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Research Article

Effects of Sulphur Application Times on the Sulphur Accumulation and Distribution for Summer Maize in Fluvo-aquic Soil

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Abstract: This study aimed to find out the efficacy of sulphur application times on the sulphur accumulation and distribution, especially in grain in summer maize in fluvo-aquic soil, the field experiment was conducted with two varieties (Nongda108 and Jinhai 5) by application 40 kg/ha sulphur fertilizer as $(NH_4)_2$ SO_4 at different growth stages (sowing, V6 and silking stage). Sulphur accumulation in shoot was significantly affected by the times of sulphur application. When sulphur application with treatment T2 (50% sulphur at sowing +50% sulphur at silking stage), the sulphur accumulation and concentration in shoot at maturity stage were significantly increased for both varieties and was also significantly higher than that in sulphur convention application way T1, i.e., 100% sulphur at sowing. Compared with Jinhai 5, Nongda108 accumulated more sulphur in shoot, but no obvious difference existed in shoot sulphur concentration between varieties. For all treatments, most sulphur accumulated was distributed into kernels and leaves for both varieties and the order of sulphur concentration was: leaf> husks >stalk-kernel>cob. The maximum sulphur concentration in kernel was found in T1 (100% sulphur at sowing) and T2 (50% sulphur at sowing +50% sulphur topdressed at silking stage) treatments for Nongda 108 and in T2 treatment for Jinhai 5. With above results, it could be concluded that split S application (50% S at sowing +50% S topdressed at silking stage) would be more effective for improving plant S nutrient status in fluvo-aquic soil condition.

Keywords: Maize, split application, sulphur concentration, sulphur harvest index, *Zea mays* L.

INTRODUCTION

Like nitrogen, phosphorus and potassium, Sulphur (S) is an essential element and plays an important role in the growth of higher plants, influence the protein and amino acid contents. Without adequate S, crops cannot reach their full potential in terms of yield or protein content (Zhao *et al*., 1999; Li, 1993). Earlier studies have shown S fertilization significantly improves both yield and quality of crops if adequate application in the field is ensured (Ahmad and Abdin, 2000; Luo *et al*., 2000; Xie *et al*., 2003; Yin *et al*., 2011) and the amount of S accumulation in plant is proportional to that incorporated into protein (Rendig *et al*., 1976). S fertilizer application could also increase N, P, K accumulation and plant requirements for sulfur are closely linked to nitrogen availability (Xie *et al*., 2004). It is well known that most of plant's requirement for S is absorbed through the roots in the sulphate (SO_4^{-2}) form, however, in recent years, continuous crop removal of S by crops with higher yields, increased use of S-free fertilizers, lower S deposits to soil from the atmosphere and many other reasons have reduced the soil capacity to application S for crops. And S deficiency has become widespread over the past several decades in most of agricultural areas of the world, especially in Africa and Asia (Ceccotti, 1996; McGrath *et al*., 2002; Messick *et al*., 2005). Furthermore, the deficit in the input/output of sulphur is likely to increase, unless sulphur fertilizers are used (Zhao *et al*., 1999; Blake-Kalff *et al*., 2000). In china, about 30% of cropped soils were S deficiency and four million hm^2 soils were potentially S deficiency (Ma and Gao, 2008). Consequently, in recent years, people have paid more attention to the use of S fertilizer in agriculture. Among cereals, maize (*Zea may* L.) is an important food and feed crop. In Huanghuaihai plain of China, on an average maize crop absorbs as much S as it absorbs P and the maize season could take up about 21.75 kg/hm from soil (kernel yield 12960 kg/hm) (Wang *et al*., 2000). For S fertilizer application times, in barley and wheat, studies have shown the importance of availability of soil S during grain filling (Adiputra and Anderson, 1995; Eriksen *et al*., 2001; Eriksen and

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Mortensen, 2002; Fitzgerald *et al*., 1999; Monaghan *et al*., 1999), which might be explained by less redistribution of S than N from vegetative tissue to the grain, especially under S-limiting conditions. In maize, most research focused on the response of S application as single basal fertilizer. However, maize took up more than 45% of their total S after silking (Wang *et al*., 2000). The aim of this study was to investigate the effect of S application times on the S accumulation and distribution, especially in grain in summer maize in fluvo-aquic soil in China.

MATERIALS AND METHODS

Experiment design: The field experiment was conducted in 2009 in fluvo-aquic soil[19] at Laiyang Experiment Station (120°71' N, 36°97' E) of Qingdao Agricultural University, Shandong province, China. The experimental soil pH was 6.85 and available S was 61.7 mg/kg. The experimental design was a split-plot, with three replications, main plots were five S application times, i.e., no S (CK), 100% S at sowing (T1), 50% S at sowing +50% S topdressed at silking (T2), 50% S at sowing +50% S top dressed at V6 (T3) and 100% S topdressed at V6 (T4) and subplots were two maize cultivars (Nongda 108 and Jianhai 5). Each subplot was 36 m^2 (5 rows, inter-row distance 0.6 m), plant spacing within the row was 0.22 m. 480 kg/hm^2 composite fertilizers (N-P_2O_5-K_2O: 15-15-15) were incorporated at sowing and 140 kg N/hm^2 was top-dressed for each plot as ammonium nitrate at 6-leaf stage. And S fertilizer (only in the +S plots) was supplied at the rate of 40 kg S/ha, added as NH_4SO_4.

Plant harvest and sulphur analysis: Five even plants were labelled at flowering stage and three of them were harvested at physiological maturity. The harvested plants were partitioned into individual organs. All plant material was firstly dried at 105°C for one hour and then dried at 80°C for 48 h. Dried plant samples were ground in a stainless steel mill and passed through a 0.25-mm sieve before analysis. In each plot, two row plants were harvested for measuring yield. Sub-samples were digested in a bi-acid mixture (HNO_3: $HClO_4$ = 3:2). S was determined by ultraviolet spectrophotometer (Unico, UV-2102PC, USA) at 420 nm wavelength.

Statistical methods: Data were subjected to two-way (S application times and varieties) Analysis of Variance (ANOVA). All statistical analyses were performed with SAS (SAS Institute, 2001). Results for ANOVA were considered significant at $p \leq 0.05$.

RESULTS

Dry matter and yield: There was no significant treatments' effect of Sulphur (S) application times on the kernel yield and harvest index neither for Nongda 108 or Jinhai 5 (Table 1). However, the dry matter above ground was influenced by S application times, among all S treatments, T3 (50% S at sowing +50% S topdressed at V6) treatment recorded highest dry matter for Nongda 108 and T2 (50% S at sowing +50% S at silking stage) for Jinhai 5. The difference between varieties was significance both in dry matter and kernel yield.

S accumulation in shoot and distribution among individual organs: The S accumulation in shoot at mature stage was significantly influenced by S application times (Fig. 1). And when S application with treatment T2 (50% S at sowing +50% S at silking stage), the S accumulation in shoot was significantly higher than the other treatments for both varieties. And T1 (100% S at sowing) performed better than T3 (50% S at sowing +50% S topdressed at V6) and T4 (100% S topdressed at V6). In shoot S accumulation, the difference between varieties was also significant, compared with Jinhai 5, Nongda108 accumulated more S, especially in treatments T2 and T1. Among all individual organs, for both varieties, most S accumulated in the shoot was distributed into kernels and leaves for all S application times.

S concentration in shoot: The S concentration shoot at maturity stage was significantly affected by S application times (Fig. 2). And the S application time T2 (50% S at sowing +50% S at flowering stage) recorded highest shoot S concentration for both varieties. And T1 (100% S as basal application)

Table 1: Effects of surphur application times on the dry matter and yield at maturity stage of two test cultivars, Jinhai 5 and Nongda 108

	Dry matter (kg/ha)		Yield (kg/ha)		Harvest index	
S application times†	Nongda 108	Jinhai 5	Nongda 108	Jinhai 5	Nongda 108	Jinhai 5
CK	20276	17860	10122.82	9056.27	0.50	0.51
T1	19721	17966	9988.51	9395.44	0.51	0.52
T2	21928	20210	10824.74	9957.65	0.50	0.50
T3	23023	17640	11853.88	8910.83	0.52	0.50
T4	20310	16109	10472.95	8418.04	0.51	0.52
Significance variety	*		*		NS	
S	*		NS		NS	
S×variety	NS		NS		NS	

*: p<0.05; NS: Not statistically significant; †S application times: no S (CK), 100% S at sowing (T1), 50% S at sowing +50% S topdressed at silking (T2), 50% S at sowing +50% S topdressed at V6 (T3) and 100% S top dressed at V6 (T4)

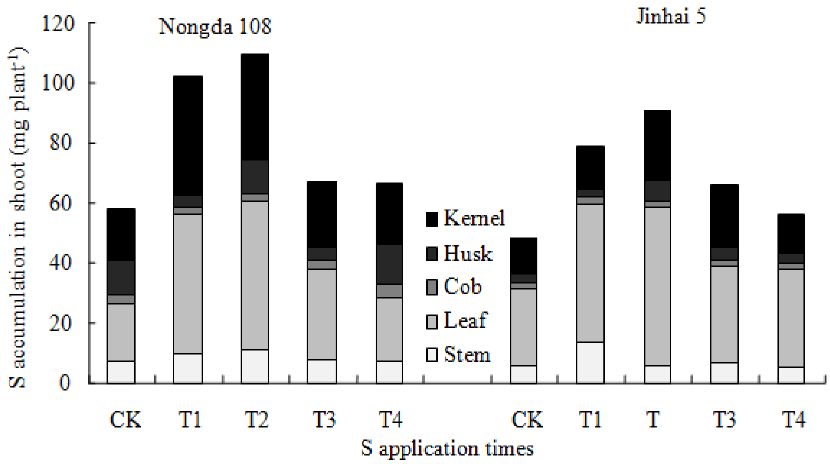

Fig. 1: Effects of S application times on S accumulation in shoot and distribution among individual organs at maturity stage for two varieties, nongda 108 and jinhai 5. S application times including: no S (CK), 100% S at sowing (T1), 50% S at sowing +50% S topdressed at silking (T2), 50% S at sowing +50% S topdressed at V6 (T3) and 100% S topdressed at V6 (T4)

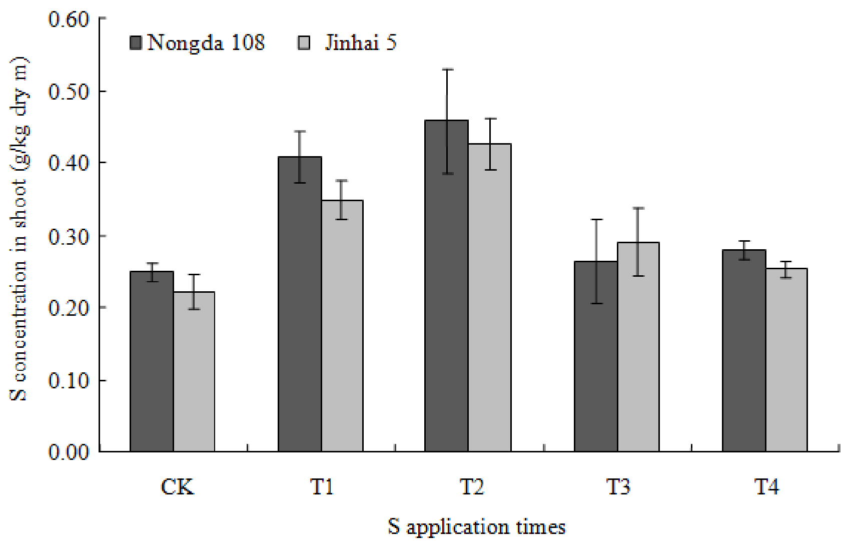

Fig. 2: Effects of S application times on shoot S concentration at maturity stage for two cultivars, jinhai 5 and nongda 108. The error bars indicate the standard deviation (n = 3). S application times including: no S (CK), 100% S at sowing (T1), 50% S at sowing +50% S topdressed at silking (T2), 50% S at sowing +50% S topdressed at V6 (T3) and 100% S topdressed at V6 (T4)

performed better than T3 (50% S at sowing +50% S top dressed at V6) and T4 (100% S top dressed at V6). There was no obvious difference between varieties in shoot S concentration.

S concentration in individual plant organs: Among all individual organs, for all S application treatments, the order of S concentration at maturity stage was: leaf>husks>stalk-kernel>cob (Table 2). S concentration was affected by S application times for all individual plant organs. Among all S treatments, T1 (100% S as basal application) and T2 (50% S as base fertilizers +50% S topdressed at silking stage) treatments highly increased leaf S concentration. And the maximum S concentration in kernel was found in T1 and T2 treatments for Nongda 108 and in T2 treatment for Jinhai 5.

S harvest index: Sulphur harvest index was affected by S application treatments significantly, but the change trend was inconsistent between cultivars (Fig. 3). For Nongda 108, the maximum S harvest index was found in T1 treatment (100% S at sowing) and the lowest in CK, while for Jinhai 5, the maximum S harvest index

Table 2: Effects of sulphur application times on S concentration in individual plant organs of at maturity stage for two test cultivars, jinhai 5 and nongda 108

Varieties	S application times†	S concentration in individual organs (g/kg dry weight) Stalk	Leaf	Husk and silk	Cob	Kernel
Nongda 108	CK	0.111	0.578	0.604	0.134	0.145
	T1	0.141	1.355	0.227	0.103	0.314
	T2	0.162	1.444	0.557	0.122	0.303
	T3	0.109	0.843	0.259	0.115	0.165
	T4	0.110	0.650	0.682	0.211	0.164
Jinhai 5	CK	0.101	0.821	0.132	0.073	0.112
	T1	0.234	1.553	0.150	0.093	0.118
	T2	0.102	1.590	0.374	0.102	0.210
	T3	0.113	0.939	0.217	0.095	0.179
	T4	0.096	1.022	0.145	0.090	0.115
Significance variety		NS	*	*	NS	*
S		*	*	*	*	*
Variety×S		*	NS	*	NS	*

*: $p<0.05$; NS: Not statistically significant; †S application times: no S (CK), 100% S at sowing (T1), 50% S at sowing +50% S topdressed at silking (T2), 50% S at sowing + 50% S top dressed at V6 (T3) and 100% S topdressed at V6 (T4)

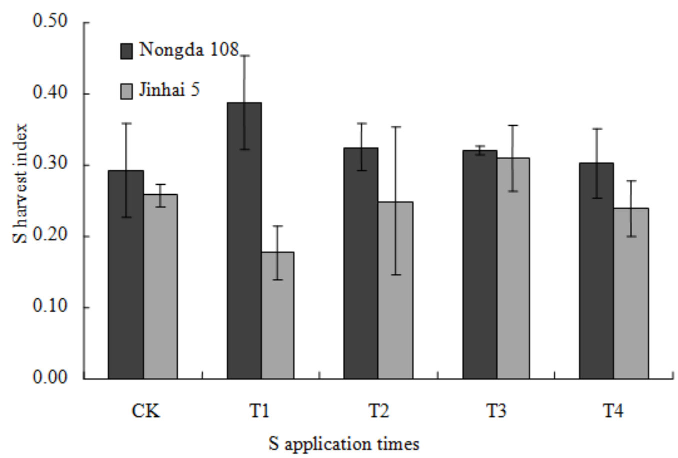

Fig. 3: Effects of S application times on S harvest index of two cultivars, jinhai 5 and nongda 108. The error bars indicate the standard deviation (n = 3). S harvest index = S accumulation in kernel/S accumulation in shoot. S application times including: no S (CK), 100% S at sowing (T1), 50% S at sowing +50% S top dressed at silking (T2), 50% S at sowing + 50% S topdressed at V6 (T3) and 100% S top dressed at V6 (T4)

was in T3 treatment (50% S at sowing +50% S top dressed at V6) and the lowest in T1 treatment (100% S at sowing).

DISCUSSION

Under field conditions, the availability of S for crop growth mainly depends on soil availability and atmospheric depositions of SO_2 and H_2S. However, In China, S availability has been decreasing in recent areas (Ma and Gao, 2008; Wu *et al*., 2007) and without adequate S, crops could not reach their full potential in terms of yield, quality, nor could they make efficient use of applied nitrogen (Järvan *et al*., 2008). So intensive crop production requires sulfur fertilizer inputs. In this study, we found S accumulation in shoot was significantly affected by the time of sulphur application. When sulphur application in treatment T2 (50% S at sowing +50% S at silking stage), the S accumulation and concentration in shoot were significantly increased (Fig. 1) and was also higher than that in S convention application way T1, i.e., 100% S at sowing, which indicates that the late S application should be effective to increase S accumulation in plant. Compared with Jinhai 5, Nongda 108 accumulated more S in shoot, but no obvious difference existed in shoot S concentration between varieties, which might be diluted by higher shoot dry weight for Nongda 108.

The distribution of S among organs at maturity stage was unaffected by the times of S application, for all S application times, most S was distributed into kernels and leaves (Fig. 1) and the S concentration was highest in leaves (Table 2), this is comparable to what was found in maize (Wang *et al*., 2000) and in winter oilseed rape (Abdallah *et al*., 2010). The maximum S concentration in kernel was found in T1 (100% S at sowing) and T2 (50% S at sowing +50% S topdressed at silking stage) treatments for Nongda 108 and in T2 treatment for Jinhai 5. However, this doesn't mean that the percentage of S partitioned to kernels (S harvest index) is increased simultaneously (Fig. 3).

Therefore, our findings suggest that split S application (50% S at sowing +50% S topdressed at silking stage) would be more effective for improving plant S nutrient status, i.e., increasing S accumulation and concentration in shoot and also kernel S concentration in summer maize in fluvo-aquic soil.

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