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Accumulation of Soil Soluble Salt in Vegetable Greenhouses Under Heavy Application of Fertilizers

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Abstract: Soil salt accumulation has been regarded as a key factor that limits vegetable production in greenhouses in China. The changes in soil salt ions, *i.e.*, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, HCO_3^-; Cl^-, SO_4^{2-} and NO_3^- and soil electrical conductivity (EC) in vegetable greenhouses were examined under heavy application of both chemical and organic fertilizers in Shenyang suburb, Liaoning province of China. Soil samples were collected at the depths of 0-10, 10-20 and 20-30 cm, respectively, from 1-, 4- and 10-year greenhouses and their adjacent open vegetable field in October 2004. Both the soil total salt and EC were significantly higher in greenhouse than in open field ($p<0.01$) and they were increased with the increasing age of greenhouses. Average soluble salt concentration in 1-, 4- and 10-year greenhouses at the depth of 30 cm was 2.09, 2.31 and 3.69 times as much as in open field, respectively and it was 77 and 60% higher in 10-year greenhouse than in 1- and 4-year greenhouses, respectively. Soil salt was positively correlated with soil organic carbon ($p<0.01$), but negatively with soil pH ($p<0.01$). In the 10-year greenhouse, the examined soil K^+ and NO_3^- were the dominant cation and anion, respectively. The accumulation of soil salt in the surface soil layer of greenhouses may be due to (a) the heavy applications of both chemical fertilizer and organic manure that exceed crop requirements and (b) the upward movement of soil ions with water evapotranspiration. The accumulation of soil NO_3^- and K^+ in greenhouse is regarded as the results of heavy N and K fertilizer applications, while those of the other ions the movement of water under the greenhouse conditions. Application of chicken manure has the potential to prolong the process of salinization in soils of vegetable greenhouse, according to the results of this study.

Key words: Vegetable greenhouse, soil soluble salt, fertilization, soil quality

INTRODUCTION

Greenhouse vegetable gardening implies high human disturbance that may affect the environment seriously[1,2]. Many problems have already appeared in soils of vegetable greenhouses under heavy application of fertilizers and other chemicals like pesticides and hormones, e.g., the frequent occurrence of soil borne diseases, soluble salt accumulation, degradation of soil quality and decrease in soil productivity[3-9]. These problems affect not only the vegetable economic efficiency, but also the vegetables quality and soil health[8,10]. In order to improve the greenhouse vegetable production and avoid adverse effects, more attention has been paid to greenhouse gardening in the horticultural aspect, but relatively less work has been done in the soil aspect of the barrier factors related to soils, soil salt accumulation has been regarded as the key factor that limits vegetable production in greenhouses[11,12]. However, more works concerning salt accumulation have been done on the basis of soil survey in the regional scales[5,10,13], or focused on control measures[3,11] and the studies on the accumulation of soil salt as affected by heavy application of fertilizers at a comparatively small scale in northeast China are still limited. This study aimed to examine soil soluble salt changes in vegetable greenhouses under heavy application of both chemical and organic fertilizers in a vegetable production base in Shenyang suburb, Liaoning Province of China, the results obtained may be helpful in establishing rational fertilization strategies, maintaining soil quality and improving vegetable quality under greenhouse gardening in northeast China.

MATERIALS AND METHODS

This study was conducted at Zhujiafang village, Damintun town (41°50′ N, 122°55′ E), a famous vegetable production base located in Shenyang suburb, Liaoning province in October 2004. Three greenhouses of different ages, i.e., 1-, 4- and 10-year greenhouses and an adjacent open vegetable field were selected as treatments. The greenhouses were with similar management way, each greenhouse was about 0.1 ha. The greenhouse was planted with tomato in the winter and early spring seasons and with the yield of tomato100 000-120 000 kg ha^{-1}. Greenhouse soil was fertilized with 3500-4200 kg ha^{-1} chemical fertilizers. Of the chemical fertilizers,

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Diammonium orthophosphate was about 1500-1800 kg ha^{-1}, ammonium sulfate 500-600 kg ha^{-1}, potassium sulfate 1000-1200 kg ha^{-1}, potassium nitrate 300-350 kg ha^{-1} and urea or liquid ammonium 200-250 kg ha^{-1}. Chicken manure, with its rapid release of nutrients in soils, was the major type of organic manure used in the study sites. Greenhouse soil was amended with 80-100 t ha^{-1} of chicken manure each year, which was about 4-6 times as much as that in the open vegetable field.

Soil samples were taken from each greenhouse and open field at the depths of 0-10, 10-20 and 20-30 cm with 4 replications. Electrical conductivity (EC) was determined in water (1:5 soil/water ratio), as were soluble salts. Atomic absorption spectrophotometry was used to determine Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} in the water extracts. Cl^{-} was determined by electrometric titration with silver, NO_3^- using a specific ion electrode, SO_4^{2-} using a turbidimetric method in which sulfate is converted into $BaSO_4$ suspension under controlled conditions and the turbidity measured spectrophotometrically and CO_3^{2-} by potentiometric titration of the extract with HCI to pH 4.4[14]. Soil organic carbon (SOC) was analyzed by dry combustion using TOC 5000 analyzer (Shimadzu, Kyoto); and soil pH (1: 2.5 soil/water ratio, w/w) and total nitrogen was determined using routine analytical methods[14].

All the data were subjected to statistical Analysis of Variance (ANOVA). Differences with $p < 0.05$ were considered significant.

RESULTS

Salt components and electrical conductivity in soil: Soil soluble cation concentration was higher in greenhouse than in open field (Table 1). No significant difference in soil Ca^{2+} was found among the three greenhouses at the depth of 0-10 cm. Soil K^{+} was significantly higher in 10-year greenhouse than in open field and in greenhouses of 1- and 4- years and it was slightly higher in 1-year greenhouse than in open field at all the three depths, but no significant difference was observed between them. The four soil anions, i.e., HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-, were significantly higher in 10-year greenhouse than in 1-year greenhouse and open field at the depth of 0-10 cm. Soil total salt concentration was significantly higher in greenhouses than in open field at all the three depths, it was also significantly higher in 10-year greenhouse than in 1- and 4-year greenhouses at the depths of 0-10 cm and 10-20 cm. Soil EC exhibited a similar trend to that of the soil total salt (Table 1).

Significant differences for each cation and anion, the sum of cations and of anions and total salt and EC in soils were found among the four treatments. No significant differences for Ca^{2+}, Mg^{2+}, total cations, SO_4^{2-}, total salt and EC in soils were observed among the three depths. All the variables showed a obvious treatment × depth effect except for soil Na^{+}, which had no significant treatment × depth effect even though it was significantly different among treatments and at depths, respectively (Table 2).

Table 1: Ion concentration and electrical conductivity (EC) in soil under different treatments

Item	Depth (cm)	Open field	1-year Greenhouse	4-year greenhouse	10-year greenhouse
Ca^{2+}	0-10	12.99±3.36b [1)]	21.99±1.51a	26.12±4.38a	23.18±4.45a
($mg\ kg^{-1}$)	10-20	13.39±3.24c	28.48±4.74b	49.90±6.95a	16.96±3.03c
	20-30	15.04±2.12bc	41.55±17.76a	34.20±10.64ab	8.96±0.82c
Mg^{2+}	0-10	3.78±0.86c	7.18±1.32b	7.95±1.62b	13.47±1.36a
($mg\ kg^{-1}$)	10-20	3.64±0.62c	9.32±1.44b	13.50±1.78a	11.94±2.14ab
	20-30	3.72±0.7b	12.17±6.39a	9.86±5.05ab	6.63±1.85ab
K^{+}	0-10	4.92±0.45b	11.28±2.39b	9.87±2.78b	85.19±6.07a
($mg\ kg^{-1}$)	10-20	4.46±0.47b	12.31±6.46b	10.65±2.94b	79.51±7.69a
	20-30	1.94±0.28b	6.64±3.69b	6.68±2.96b	56.07±4.88a
Na^{+}	0-10	11.90±1.58c	18.98±1.63b	20.32±1.39b	27.23±1.63a
($mg\ kg^{-1}$)	10-20	10.80±1.85b	28.13±10.27a	19.96±2.7ab	24.36±3.31a
	20-30	18.32±3.16b	40.26±19.05a	24.77±4.01ab	23.35±1.22ab
HCO_3^-	0-10	37.33±4.31b	33.18±11.50b	64.71±17.24a	63.05±5.75a
($mg\ kg^{-1}$)	10-20	29.87±2.49b	26.55±15.20b	21.57±8.74b	57.24±2.49a
	20-30	46.46±1.44b	45.63±16.94b	92.92±12.77a	65.54±6.27b
Cl^-	0-10	18.08±5.69c	24.65±7.89bc	37.47±11.96ab	50.95±2.85a
($mg\ kg^{-1}$)	10-20	32.88±2.85a	25.32±7.40ab	24.65±4.94ab	19.72±0.00c
	20-30	14.79±0.00b	16.11±7.66b	17.09±2.48b	26.30±2.85a
SO^{2-}	0-10	17.21±7.06c	33.30±2.81b	22.66±9.44bc	69.21±1.29a
($mg\ kg^{-1}$)	10-20	9.58±2.86c	41.25±12.13b	64.562.62a	66.41±7.67a
	20-30	17.83±4.19b	80.84±41.07a	29.53±5.75b	42.38±1.22ab
NO_3^-	0-10	12.27±3.46c	76.55±21.98bc	105.82±51.12b	272.08±45.49a
($mg\ kg^{-1}$)	10-20	18.64±7.09b	74.99±29.50b	86.88±26.75b	177.49±77.30a
	20-30	14.97±3.48c	65.74±17.47b	64.11±9.53b	94.69±9.25a
Total salt	0-10	118.50±9.59c	227.11±21.81b	294.93±45.00b	604.36±57.56a
($mg\ kg^{-1}$)	10-20	123.25±3.67c	246.34±17.34b	291.66±32.08b	453.62±54.08a
	20-30	133.08±11.50c	308.93±85.77a	279.15±16.25a	323.91±15.70a
EC	0-10	0.026±0.008c	0.055±0.009b	0.059±0.008b	0.129±0.010a
($S\ m^{-1}$)	10-20	0.025±0.005c	0.073±0.017b	0.124±0.015a	0.119±0.023a
	20-30	0.029±0.006b	0.105±0.056a	0.088±0.044ab	0.084±0.009ab

[1)] Mean values of 3 replicates ± standard deviation, different letters in a row mean significantly different by Duncan's multiple range test ($p < 0.05$)

Table 2: Univariate Analysis of Variance (ANOVA) for ions, total salt and electrical conductivity (EC) in four treatments and three depths

	Treatment		Depth		Treatment × Depth	
Item	F-value	p	F-value	p	F-value	p
Ca^{2+}	22.988	<0.001	2.387	0.113	5.391	0.001
Mg^{2+}	13.390	<0.001	1.241	0.307	3.313	0.016
K^+	572.401	<0.001	20.912	<0.001	7.809	<0.001
Na^+	8.776	<0.001	3.903	0.034	1.924	0.118
Total cations	47.781	<0.001	0.827	0.450	5.274	0.001
HCO_3^-	16.667	<0.001	23.215	<0.001	5.929	0.001
Cl^-	6.404	0.002	17.930	<0.001	8.703	<0.001
SO_4^{2-}	19.456	<0.001	1.761	0.193	7.337	<0.001
NO_3^-	38.659	<0.001	8.752	0.001	4.636	0.003
Total anions	89.164	<0.001	8.365	0.002	10.598	<0.001
Total salt	30.499	<0.001	0.440	0.649	6.357	<0.001
EC	20.909	<0.001	1.768	0.192	3.516	0.012

Table 3: Relationships of soil salt with its components and with other chemical properties

	Ca^{2+}	Mg^{2+}	K^+	Na^+	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Salt	EC
Ca^{2+}	1.00									
Mg^{2+}	0.74**	1.00								
K^+	-0.23	0.42*	1.00							
Na^+	0.53**	0.64 **	0.19	1.00						
HCO_3^-	-0.11	0.08	0.30	0.24	1.00					
Cl^-	-0.06	0.20	0.41*	0.01	0.11	1.00				
SO_4^{2-}	0.57**	0.86**	0.50**	0.70**	-0.05	0.01	1.00			
NO_3^-	0.06	0.54**	0.81**	0.28	0.23	0.59**	0.53**	1.00		
TS	0.22	0.72**	0.83**	0.50**	0.36*	0.51**	0.70**	0.94**	1.00	
EC	0.63**	0.96**	0.58**	0.62**	0.15	0.19	0.88**	0.60**	0.79**	1.00
SOC	0.03	0.50**	0.75**	0.15	0.11	0.54**	0.46**	0.81**	0.78**	0.54**
pH	-0.04	-0.43**	-0.60**	-0.18	0.02	-0.36*	-0.46**	-0.52**	-0.55**	-0.52**
TN	0.20	0.30	0.10	0.28	-0.31	0.13	0.31	0.24	0.22	0.23

*, ** significant at the 0.05 and 0.01 levels, respectively, TS: Total salt; EC: Electrical conductivity; SOC: Soil organic carbon and TN: Soil total nitrogen

Table 4: Total salt and its components in irrigation water of the three greenhouses

Item	1-year	4-year	10-year	Average
pH	7.48	7.45	7.42	7.45
Ca^{2+} (mg L^{-1})	76.18	55.21	23.19	51.53
Mg^{2+} (mg L^{-1})	10.16	8.99	4.07	7.74
K^+ (mg L^{-1})	0.83	0.52	0.45	0.60
Na^+ (mg L^{-1})	69.11	46.47	34.41	50.00
HCO_3^- (mg L^{-1})	358.14	276.75	112.74	249.21
Cl^- (mg L^{-1})	44.97	32.74	29.19	35.63
SO_4^{2-} (mg L^{-1})	26.35	12.80	18.07	19.07
NO_3^- (mg L^{-1})	0.73	0.39	0.44	0.52
Total salt (mg L^{-1})	593.95	441.33	229.98	421.75

Relationships of soil salt with its components and with other chemical properties: Soil total salt concentration was significantly correlated with ions except for Ca^{2+}, while the test soil EC was significantly correlated with all the cations and SO_4^{2-} and NO_3^-. Of the four cations in soils, Ca^{2+}, Mg^{2+} and Na^+ exhibited close relationships, but K^+ was only significantly correlated with Mg^{2+}. The concentration of soil HCO_3^- was not significantly correlated with all the cations, Cl^- was not with Ca^{2+}, Mg^{2+} and Na^+, NO_3^- was not with Ca^{2+} and Na^+. The concentration of SO_4^{2-} in soils was significantly correlated with all the cations, but not with HCO_3^- and Cl^- (Table 3).

Soil organic carbon was significantly correlated with total salt and EC and it was also positively correlated with Mg^{2+}, K^+, Cl^-, SO_4^{2-} and NO_3^- ($p<0.01$), but not with the other three ions. In contrast, soil pH was negatively with total salt, EC ($p<0.01$) and ions which were positively correlated with SOC ($p<0.05$) (Fig. 1). However, no significant correlation was found between soil total nitrogen and total salt, EC, or each of the ions (Table 3). The irrigation water in test soil contained high concentrations of HCO_3^-, Ca^{2+} and Na^+, but low concentrations of NO_3^- and K^+ (Table 4), as a result the dominant ions were tended to be Ca^{2+} and Na^+ in open field.

DISCUSSION

Soil salt was higher in greenhouse than in open field, it was tended to increase with the increasing of gardening time. Soil K^+ accounted for more than 40% of the total cations (in cmol concentration) and was the most dominant cation in the 10-year greenhouse, while Ca^{2+} and Na^+ were dominant cations in open field and 1- and 4-yaer greenhouses, reflecting the influence of heavy application of chemical K and high K contained chicken manure on soil cation dynamics in greenhouses. Of the four cations, soil K^+ was the highest and correlated with total salt (Table 3), owing to heavy fertilization in greenhouses[12]. Soil NO_3^- is always the dominant anion in vegetable greenhouses owing to heavy application of N fertilizers[5,10,12,14]. Farmers perceive N fertilizer as one of the most important factors contributing to vegetable production, thus many types of N fertilizers, e.g., diammonium orthophosphate, ammonium sulfate,

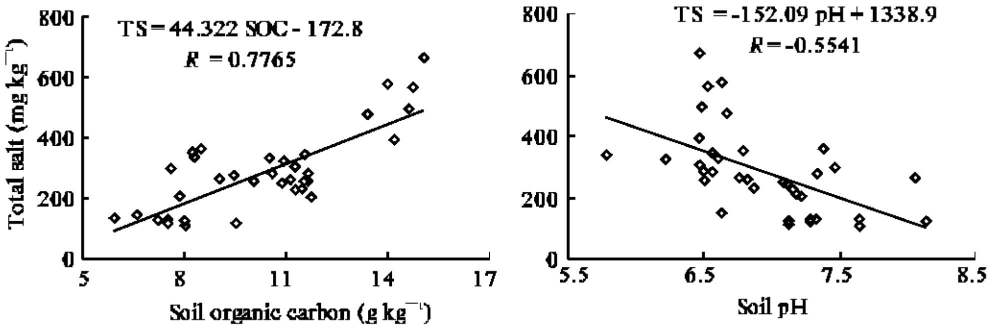

Fig. 1: Contrast of soil organnic carbon and soil pH with total salt

potassium nitrate, urea and liquid ammonium, were heavily applied in greenhouses. Tong *et al.*[3] found that soil NO_3^- was highly correlated with total salt in greenhouses. In this study, the coefficient of correlation was 0.94 ($p<0.001$) between NO_3^- and total salt (Table 3). Soil NO_3^- increases caused by heavy fertilization not only contributes to soil salt increasing but also leads to NO_3^- leaching from top to deep soil layer in greenhouses[12,13] and NO_3^- accumulation in produce and groundwater[8,10].

The absolute soil salt concentration did not reach the harmful level even in the 10-year greenhouse, but it was positively correlated with SOC and negatively with soil pH (Fig. 1). Soil salt increases with the heavy application of fertilizers that exceed vegetable requirements, SOC on the other hand increases markedly in greenhouse with the heavy application of chicken manure or other organic fertilizers and hence soil salt is often significantly correlated with SOC in greenhouses[12].

Since the increase of soil salt is often accompanied with the decrease of soil pH in greenhouses, soil salt was highly correlated with soil pH value. According to Liu *et al.* [15], the decrease of soil pH was mainly induced by the increase of organic acid after heavy application of chicken manure, while the increase of cations and NO_3^- under heavy application of chemical fertilizers was also considered as a leading cause of soil pH decrease[6].

Besides the heavy application of fertilizers, the heavy irrigation of ion-enriched water under the greenhouse conditions is also a main cause of soil salt accumulation in the surface layer[5,9,16]. The water irrigated in greenhouse was more than 20 000 $m^3\ ha^{-1}\ yr^{-1}$, which was about three times as much as that in open field, thus most of the test soil ions were higher in greenhouse than in open field. The upward movement of soil ions with water vapotranspiration led to salt accumulation in the surface soil layer in greenhouses[5,12]. Since K^+ and NO_3 concentrations were low in the irrigation water, the accumulations of K^+ and NO_3^- could be explained by heavy application of fertilizers. Moreover, the relative humidity in vegetable greenhouse was always maintained up to 60-100%. The high humidity and temperature conditions accelerated the decomposition of soil solid phase and the release of base cations, which increased salt concentration in the surface soil layer in greenhouses[13].

The best measure to avoid the accumulation of soil salt in greenhouses is to apply fertilizers rationally according to soil fertility, vegetable varieties and fertilizer properties. Since organic fertilizers are often preferred rather than chemical fertilizers to prolong the time of soil salinization in greenhouses[11], it is suggested that less chemical fertilizer be applied in soils of greenhouses. For the sake of food safety and soil health, it is strongly suggested that chemical N inputs be reduced in soils containing too much NO_3^- (the 10-year greenhouse in this study is a good example). Moreover, subsurface and drop irrigations, inter-crop and rotation systems are also recommendable in decreasing soil salt accumulation in greenhouses. For soils with too high salt concentrations, leaving the greenhouses open to natural leaching or changing soils should be taken into account.

CONCLUSION

Heavy application of fertilizers was regarded as the most important factor that accumulating salt in soils of greenhouses in northeast China. The examined soil K^+ and NO_3^- were the dominant cation and anion, respectively, in the 10-year greenhouse. It would be induced by the heavy application of K and N fertilizers. The upward movement of ions with water evapotranspiration was considered as the second key factor that leading to soil salt accumulation in the surface soil layer in greenhouses. It is suggested that the best measure to avoid the accumulation of soil salt in greenhouses is to apply fertilizers rationally according to the soil fertility, vegetable varieties and fertilizer properties.

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