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RESEARCH ARTICLE

Foliar Zn fertilization impacts on yield and quality in pearl millet (*Pennisetum glaucum*)

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Abstract **Zn is an essential mineral nutrient for plant growth and development. Its effect on crop yield and quality has not been well documented. The objective of this study was to investigate the effects of foliar application of zinc fertilizers on yield and quality of millet (*Pennisetum glaucum*). Six levels of $ZnSO_4 \cdot 7H_2O$ (0, 0.75, 1.13, 1.50, 2.25, 3.00 kg/hm^2) were applied to two millet cultivars (Jigu 20 and Jiyou 2) to obtain 12 treatments. Zinc fertilization increased millet yield and improved quality when applied at a proper rate in both cultivars. The yield was the highest in Jigu 20 when applied at 1.50 kg/hm^2, and in Jiyou 2 when treated with 1.50 kg/hm^2. Zn application at 1.5 kg/hm^2 increased protein content by 11.13% for Jigu 20 and 10.53% for Jiyou 2. The Zn application at all rates increased lysine acid and soluble sugar content in the grain in both cultivars. The results of this study suggest that foliar Zn application increases yield and also improves grain quality when applied at 1.50 to 2.25 kg/hm^2 for soils with low zinc content.**

Keywords millet, zinc, yield, protein, soluble sugar, lysine

Introduction

Millet is one of the most important and the oldest food crops in northern China (Chen et al., 2000) and in the world. The earliest cultivation of common millet (*P. miliaceum*) in China can be traced back to 10000 years ago (Lu et al., 2009) with several excellent agronomic and physiologic traits such as short growth season, strong adaptability to poor soil, good tolerance to drought, and long shelf life. Millet is highly nutritious, with many useful components such as amino acids, vitamins and carotenes in the grain.

Zinc is an essential trace element for the growth and development of humans, animals, and plants. Zinc deficiency is one of the most important reasons affecting human health. The growth, immune system and study capability of humans can be impaired by Zn deficiency (Ho, 2004; Hotz and Brown, 2004). Zinc deficiency in soils may reduce crop yield and quality (Liu, 1994). Because Zn plays a vital role in protein metabolism, Zn fertilizer can improve protein content in many crops (Wang et al., 1999). Zinc deficiency in plants can inhibit protein synthesis. Nishizawa at Yan Shou University in Japan found that the protein in millet grain can significantly increase the concentration of high-density lipoprotein with an anti-atherogenic function in blood plasma (Nishizawa et al., 1996). In addition, the protein in the millet grain can also adjust the metabolism of cholesterol. However, few studies have reported on the effect of Zn fertilization on the qualities of millet.

In China, total Zn content in soils ranges from 3 to 709 mg/kg, with an average value of 100 mg/kg, which is much higher than the world average (50 mg/kg). In northern China where millet is grown (Liu, 1996; Bao, 2000), Zn deficiency is commonly observed in calcareous soil with generally less zinc content than the critical value of Zn deficiency (0.5 mg/kg; Liu, 1994).

Barrow (1993) reported that $ZnSO_4 \cdot 7H_2O$ was susceptible

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to being absorbed and fixed because of its higher pH value and $CaCO_3$ content in calcareous soil. Zinc applied into the calcareous soil becomes unavailable to crops. 70% of Zn in wheat leaves goes to the grain (Miller et al., 1993). Spraying zinc on the leaves may improve the efficiency of zinc uptake. This is consistent with the result of Ning et al. (2009). The objective of this study was to investigate the effect of foliar application of zinc fertilizer on yield and the contents of protein, soluble sugar, lysine of the two millet cultivars (Jigu 20 and Jiyou 2), and the effective rate of Zn fertilizer in promoting the quality of millet.

Materials and methods

Experiment site

This study was conducted in Youjiazuo, Tangxian County, Taihang Mountain area of Hebei Province, China in 2009. The experiment site was residual loess located in the limestone hilly regions. The available Zn in the soil was quite low (Table 1).

Zinc fertilization treatments

Two factors in the experiment were cultivars (A) and rate of $ZnSO_4 \cdot 7H_2O$ fertilization (B). The two pearl millet cultivars used in this study were Jigu 20 and Jiyou 2. There were six rates of zinc fertilization: 0, 0.75, 1.13, 1.50, 2.25 and 3.00 kg $ZnSO_4 \cdot 7H_2O$ per hm^2. A total of 12 treatments were obtained by combining the two cultivars with the six zinc levels. The control treatment received water only. Randomized complete block design was used with three replicates. The plot size was 2 m × 5 m. The millets were sown on 4th June, 2009 and thinned on 20th June, 2009 to obtain a seedling density of 900000 plant/hm^2. The zinc treatments were applied by spraying 500 mL per treatment of the Zn fertilizer on the plant canopy in their assigned concentrations at the booting stage. Other cultural practices were the same as those recommended for this area. The millet was harvested at maturation and crop yield was weighted.

Sampling method

The harvested millet crop was air-dried, threshed and shelled to obtain edible gains. The edible gains were shattered by a mini-type miller (WK-100A). The millet powder was passed through a fine sieve for analysis of lysine acid and soluble sugars.

Measurement methods

Auto KJELDAHL nitrogen determination method was used for the determination of the protein content. Dye binding lysine method was used for the determination of lysine acid. Soluble sugar was determined by an alcohol solution-Anthrone Colorimetric Method.

Experimental design and data analysis

A randomized complete block design was used with three replicates. The data were analyzed using Microsoft Excel and SAS 8.0 for Windows (SAS Institute Inc.).

Results

Effects of foliar application of Zn fertilizer on yield

Each application of zinc treatment increased the yield of Jigu 20 when compared to the control (Fig. 1). The Zn application at 1.13 and 1.5 kg/hm^2 also increased the yield of Jiyou 2 compared to the control. The highest yield was achieved with 1.5 kg/hm^2 for Jigu 20 and Jiyou 2.

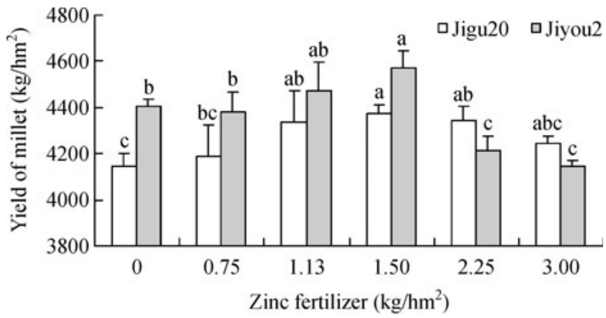

Figure 1 Effects of foliar application of zinc fertilizer on the yield of two millet cultivars. Vertical bars are s.d. Different letters mean significant difference at $P < 0.05$.

Effects of foliar application of zinc fertilizer on protein content

Foliar application of Zn fertilizer at various rates increased the protein content in both cultivars ($P < 0.05$) when compared with the controls. The highest yield was obtained with Zn applications at 1.5, 2.25 and 3.0 kg/hm^2 regardless of cultivars (Fig. 2). The Zn application at 1.5 kg/hm^2 increased the protein content by 11.13% in Jigu 20 and 10.53% in Jiyou 2.

Table 1 Chemical characteristics the soil

Organic matter (g/kg)	Total N (g/kg)	Alkali-hydrolysable N (mg/kg)	Total P (g/kg)	Available P (mg/kg)	Available K (mg/kg)	Available zinc (mg/kg)
13.29	1.14	117.7	0.73	43.20	53.30	0.78

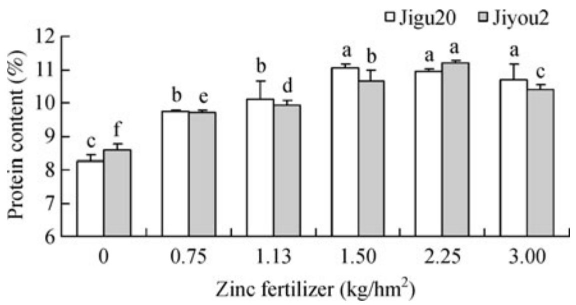

Figure 2 Effects of foliar application of zinc fertilizer on the protein content of two millet cultivars. Vertical bars represent s.d. Different letters mean significant difference at $P < 0.05$.

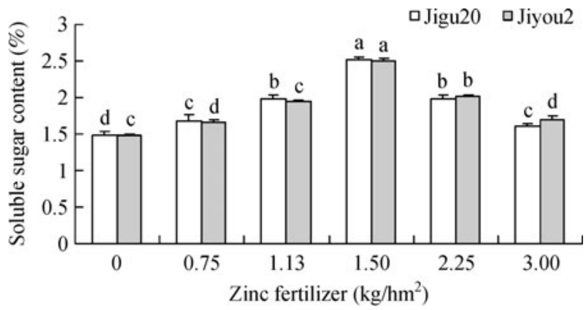

Figure 3 Effects of foliar application of zinc fertilizer on soluble sugar of two pearl millet cultivars. Vertical bars are s.d. Different letters mean significant difference at $P < 0.05$.

Table 2 Effects of foliar application of zinc fertilizer on lysine acid of pearl millet

Treatment	Lysine acid content (%)					
	B0	B1	B2	B3	B4	B5
Jigu 20	0.180±0.005d	0.216±0.010c	0.231±0.005c	0.266±0.010b	0.298±0.011a	0.218±0.009c
Jiyou 2	0.193±0.008c	0.229±0.023b	0.249±0.013b	0.257±0.015b	0.293±0.006a	0.232±0.002b

The data were reported as mean±s.d. Different letters in a line mean significant at 0.05 level.

Effects of foliar application of Zn fertilizer on grain lysine acid

The zinc application at all rates increased lysine acid content in the grain in both cultivars (Table 2). The highest lysine acid content was obtained when the millet was treated with 2.25 kg/hm^2 of zinc in the two cultivars. The zinc application at 2.25 kg/hm^2 increased lysine acid content by 65.6% in Jigu 20 and 51.8% in Jiyou 2 compared with the controls.

Effects of foliar application of Zn fertilizer on grain soluble sugar content

The zinc application at all rates increased soluble sugar content in the grain in both cultivars (Fig. 3). The highest soluble sugar content was achieved with zinc treatment at 1.5 kg/hm^2 for both cultivars. The zinc application at 1.5 kg/hm^2 increased the soluble sugar content by 70.3% in Jigu 20 and 69.5% in Jiyou 2 when compared with the controls.

Discussion and conclusion

The results showed that the yield of the two pearl millet cultivars was significantly increased by Zn foliar application to plants in the soil with low Zn content. The results were similar to many other researches (Hao et al., 2003; Li, 2004; Zhang, 2008). When supplied with 1.5 kg of $ZnSO_4 \cdot 7H_2O$ per hectare, the yield of Jigu 20 and Jiyou 2 increased by 5.54 and 3.73%, respectively. The cultivar Jigu 20 was more sensitive to Zn fertilizer than Jiyou 2.

Zn application also improved the quality traits of pearl millet, which is consistent with the results of Han et al. (2007) and Huang et al. (2010). The results confirmed that millet quality can be optimized by applying $ZnSO_4 \cdot 7H_2O$ at an application rate of 1.50 or 2.25 kg/hm^2. When economic benefit was considered, the Zn application rate of 1.50 kg/hm^2 can be considered as the optimal rate for this area.

The factors determining the quality parameters of pearl millet are many, such as soil texture, climate, and water and nutrient level. Even under the same environmental conditions, the millet may show different quality parameters (Wei et al., 1999; Cheng and Liu, 2003). Zinc is one of the key factors contributing to the variation in millet quality because of its close relation to the protein metabolic pathway. Li (1997) concluded that zinc is a necessary component of RNA polymerase, which produces the protein, proteinase and peptidase that influences nitrogen metabolism, and the glutamic dehydrogenase that synthesizes glutamic acid. Zinc is also the component of ribose and proteins. The application of zinc improved the quality of both cultivars. These findings are meaningful to the production of pearl millet, particularly for high quality pearl millet. Further research is needed to investigate the effect of Zn application on other quality parameters.

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