Effects of zinc fertilizer rate and application method on photosynthetic characteristics and grain yield of summer maize

H. Liu¹, W. Gan¹, Z. Rengel², P. Zhao^{1,3*}

¹Resources and Environment College, Henan Agricultural University, Zhengzhou, P.R. China. ²Soil Science and Plant Nutrition, School of Earth and Environment, UWA Institute of Agriculture, University of Western Australia, Crawley, Australia. ³Collaborative Innovation Center of Henan Grain Crops, Zhengzhou, P.R. China.

*Corresponding author: zhpddy@163.com

Abstract

The Zinc deficiency is a worldwide nutritional constraint for crop production in many types of soil, particularly in cereals growing in calcareous soil. Two field trials were conducted to study the effects of zinc fertilizer doses and application method on photosynthetic characteristics and grain yield of summer maize, from June to September of 2013, in Xun County (34°40'12"N, 114°32'24"E) and Yuzhou County (33°59'19"N, 113°33'47"E). Optimal Zn fertilizer application (30 kg ZnSO₄•7H₂O hm⁻²) increased chlorophyll content in leaves, improved photosynthesis, and increased grain yield of summer maize. At 15 kg ZnSO₄•7H₂O hm⁻², grain yield was higher in Xun County and lower in Yuzhou County when the entire amount was applied as basal fertilization as opposed to being split between the basal and foliar fertilization. The opposite result (grain yield lower in Xun County than in Yuzhou County) was obtained at 30 kg ZnSO₄•7H₂O hm⁻². These results have important implications for guiding the rational application of Zn fertilizer and improving the grain yield of summer maize in Henan province.

Keywords: Zn fertilizer, photosynthesis, grain yield, summer maize

1. Introduction

Alth Zinc (Zn) is an essential element for higher plants, and its importance in agriculture is increasingly being recognized (Genc *et al.*, 2006). Low Zn availability in soil is common worldwide, and Zn deficiency leads to reductions in crop yield (Cakmak *et al.*, 1996; Rengel and Graham, 1995). In China, 40% of soils are low in Zn (Wang *et al.*, 1998), especially calcareous soils in North China (Liu, 1996).

Zinc deficiency is the fifth major factor affecting human health in developing countries (Anthony *et al.*, 2002). Maize is one of the three major world food crops, is recognized as the “golden food” because of its high grain yield and nutrition value, and plays a very important role in the daily calorie intake of humans (WHO). Maize is one of the crops most sensitive to Zn deficiency (Mattiello *et al.*, 2015); Zn

deficiency hinders maize growth, resulting in decreased grain yield and quality (Behera *et al.*, 2015). Zinc is important in photosynthesis and respiration, and Zn deficiency decreases the photosynthetic rate, chlorophyll content, activity of carbonic anhydrase, and protein biosynthesis (Cakmak, 2008; Kaya and Higgs, 2002; Fu *et al.*, 2016). Therefore, application of Zn fertilizer may be an important measure for improving the yield and quality of maize.

Suitable and proper application methods of Zn fertilizer are still unclear. It has been reported that basal Zn fertilizer may have a strong residual effect (Liu *et al.*, 2004), but in some soils, Zn can be fixed and is therefore not utilized by the crop (Rengel, 2015). Therefore, foliar application of Zn fertilizer is a better way to supply Zn to crops.

Both growth and grain yield of summer maize are closely related to the main ecological factors (e.g., light, temperature, and water availability) during the growth period (Gong *et al.*, 2013). Crop photosynthetic efficiency is not only influenced by the above-mentioned ecological factors but also by the physical, chemical and biological properties of the soil. Xun County (in the north of Henan province) is located in the transition zone of the eastern slopes of Taihang Mountain and the North China Plain. It has a warm and semi-humid monsoon climate and alluvial soils (Zhang *et al.*, 2009). Yuzhou County (in the center of Henan Province) has a warm-temperate continental monsoon climate and calcareous brown soil. Xun County and Yuzhou County are the major maize-planting areas in Henan province.

The main objective of this study was to investigate the effects of Zn fertilizer doses and application methods on the photosynthetic characteristics and grain yield of summer maize, through an experiment in Hebi City of Xun County and another experiment in Xuchang City of Yuzhou County. The results of this study are important for optimizing Zn fertilizer application and

increasing the grain yield of summer maize in different areas of Henan Province.

2. Materials and Methods

2.1. Experiment location and description of materials

Two field experiments were conducted, one in Xun County of Hebi City in the north of Henan Province (34°40'12"N, 114°32'24"E) and another in Yuzhou County of Xuchang City in the center of Henan Province (33°59'19"N, 113°33'47"E). The physical and chemical characteristics of the soil are displayed in Table 1. The chemical properties of the soil were analyzed following the procedures provided by Bao (2002).

The seeds of summer maize were Xundan No. 29 from Henan Agricultural High-Tech Group Co. Ltd. The fertilizers used in the experiments were $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, $\text{CO}(\text{NH}_2)_2$, $(\text{NH}_4)_2\text{HPO}_4$ and KCl.

2.2. Experimental design

There were six treatments in each field experiment, including Zn0, three doses of Zn fertilizer applied to soil (Zn15, Zn30 or Zn45 with 15, 30 or 45 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}/\text{ha}$ hm^{-2} , respectively) and two doses of Zn fertilizer with combined soil and foliar application ($\text{xZn15}=7.5$ kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} applied to the soil plus foliar application of the same amount, $\text{xZn30}=15$ kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} applied to the soil, as well as two foliar applications each of 7.5 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2}). Zinc fertilization of soil was performed at seeding in June, and foliar Zn applications occurred in July and August (Table 2). The treatments were replicated three times in a randomized block design. The plot size was 8 m $\times$ 4 m=32 m².

$\text{CO}(\text{NH}_2)_2$, $(\text{NH}_4)_2\text{HPO}_4$ and KCl were applied to each plot at the doses (in kg hm^{-2}) of 240 N, 75 P_2O_5 and 90 K_2O , respectively.

Phosphorus and potassium fertilizers were applied at the leaf development stage with irrigation; nitrogen fertilizer was also applied at the leaf development

stage with irrigation. Maize planting density was 67,500 plants hm^{-2} , with plant spacing of 25 cm and row spacing of 60 cm.

Table 1. Physical and chemical properties of tested soils

Location	Soil type	Organic matter g kg^{-1}	Available N mg kg^{-1}	Available P mg kg^{-1}	Available K mg kg^{-1}	Available Zn mg kg^{-1}	pH soil:water =1:5
Xunxian County	alluvial soil	18.3	28.0	2.57	206.67	0.50	7.33
Yuzhou County	cinnamon soil	20.7	21.0	5.12	180.00	0.38	7.62

Table 2. Specific implementation dates in the two field experiments

Location	Sowing date	Fertilization date			Sampling date			
		Basal application	First spraying	Second spraying	Leaf development stage	Inflorescence emergence stage	Grain development stage	Harvest date
Xun County	June 14th	July 6th	July 29th	August 11th	August 6th	August 18th	August 29th	September 25th
Yuzhou County	June 6th	June 30th	July 23th	August 5th	July 30th	August 12th	August 24th	September 18th

2.3. Plant analyses

Photosynthetic parameters of maize leaves were determined using a Li-6400 Portable Photosynthesis Analysis System (LI-COR Inc., Lincoln, Nebraska USA). Net photosynthesis rate (Pn), stomatal conductance (Gs), transpiration rate (Tr) and intercellular CO_2 concentration (Ci) of seedling leaves were measured under the following conditions: external CO_2

concentration of 400 $\mu\text{mol/mol}$ supplied from a CO_2 steel gas cylinder, and photosynthetic active radiation (PAR) of approximately 1,200 $\mu\text{mol/m}^2$ per s provided by a Li6400-02B LED Red/Blue Light Source. Chlorophyll concentration in seedling leaves was determined by anhydrous ethanol extraction (Li, 2001). Chlorophyll concentrations and photosynthetic parameters in the leaves from the same position (the newest fully expanded leaves and the ear leaves) were

determined from 9:00–11:00 AM on a sunny day. At grain maturity, twenty maize plants were harvested and air-dried. Dry matter weight of shoots, as well as grain yield and yield components (including the number of seeds per ear and 1,000-seed weight) were determined.

2.4. Statistical analysis

All data were statistically analyzed with a two-way ANOVA procedure using the SPSS 19.0 software (Chicago, USA). The main effects and the interaction were analyzed using the F-value test. The mean values were subjected to multiple comparisons using Duncan's-test ($P < 0.05$).

3. Results

3.1. Effects of Zn fertilizer doses and application method on photosynthetic characteristics of summer maize

3.1.1. Net photosynthetic rate (Pn)

Compared to the treatment with no Zn fertilizer application, Zn applied as either basal fertilizer or basal + foliar significantly ($P \leq 0.05$) increased the net photosynthetic rate (Pn) in summer maize at each growth stage in both field trials (Xun County and Yuzhou County) (Figure 1). At the leaf development stage, with increasing Zn doses as basal fertilizer only, the Pn in summer maize increased (up to Zn45) in Xun County, but in Yuzhou County, it increased up to Zn30 and then decreased. At the stages of inflorescence emergence and grain development, as the basal Zn fertilizer doses increased, the Pn in summer maize leaves increased up to Zn30 and then declined in both Xun County and Yuzhou County.

At the stages of leaf development and inflorescence emergence, in the treatments with the same doses of Zn application ($15 \text{ kg ZnSO}_4 \cdot 7\text{H}_2\text{O hm}^{-2}$ or $30 \text{ kg ZnSO}_4 \cdot 7\text{H}_2\text{O hm}^{-2}$), the Pn in summer maize leaves in Xun County and Yuzhou County was higher with Zn application as basal + foliar fertilizer compared with Zn application only as basal fertilizer. However, at the grain development stage, the Pn of summer maize leaves in Xun County was lower with Zn application at $30 \text{ kg ZnSO}_4 \cdot 7\text{H}_2\text{O hm}^{-2}$ (yZn30) as basal fertilizer + foliar compared with Zn application as basal fertilizer only. In Yuzhou County, the Pn of summer maize leaves was higher with Zn application at $15 \text{ kg ZnSO}_4 \cdot 7\text{H}_2\text{O hm}^{-2}$ (xZn15) as basal fertilizer + foliar compared with Zn application as basal fertilizer only.

3.1.2. Stomatal conductance (Gs)

Compared with the Zn0 treatment, applying Zn as either basal fertilizer only or as basal + foliar fertilizer significantly increased ($P \leq 0.05$) Gs in summer maize leaves at each growth stage in Xun County and Yuzhou County, except for the treatment yZn30 (Zn applied as both basal and foliar fertilizer) at the grain development stage in Yuzhou County (Figure 2). With an increase in the Zn application doses as basal fertilizer of up to $30 \text{ kg ZnSO}_4 \cdot 7\text{H}_2\text{O hm}^{-2}$, Gs in summer maize leaves increased and then declined at Zn45 in Xun County and Yuzhou County.

In Xun County, at the stages of leaf development and inflorescence emergence, Gs in summer maize leaves was higher in the treatment with basal + foliar Zn fertilizer than in basal Zn fertilizer only. At the grain development stage and $15 \text{ kg ZnSO}_4 \cdot 7\text{H}_2\text{O hm}^{-2}$, Gs was higher ($P \leq 0.05$) with basal + foliar Zn fertilizer than with basal Zn fertilizer only. However, at $30 \text{ kg ZnSO}_4 \cdot 7\text{H}_2\text{O hm}^{-2}$, Gs was higher with basal Zn fertilizer than with basal + foliar Zn fertilizer.

Figure 1. Effects of Zn fertilizer doses and application method on net photosynthetic rate (Pn) in summer maize (A: Xun County and B: Yuzhou County). Means and standard errors ($n=3$). Means with different letters are significantly different at $P \leq 0.05$. F-test: Xun County $F(\text{Growth stage})=131^{**}$, $F(\text{Zn})=124^{**}$, $F(\text{Growth stage} \times \text{Zn})=37^{**}$; Yuzhou County $F(\text{Growth stage})=116^{**}$, $F(\text{Zn})=84^{**}$, $F(\text{Growth stage} \times \text{Zn})=13^{**}$. * $P < 0.05$, ** $P < 0.01$.

Figure 2. Effects of Zn fertilizer doses and application method on stomatal conductance (Gs) in summer maize (A: Xun County and B: Yuzhou County). Means + standard errors ($n=3$). Different letters indicate significant difference at $P \leq 0.05$. F-test: Xun County $F(\text{Growth stage})=195^{**}$, $F(\text{Zn})=147^{**}$, $F(\text{Growth stage} \times \text{Zn})=30^{**}$; Yuzhou County $F(\text{Growth stage})=73^{**}$, $F(\text{Zn})=46^{**}$, $F(\text{Growth stage} \times \text{Zn})=13^{**}$. * $P < 0.05$, ** $P < 0.01$.

Figure 3. Effects of Zn fertilizer doses and application method on transpiration rate (Tr) in summer maize (A: Xun County and B: Yuzhou County). Means + standard errors ($n=3$). Different letters indicate significant difference at $P \leq 0.05$. F-test: Xun County $F(\text{Growth stage})=320^{**}$, $F(\text{Zn})=124^{**}$, $F(\text{Growth stage} \times \text{Zn})=15^{**}$; Yuzhou County $F(\text{Growth stage})=445^{**}$, $F(\text{Zn})=52^{**}$, $F(\text{Growth stage} \times \text{Zn})=8.2^{**}$ * $P < 0.05$, ** $P < 0.01$.

3.1.3. Transpiration rate (Tr)

Compared with the Zn0 treatment, the application of Zn as basal fertilizer or as both basal and foliar fertilizer significantly ($P \leq 0.05$) increased the Tr in summer maize leaves at each growth stage in Xun County and Yuzhou County (Figure 3).

With an increase in the Zn application doses as basal fertilizer, the Tr of summer maize leaves in Xun County and Yuzhou County showed a trend of increasing first and then declining, and the highest Tr was in the Zn30 treatment. At the same doses of Zn application in Xun County, Tr was significantly higher ($P < 0.05$) with Zn application as both basal and foliar fertilization than with Zn application only as basal fertilizer, except for the treatment yZn30 at the grain development stage. However, in Yuzhou County, the Tr with Zn application both as basal and foliar fertilization was higher at Zn15 and lower at Zn30 compared with Zn application only as basal fertilizer.

3.1.4. Intercellular CO_2 concentration (Ci)

Compared with no Zn fertilizer, the Ci significantly decreased ($P \leq 0.05$) at each growth stage in Xun County and Yuzhou County with Zn application (regardless of whether basal fertilizer only or both basal and foliar fertilization was used) (Figure 4).

In Xun County, with an increase in the Zn application doses as basal fertilizer, the Ci markedly decreased ($P \leq 0.05$) in the stages of leaf development and inflorescence emergence.

In contrast, the Ci showed a decline first ($P \leq 0.05$) and then increased in the grain development stage, with the lowest Ci in the treatment Zn30. However, in Yuzhou County, with an increase in Zn application doses as basal fertilizer, the Ci first decreased ($P \leq 0.05$) and then increased ($P \leq 0.05$), and the lowest Ci occurred in the treatment Zn30.

At the same doses of Zn application, in Xun County, the Ci was significantly lower ($P \leq 0.05$) with Zn application as both basal and foliar fertilizer compared with Zn application only as basal fertilizer, except in the treatment xZn15 at the inflorescence emergence stage.

However, in Yuzhou County, compared with the treatment of Zn application only as basal fertilizer, the Ci significantly decreased ($P \leq 0.05$) with Zn application both as basal and foliar fertilizer at Zn15 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O} \text{ hm}^{-2}$ but increased ($P \leq 0.05$) at Zn30.

Figure 4. Effects of Zn fertilizer doses and application method on intercellular CO_2 concentration (Ci) in summer maize (A: Xun County and B: Yuzhou County). Means + standard errors ($n=3$). Different letters indicate significant difference at $P \leq 0.05$. F-test: Xun County $F(\text{Growth stage})=1128^{**}$, $F(\text{Zn})=591^{**}$, $F(\text{Growth stage} \times \text{Zn})=214^{**}$; Yuzhou County $F(\text{Growth stage})=94^{**}$, $F(\text{Zn})=159^{**}$, $F(\text{Growth stage} \times \text{Zn})=23^{**}$. $^{*}P < 0.05$, $^{**}P < 0.01$.

3.2. Effects of Zn fertilizer doses and application method on chlorophyll concentrations in summer maize leaves

Compared with no Zn fertilizer, Zn application (regardless of whether basal fertilizer only or both basal and foliar fertilization was used) resulted in a significant increase ($P \leq 0.05$) in concentrations of chlorophyll a and chlorophyll b at each growth stage in Xun County and Yuzhou County (Figure 5).

In Xun County, Zn application had significant ($P \leq 0.05$) effects on the concentrations of chlorophyll a and b at the inflorescence emergence and grain development stages. Compared with no Zn fertilizer application, Zn as basal fertilizer at 45 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O} \text{ hm}^{-2}$

increased the concentrations of chlorophyll a and b substantially, and Zn fertilizer applied as both basal and foliar fertilizer could further improve the concentration of chlorophyll a and b in the leaves of summer maize at Zn15 and Zn30, compared with Zn application only as basal fertilizer. In Yuzhou County, Zn as basal fertilizer at 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O} / \text{ha}$ increased the concentrations of chlorophyll a and b in the leaves of summer maize significantly compared with Zn applied as both basal and foliar fertilizer. At Zn15, Zn applied as both basal and foliar fertilizer had more positive effects on chlorophyll a and b concentrations in the leaves of summer maize compared with Zn applied only as basal fertilizer, but there was no such effect at Zn30.

Figure 5. Effects of Zn fertilizer doses and application method on chlorophyll a (A1: Xun County and B1: Yuzhou County) and chlorophyll b (A2: Xun County and B2: Yuzhou County) concentrations in summer maize. Means + standard errors (n=3). Different letters indicate significant difference at $P \leq 0.05$. F-test: Xun County: chlorophyll a: $F(\text{Growth stage})=51^{**}$, $F(\text{Zn})=18^{**}$, $F(\text{Growth stage} \times \text{Zn})=5.6^{**}$; chlorophyll b: $F(\text{Growth stage})=0.51$, $F(\text{Zn})=15^{**}$, $F(\text{Growth stage} \times \text{Zn})=3.6^{**}$; Yuzhou County: chlorophyll a: $F(\text{Growth stage})=32^{**}$, $F(\text{Zn})=40^{**}$, $F(\text{Growth stage} \times \text{Zn})=18^{**}$; chlorophyll b: $F(\text{Growth stage})=73^{**}$, $F(\text{Zn})=18^{**}$, $F(\text{Growth stage} \times \text{Zn})=2.8^{*}$. $^{*}P < 0.05$, $^{**}P < 0.01$.

3.3. Effects of Zn fertilizer doses and application method on grain yield and yield components of summer maize

Compared with no Zn fertilizer, Zn application (either as basal fertilizer or basal + foliar fertilizer) significantly increased ($P \leq 0.05$) the grain yield of summer maize in Xun County and Yuzhou County (Figure 6). The highest grain yield occurred in the treatment with 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} applied as both basal and foliar fertilizer in Xun County, and in the treatment of 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} Zn as only basal fertilizer in Yuzhou County.

In Xun County, compared with no Zn fertilizer, Zn application (regardless of whether it was applied as basal fertilizer or as both basal and foliar fertilizer) significantly increased ($P \leq 0.05$) 1000-grain weight, grain numbers and ear length, with the highest values observed in the treatment with 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} Zn as basal fertilizer (Figure 7).

At the same doses of Zn application, there were no significant differences between Zn as basal fertilizer and Zn applied as both basal and foliar fertilizer.

In Yuzhou County, compared with no Zn fertilizer, Zn application (either as basal fertilizer or as both basal and foliar fertilizer) significantly increased ($P \leq 0.05$) grain numbers and ear length, with the highest values observed in the treatment with

30 kg hm^{-2} $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ as basal fertilizer. The only treatment that significantly increased ($P \leq 0.05$) 1000-grain weight was Zn fertilizer at 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} applied as both basal and foliar fertilizer.

Figure 6. Effects of Zn fertilizer doses and application method on grain yield (A), grain number per ear (B) and 1000-grain weight (C) in summer maize. Means + standard errors ($n=3$). Different letters indicate significant difference at $P \leq 0.05$. F-test: Grain yield: $F(\text{Location})=1247^{**}$, $F(\text{Zn})=499^{**}$, $F(\text{Location} \times \text{Zn})=53^{**}$; Grain number ear⁻¹: $F(\text{Location})=57^{**}$, $F(\text{Zn})=19^{**}$, $F(\text{Location} \times \text{Zn})=3.9^{*}$; 1000-grain: $F(\text{Location})=183^{**}$, $F(\text{Zn})=119^{**}$, $F(\text{Location} \times \text{Zn})=38^{**}$. $^{*}P < 0.05$, $^{**}P < 0.01$.

Figure 7. The main effects of location and Zn application method on total yield (A) and ear length (B) in summer maize. Means + standard errors (n=3). Different letters indicate significant difference at $P \leq 0.05$. F-test: Total yield: $F(\text{Location})=88^{**}$, $F(\text{Zn})=8.9^{**}$, $F(\text{Location} \times \text{Zn})=2.5$; Ear length: $F(\text{Location})=8.2^{**}$, $F(\text{Zn})=19^{**}$, $F(\text{Location} \times \text{Zn})=2.5$. * $P < 0.05$, ** $P < 0.01$.

4. Discussion

4.1. Effects of Zn fertilizer doses on photosynthesis in summer maize

Zinc fertilizer plays an important role in the photosynthetic processes (increases in chlorophyll content, net photosynthetic rate, stomatal conductance and transpiration rate) of higher plants and results in increases of leaf photoassimilates as well as grain yield of maize (Du and Zhang, 2008; Hashemi *et al.*, 2005; Li and Liu, 2001; Simmons and Jones, 1985; Sun and Yang, 2002; Wei *et al.*, 2005). The findings of the aforementioned studies are consistent with those of our study.

In Xun County and Yuzhou County, the appropriate application of Zn fertilizer increased photosynthesis and improved the grain yield of summer maize, but the application of excessive Zn fertilizer resulted in a decrease in photosynthetic rate and grain yield. The appropriate doses of Zn fertilizer for improving chlorophyll content in summer maize leaves differed between the two sites: Zn application as basal fertilizer at 45 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O} \text{ hm}^{-2}$ in Xun County and at 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O} \text{ hm}^{-2}$ in Yuzhou County was beneficial for improving the chlorophyll concentration in summer maize. The reasons underlying these differences need to be studied further.

4.2. Effects of Zn fertilizer application method on photosynthesis in summer maize

During the growth period, multiple foliar spraying of Zn fertilizer increased the net photosynthetic rate in leaves of Fuji apple trees, which had important implications for nutrient accumulation in Fuji apple trees at the late stage (Zhao and Han, 2002). The effectiveness of Zn fertilizer for crops growth and yield depends on crop species and application methods (Mao *et al.*, 2014). We obtained similar results in our study. In Xun County and Yuzhou County, in the case of 15 kg or 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} of Zn fertilizer, foliar spraying of Zn fertilizer improved photosynthesis in maize, but the effects of foliar spraying of Zn fertilizer on leaf chlorophyll concentration varied between the two sites. In Xun County, based on Zn application of 15 kg or 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} , Zn applied as both basal and foliar fertilizer had better effects in terms of increasing chlorophyll concentration in leaves of summer maize than Zn application only as basal fertilizer. In Yuzhou County, with Zn application of 15 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} , Zn applied as both basal and foliar fertilizer had better effects in terms of increasing chlorophyll concentration than Zn applied only as basal fertilizer.

4.3. Effects of Zn fertilizer application on grain yield of summer maize

In our study, compared with no Zn fertilizer, Zn application increased the grain yield of summer maize in Xun County and Yuzhou County. The optimum doses of Zn fertilizer with the highest grain yield of summer maize was 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} in Xun County and 15 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} in Yuzhou County. These results were consistent with the studies of Wang *et al.* (2003) and Ruffo *et al.* (2016). In Xun County, Zn applied as both basal and foliar

fertilizer increased the grain yield of summer maize with Zn application of 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} but decreased the grain yield with Zn application of 15 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} , compared with Zn application only as basal fertilizer. In Yuzhou County, there was a contrary result.

5. Conclusions

Zn application of 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} increased chlorophyll content in leaves, improved photosynthesis, and increased grain yield of summer maize. At 15 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} , grain yield was higher in Xun County and lower in Yuzhou County when the entire amount was applied as basal fertilization as opposed to being split between the basal and foliar fertilization.

The opposite result that grain yield lower in Xun County than in Yuzhou County, was found at 30 kg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ hm^{-2} . These results have important implications for guiding Zn fertilizer application of summer maize at different soils and regions in Henan province.

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