranged from 2.4 to 16.7 with 6.9 being average, indicating that soil Na^+ content was not high while Ca^{2+} and Mg^{2+} were the predominant cations.

Table 4 indicates that Cl^-, NO_3^-, HCO_3^- and SO_4^{2-} were the predominant anions. TSS was from 0.07 to 1.11% with 0.29% being average. Commonly, the TSS content in soil is more than 0.3%, resulting in significant salt stress to the growth of crop (Zhao and Shi, 2007). Precise management of soil quality rather than overall uniform management is important for high yields of horticultural crops due to the heterogeneity of the soil environment and ecology. The coefficient of variation (CV) is an important index because it is dimensionless and so permits comparison of values from one parameter to another.

In this study (Table 4), according to the classification by Hillel (1980), pH values had low variation (CV < 10%), whereas the content of NO_3^- had high variation (CV > 100%) and other soil properties had intermediate variations (10% < CV < 100%). Skewness and kurtosis coefficients have been used to verify the statistical distribution of parameters (Mapa and Kumaragamage,

Table 5. The parameters of the fitted variograms for the soil properties.

Variable	Model	Major range (m)	Minor range (m)	Direction (°)	PNS (%)
ECa (mS cm^{-1})	Spherical	321	120	359.9	25.5
EC (mS cm^{-1})	Spherical	448	240	359.8	33.8
pH	Gaussian	436	142	1.3	18.5
OM (%)	Gaussian	318	126	354.9	50.6
HCO_3^- (mg L^{-1})	Pentaspherical	391	162	356.8	45.3
F^- (mg L^{-1})	Tetraspherical	251	67	0.9	31.6
Cl^- (mg L^{-1})	Pentaspherical	340	106	355.8	55.7
NO_3^- (mg L^{-1})	Gaussian	340	148	353.1	54.7
SO_4^{2-} (mg L^{-1})	Spherical	216	69	357.9	57.0
Na^+ (mg L^{-1})	Gaussian	543	318	31.9	63.0
K^+ (mg L^{-1})	Exponential	292	96	358.5	0.2
Mg^{2+} (mg L^{-1})	Exponential	320	125	355.0	2.7
Ca^{2+} (mg L^{-1})	Exponential	320	110	354.9	12.3
SAR	Exponential	536	303	33.7	40.8
ESP	Exponential	533	298	31.4	37.6
TSS (%)	Circular	340	163	351.9	41.1

ECa: *in situ* electrical conductivity; EC: electrical conductivity; OM: organic matter; SAR: sodium adsorption rate; ESP: exchangeable sodium percentage; TSS: total soluble salt, which is equal to the sum of HCO_3^-, F^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+} and Ca^{2+}; PNS: proportion of nugget to sill.

1996; Cerri et al., 2004). When the skewness and kurtosis are close to zero and three, respectively, parameters are considered to follow the classical, normal distribution. When skewness is positive, the data distribution indicates that there is a long tail of high values (to the right), making the median less than the mean. The converse also applies, in which case the median is greater than the mean. In this study, all variables except pH and OM presented positive skewness values (Table 4). Kurtosis is a parameter that describes the shape of a random variable's probability density function. For a kurtosis greater than three for a random variable, this is said to be leptokurtic but if less than three, then it is platykurtic. Table 4 shows that, the kurtosis of all variables except soil pH was greater than three.

Table 5 shows the models which were selected for the different soil properties according to the universal kriging method. The spherical model was selected for the spatial variability of EC, ECa and SO_4^{2-}, the Gaussian model for pH, OM, NO_3^- and Na^+, the pentaspherical model for HCO_3^- and Cl^-, the tetraspherical model for F^-, the exponential model for K^+, Mg^{2+}, Ca^{2+}, SAR and ESP, and the circular model for TSS. The analysis of spatial dependence indicates that, the soil property variations were anisotropic. The variations of Na^+, SAR and ESP were similar, which were northeast-southwest in direction. However, the variations of all properties measured except Na^+, SAR and ESP presented mainly in the north-south direction, with major and minor ranges of 216 to 448 m and 67 to 240 m, respectively.

The proportion of nugget to sill describes the extent of spatial dependence (Cambardella et al., 1994). Table 5 shows that pH, K^+, Mg^{2+} and Ca^{2+} were < 25%, while the other variables were 25 to 75%.

Figures 3 and 4 show interpolated maps of some soil properties, according to the universal kriging method. ECa and EC interpolated maps were similar, indicating that there was a high correlation between them. In addition, the greenhouse area having EC values more than 0.90 mS cm^{-1} approached to 27.3% of the whole. According to Warncke and Krauskopf (1983), EC values of more than 0.90 mS cm^{-1} in greenhouse media can result in reduced growth and vigour of the crop. In general, OM was lower than 3% in the whole area, which was low for protected cultivation. The land areas having pH values of 6.6 to 7.0, 7.0 to 7.5 and 7.5 to 8.0 accounted for 7.2, 40.7 and 50.7% of the whole. Figures 3 and 4 indicate that, different soil properties had different distributions in the universal kriging interpolated maps. This was possibly caused by a combination of natural and anthropogenic factors, especially agricultural management practices.

DISCUSSION

For high yield and quality of crops under intensive greenhouse cultivation, it is necessary to consider the integrated management of irrigation water and the choice and addition of fertilizers in relation to the crop's demand and salt tolerance (Wu et al., 2000; Darwish et al., 2005). Best practice in these regards can help to reduce pollution and production costs and to increase net returns for the grower. In this study area, surface water resources

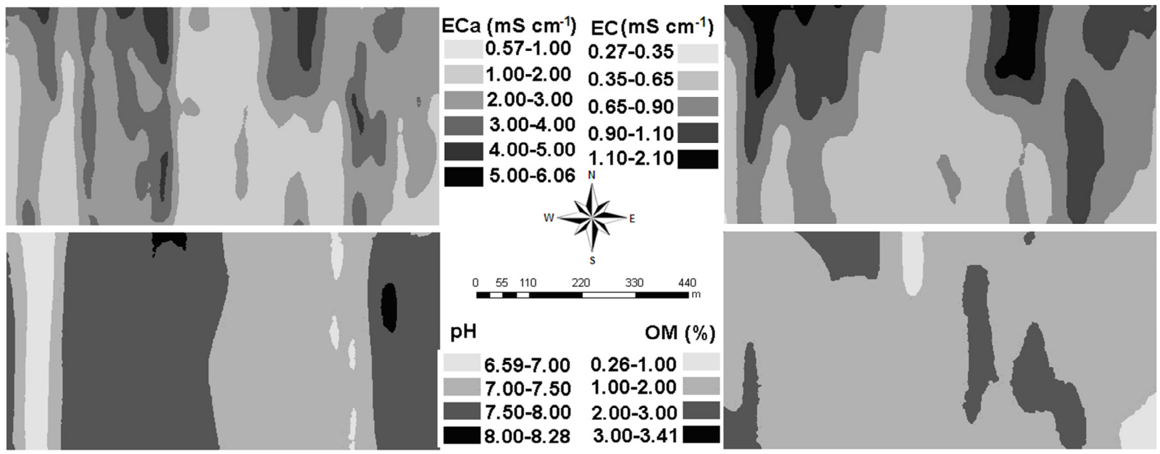

Figure 3. Universal kriging interpolated maps of *in situ* electrical conductivity (ECa), electrical conductivity in 1:5 soil:water extracts (EC), soil pH and organic matter (OM) in an area of plastic-greenhouse cultivation on Chongming Island, China.

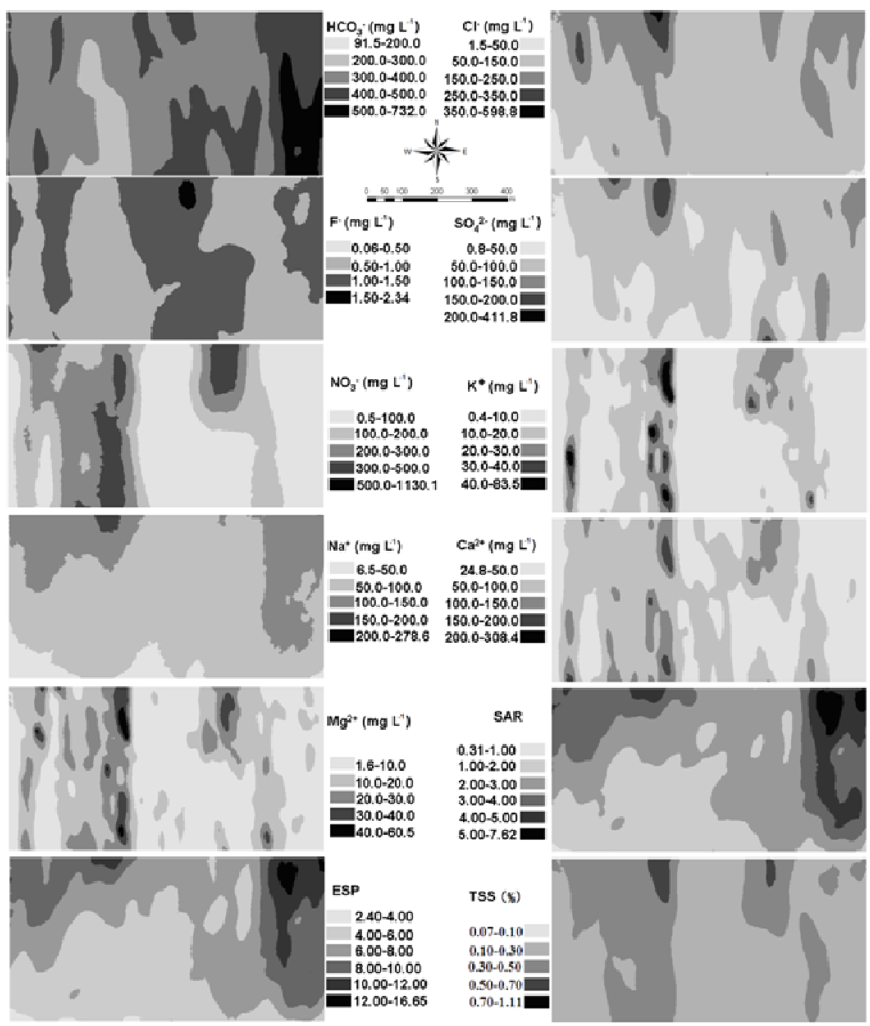

Figure 4. Universal kriging interpolated maps of soil anions (HCO_3^-, F^-, Cl^-, NO_3^- and SO_4^{2-}), cations (Na^+, K^+, Mg^{2+} and Ca^{2+}), sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP) and total soluble salt (TSS) in an area of plastic-greenhouse cultivation on Chongming Island, China.

are sufficient. Irrigation water quality belonged to the permissible category based on EC according to Wilcox (1948). The salinity build-up observed seems to be influenced instead by excessive applications of fertilizers (Cao et al., 2004; Ju et al., 2007). According to our survey, the growers used manures including pig, cattle and duck manure, fertilizers including 15:15:15 NPK compound fertilizer, urea and K_2SO_4, and commercial organic fertilizers. The fertilizer inputs in each greenhouse were very high and mostly based on a grower's individual experiences and opinion.

Growers commonly believe that there will be higher output under conditions of high fertilization and irrigation (Table 1). The greenhouse inputs of manures and fertilizers were 3 to 5 times higher than in open fields according to our survey (Data not shown). These excessive applications could explain the observed accumulation of nutrient salts in the surface soil (Cao et al., 2004). This behavior would seem to indicate a lack of a formal system of fertilizer recommendations and weaknesses in the local agricultural extension service. In addition, our survey shows that plants such as watermelon, muskmelon and cucumber, have been severely salt-stressed to the point that they could not be grown in some greenhouses. While asparagus is a salt tolerant plant, high salt concentrations in the soil do still have negative effects on yield and quality.

Therefore, it is necessary to improve grower education. Expanding the local agricultural extension services is a possible way in which this may be accomplished. Appropriate management practices, in terms of the soil environment and crop needs under protected cultivation, can ensure sustainable high yields and high net returns for the grower. Under protected cultivation, different growers prefer to apply different kinds of fertilizer such as manure, urea or 15:15:15 compound fertilizers to vegetable crops, resulting in different compositions of soil salinity. Some studies have reported that NO_3^- content has significant correlations with soil EC under greenhouse cultivation (Xue, 1994; Ju et al., 2007).

In this study, there were significant correlations between soil EC and NO_3^- content in five areas (R2 > 0.53) among the eight selected growers. Therefore, NO_3^- content in soil under protected cultivation cannot be completely predicted by soil EC. Nevertheless, soil EC may be used as an index of salt accumulation due to significant correlations with TSS (R2 = 0.88). Significant correlations between soil EC and Cl^- content occurred in seven areas (R2 > 0.65) among the eight selected growers. Overall, the cations consisted largely of Ca^{2+}, Mg^{2+} and K^+, whereas the Na^+ content was low (ESP < 15); the anions consisted largely of HCO_3^-, SO_4^{2-}, Cl^- and NO_3^-. In addition, high soil salinity significantly decreased yield and quality of asparagus spears ($P<0.05$). Corwin et al. (2003) found that, the ECa of arid-zone soils was highly correlated with some soil properties and elements such as with EC, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+ and Mg^{2+} in the saturation extract, SAR, ESP and OM. Meanwhile, ECa showed no correlation with others such as pH, HCO_3^- and Ca^{2+} in the saturation extract.

However, this study finds that under protected cultivation, ECa was highly correlated with OM, TSS, SAR and with the water soluble ions HCO_3^-, F^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+} and Ca^{2+} but not with pH. In addition, because the analysis of soil samples is very labour-intensive, it is costly and impractical to establish an intense soil-sampling protocol on a close grid to characterise soil quality. Rather, rapid and inexpensive means of ascertaining the spatial distribution of soil properties associated with soil quality is very desirable (Corwin et al., 2003). In greenhouse cultivation, the soil content of salt and OM is important, as these influence soil fertility and plant growth. The measurement of ECa is a rapid, easy and inexpensive means of obtaining large amounts of spatially-referenced information on a range of soil properties which are either directly or indirectly related to ECa because ECa is affected by salinity and OM (Corwin et al., 2003). Correlation analysis showed that, ECa was highly correlated with OM and the content of the water-soluble ions, which indicates that ECa could be useful as a basis of the precise management of soil amendments and optimal sampling for soil quality determination.

Soil OM and pH are important for the growth of horticultural plants. Increased OM content improves the soil's buffering capacity against rapid changes in salinity. Thus, the enrichment of the soil with OM can help to alleviate the negative effects of salt accumulation (Kahlown and Azam, 2003; Darwish et al., 2005). According to Zhao and Shi (2007), in general, a soil containing less than 3% of OM under greenhouse cultivation is considered to have low fertility for horticultural crops. In this study, soil OM was less than 3% in most areas. Therefore, increasing the OM content is important for the improvement of soil fertility. Soil pH also has a major effect on nutrient uptake and growth of horticultural crops (Peterson, 1981; Bailey, 1996). An overly low or high pH can result in the ionic disequilibrium and can have adverse effects on nutrient uptake and growth (Nelson, 1994; Fisher et al., 2003). According to Zhou et al. (2009), soil pH on Chongming Island ranges from 8.0 to 8.5 with 8.2 being the average in open-field systems. However, this study shows that a pH range of 6.6 to 7.5 accounted for 48% of the whole area, indicating that significant soil acidification had occurred in the greenhouses due to the very large amounts of fertilizer and manure applied.

Spatial variability is critical to our understanding of soil quality and the development of methods for soil quality assessment (Corwin et al., 2003). Geostatistics provides a set of statistical tools for analyzing spatial variability and spatial interpolation. The structure of spatial variability can be described using semivariograms. In this study, anisotropic models were the best semivariogram models for different soil properties, which may be affected by the high variability of soil formation factors, as well as soil-management practices. The nugget effect represents random variation caused mainly by measurement error or variation that cannot be detected at the minimum sampling distance used (Sylla et al., 1995; Cerri et al., 2004). In general, the ratio of nugget to sill can be used to classify the spatial dependence of soil properties. Nugget to sill ratio values of < 25%, 25 to 75% and > 75% indicate, respectively, high, moderate and weak spatial dependence (Cambardella et al., 1994). Table 5 indicates that spatial dependences of K^+, Mg^{2+} and Ca^{2+} were high, while others were moderate. The distance of spatial dependence was larger than 18 m in all the area of greenhouse cultivation, which is the distance between two sample-collecting points.

Therefore, the samples were reasonable and represented the truth. Kriging interpolation is based on the variogram and structure analysis, which is a method for predicting the values for un-measured points based on the values for the surrounding measured points. In this study, universal kriging method was applied for spatial interpolation. The GIS mapping technique was employed to produce the spatial distribution maps for different soil properties in the area of greenhouse cultivation on Chongming island. These maps were easily understood by the growers and could help the growers make good decision.

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REFERENCES

Ardahanlioglu O, Oztas T, Evren S, Yilmaz H, Yildirim ZN (2003). Spatial variability of exchangeable sodium, electrical conductivity, soil pH and boron content in salt- and sodium-affected areas of the Igdir plain (Turkey). J. Arid Environ., 54: 495-503.

Bailey DA (1996). Alkalinity, pH and acidification. In: Reed DW (Ed) Water, media and nutrition for greenhouse crops. Ball Publishing, Batavia, IL. pp. 69-91.

Bao SD (2005). Agricultural and chemical analysis of soil. China Agriculture Press, Beijing.

Cambardella CA, Moorman TB, Novak JM, Parkin TB, Karlen DL, Turco RF, Konopka AE (1994). Field-scale variability of soil properties in central Iowa soils. Soil Sci. Soc. Am., J. 58: 1501-1511.

Cao ZH, Huang JF, Zhang CS, Li AF (2004). Soil quality evolution after land use change from paddy soil to vegetable land. Environ. Geochem. Health 26: 97-103.

Casa R, Castrignanò A (2008). Analysis of spatial relationships between soil and crop variables in a durum wheat field using a multivariate geostatistical approach. Eur. J. Agron., 28: 331-342.

Cerri CEP, Bernoux M, Chaplot V, Volkoff B, Victoria RL, Melillo JM, Paustian K, Cerri CC (2004). Assessment of soil property spatial variation in an Amazon pasture: basis for selecting an agronomic experimental area. Geoderma 123: 51-68.

Corwin DL, Kaffka SR, Hopmans JW, Mori Y, van Groenigen JW, van Kessel C, Lesch SM, Oster JD (2003). Assessment and field-scale mapping of soil quality properties of a saline-sodic soil. Geoderma 114: 231-259.

Darwish T, Atallah T, Moujabber ME, Khatib N (2005). Salinity evolution and crop response to secondary soil salinity in two agro-climatic zones in Lebanon. Agr. Water Manage., 78: 152-164.

Fisher PR, Wik RM, Smith BR, Pasian CC, Kmetz-González M, Argo WR (2003). Correcting iron deficiency in calibration grown in a container medium at high pH. HortTechnology 13: 308-313.

Gotway CA, Ferguson RB, Hergert GW, Peterson TA (1996). Comparison of kriging and inverse-distance methods for mapping soil parameters. Soil Sci. Soc. Am. J. 60: 1237-1247.

Couto EG, Stern A, Klamt E (1997). Large area spatial variability of soil chemical properties in central Brazil. Agr. Ecosyst. Environ., 66: 139-152.

Han F, Zheng J, Hu W, Du F, Zhang X (2010). Spatial variability and distribution of soil nutrient in a catchment of the loess Plateau in China. Acta Agr. Scand. B-SP. 60: 48-56.

Herßner A, Schmidt S, Schonhof I, Feller C, Schreiner M (2006). Spear yield and quality of white asparagus as affected by soil temperature. Eur. J. Agr. 25: 336-344.

Hillel D (1980). Applications of soil physics. Academic Press, New York.

Journel AG, Huijbregts CJ (1978). Mining Geostatistics. Academic Press, New York, pp. 599-600.

Ju XT, Kou CL, Christie P, Dou ZX, Zhang FS (2007). Changes in the soil environment from excessive application of fertilizers and manures to two contrasting intensive cropping systems on the north China plain. Environ. Pollut. 145: 497-506.

Kahlown MA, Azam A (2003). Effect of saline drainage effluent on soil health and crop yield. Agr. Water Manage. 62: 127-138.

Kravchenko A, Bullock DG (1999). A comparative study of interpolation methods for mapping soil properties. Agr. J. 91: 393-400.

Levy GJ (1999). Sodicity. In: Sumner ME (Ed) Handbook of soil science. CRC Press, Boca Raton, FL. pp. 27-63.

Li H, Sun Q, Zhao S, Zhang W (2000). Principles and techniques of plant physiological biochemical experiment. Higher Education Press, Beijing.

Li WQ, Du BH, Luo HY, Ding FJ (1996). The influence of greenhouse cultivation on soil microflora. Soil and Fertilizer 2: 31-33.

Lin XG, Yin R, Zhang HY, Huang JF, Chen RR, Cao ZH (2004). Changes of soil microbiological properties caused by land use changing from rice–wheat rotation to vegetable cultivation. Environ. Geochem. Health 26: 119-128.

Liu ZH, Jiang LH, Li XL, Härdter R, Zhang WJ, Zhang YL, Zheng DF (2008). Effect of N and K fertilizers on yield and quality of greenhouse vegetable crops. Pedosphere 18: 496-502.

Makarian H, Mohassel MHR, Bannayan M, Nassiri M (2007). Soil seed bank and seedling populations of Hordeum murinum and Cardaria draba in saffron fields. Agri. Ecosyst. Environ. 120: 307-312.

Mapa RB, Kumaragamage D (1996). Variability of soil properties in a tropical Alfisol used for shifting cultivation. Soil Technology 9: 187-197.

Mortvedt JJ (2001). Calculating salt index. Fluid J. 9: 8-11.

Nelson PV (1994). Fertilization, In: Holcomb EJ (Ed) Bedding plants IV. Ball Publishing, Batavia, IL. pp. 151-175.

Panagopoulos T, Jesus J, Antunes MDC, Beltrao J (2006). Analysis of spatial interpolation for optimizing management of a salinized field cultivated with lettuce. Eur. J. Agr., 24: 1-10.

Peterson JC (1981). Modify your pH perspective. Florists Review 169: 34-36.

Rüth B, Lennartz B (2008). Spatial variability of soil properties and rice yield along two catenas in southeast China. Pedosphere 18: 409-420.

Sawchik J, Mallarino AP (2008). Variability of soil properties, early phosphorus and potassium uptake, and incidence of pests and weeds in relation to soybean grain yield. Agr. J., 100: 1450-1462.

Shi Z (2006). Geostatistics application to soil science. China Agriculture Press, Beijing.

Sylla M, Stein A, van Breemen N, Fresco LO (1995). Spatial variability of soil salinity at different scales in the mangrove rice agro-ecosystem in West Africa. Agr. Ecosyst. Environ. 54: 1-15.

Warncke DD, Krauskopf DM (1983). Greenhouse growth media: testing

and nutrition guideline. MSU Ag Facts Extension Bulletin E-1736.
Wilcox LV (1948). The quality of water for irrigation use. Technical Bulletin 962, USDA.
Wu FZ, Zhao FY, Liu YY (2000). Analysis of the problems in continues cropping system of protective vegetable and the controlling ways. In: Li XL, Zhang FS, Mi GH (Eds) Fertilization for sustainable production of high quality vegetables. China Agricultural University Publisher, Beijing.
Xue JC (1994). The soil factors causing physiological defect of vegetable cultivated in protected farmland and countermeasures. Soil and Fertilizer, 1: 4-9.
Yao H, Jiao X, Wu F (2006). Effects of continuous cucumber cropping and alternative rotations under protected cultivation on soil microbial community diversity. Plant Soil 284: 195-203.
Zhao Q, Shi X (2007). Generality of soil resources. Science Press, Beijing.
Zhou Y, Li D, Song Y, Li H, Ke S, Wang C, Sun Y, Li L, Zhao L (2009). Distribution of soil heavy metal and pollution evaluation in Chongming Island. J. East China Normal University, 5: 75-84.