ZINC FERTILIZATION OF SUGARCANE IN ACID AND CALCAREOUS SOILS

J.J. Wang[1], C.W. Kennedy[1], H.P. Viator[2], A.E. Arceneaux[1], and A.J. Guidry[3]
[1]Louisiana State University AgCenter, Dept. of Agronomy and Environmental Management, Baton Rouge, LA 70803
[2]Louisiana State University AgCenter, Iberia Research Station, Jeanerette, LA 70544-0466
[3]Louisiana Cooperative Extension Service, St. Martin Parish, Breaux Bridge, LA 70517-5010

ABSTRACT

Zinc (Zn) is recognized as an essential micronutrient for plant growth. The application of Zn for sugarcane production in Louisiana has not been studied in almost 30 years due to previous research reporting neutral or negative effects on sugarcane yields. In this study, a fertilization experiment was conducted to evaluate the optimum rate of Zn application for sugarcane production in soils low in DTPA-extractable Zn. An acidic Dundee silt loam and a calcareous Jeanerette silty clay loam were chosen for the experiment. The treatments consisted of five rates of soil-applied Zn as granular $ZnSO_4$ (0, 4.4, 8.9, 17.9, and 33.8 kg/ha Zn) and one foliar application rate (1.3 kg/ha Zn). Soil applications of 4.4 and 8.9 kg/ha Zn significantly ($P \leq 0.05$) increased cane and sugar yields of LCP 85-384 by an average of more than 23 % above the control for both the acidic Dundee and calcareous Jeanerette soils. The foliar application of 1.3 kg/ha Zn produced significantly greater sugar yields than the control on only the calcareous Jeanerette soil. The results of one year, with two different locations, indicated that Zn application as $ZnSO_4$ can significantly benefit Louisiana sugarcane production in soils testing low in DTPA-extractable Zn.

INTRODUCTION

Previous research of sugarcane response to zinc applications on Louisiana soils has shown neutral to negative results (Golden, 1977). In other sugarcane producing regions, zinc applications have proved beneficial for sugarcane production on Zn-deficient soils (Kumar and Singh, 1997). Research on Zn nutrition of sugarcane grown on Louisiana soils generally did not include soil test information. Therefore, the status of Zn availability in the soils used in those studies was not known. Research in this area has not been pursued in nearly 30 years. Within that period, new high-yielding sugarcane varieties have been developed that may require improved nutritional inputs. New soil extraction methods have been developed that have improved the accuracy of predicting plant-available Zn in soils (Martins and Lindsay, 1990). These factors justify a need to reassess the Zn requirement for optimum sugarcane production on Louisiana soils.

One common test for assessing soil plant-available Zn is 0.1 M HCl extraction (Wear and Sommer, 1948). However, this method tends to extract labile Zn, as well as a portion of occluded Zn, which is inaccessible for plant uptake (Martins and Lindsay, 1990). Another commonly used method is diethylenetriaminepentacetic acid-triethanolamine (DTPA-TEA) extraction (Lindsay and Norvell, 1978). This procedure has been regarded as a standard method in evaluating plant available Zn in near-neutral and calcareous soils. Nonetheless, the DTPA method has been used to index critical Zn levels for a mixture of acidic and calcareous soils (Cox and Wear, 1977). In a previous study, we also found that DTPA-extractable Zn was highly correlated with the amount of Zn extracted by the acid-buffered Mehlich 3 extractant for more than 300 Louisiana soils with a pH range of 4.2-8.3 (Wang et al., 2004). The objective of this study was to evaluate Zn concentrations in sugarcane leaf tissue and the response of sugar yield and its components to different rates of soil- or foliarly-applied Zn in an acid and a calcareous soil both low in DTPA-extractable Zn.

MATERIALS AND METHODS

Locations and Soil Types

Two locations representing acidic and calcareous soils were selected for this study. The acidic soil was a Dundee silt loam (fine-silty, mixed, thermic, Typic, Endoaqualfs) located in St. Martin Parish, Louisiana. The calcareous soil was a Jeanerette silty clay loam (fine-silty, mixed, hyperthermic, Typic, Argiaquolls) located in Iberia Parish, Louisiana. Composite surface soil samples (0-15 cm) were taken from the two sites before the experiments were initiated. The soil samples were air-dried and ground to pass through a 2-mm sieve before analysis. Selected soil chemical and physical characteristics for the two sites are presented in Table 1. Soil particle size distribution was determined by the pipette method (Gee and Bauder, 1986), organic matter (OM) content by the Walkley-Black method (Walkley, 1947), and pH was determined at a 1:1 soil/water ratio. Soil exchangeable K was determined by 1 M NH_4OAc extraction (Thomas, 1982) and CEC by saturating the soil with 1 M NH_4OAc at pH 7 followed by distillation and titration (Soil Survey Laboratory Methods Manual, 1996). Soil-test P was extracted by the Bray 2 procedure using 0.03 M NH_4F-0.1 M HCl (Bray and Kurtz, 1945) and soil-test Zn by DTPA-TEA (Lindsay and Norvell, 1978). Soil-test S was extracted by 0.5 M NH4OAc-0.25 M HOAc (Tabatabai, 1982). All elements in the extracts were analyzed by the Inductively-Coupled Plasma Spectrometry (ICP).

Treatments

The experiment consisted of five rates of Zn as granular $ZnSO_4$ (0, 4.4, 8.9, 17.9, and 33.8 kg/ha) soil-applied in the off-bar furrow in April 2003; 1.3 kg/ha Zn as foliar-applied $ZnSO_4$ in June 2003; and one soil application of 20.2 kg/ha S as gypsum ($CaSO_4$) in the off-bar furrow in April. The inclusion of S application was to address the possible deficiency due to low levels of soil S and the use of SO_4^{-2} as the counter ion in the Zn treatments.

Cultural Practices

Sugarcane grown on the Dundee soil was a first ratoon crop, and there was a second ratoon on the Jeanerette soil. The cultivar, LCP 85-384, was grown at both locations. Plot dimensions were three rows, 1.8 m wide and 15.2 m long. These experiments were located in large, commercial fields and received N-P-K fertilizer, herbicide and insecticide applications as per LSU AgCenter recommendations.

Data Collection and Experimental Design

Each experiment was a randomized complete block design with four replications. Millable stalk counts were made on the center row of each plot in early August, 2003. At the same time, 10 leaves representing the first leaf below the youngest fully emerged leaf were removed for analysis. The sample leaves represented the youngest mature leaf of the shoot. Leaves were oven-dried at 65 ^{o}C for 24 h, ground through a 0.5 mm sieve, and digested using HNO_3-30% H_2O_2 on a heating block (Huang and Schulte, 1985). The Zn in the digests was analyzed by ICP.

Experiments were harvested November 14 and 19, 2003 for the Dundee and Jeanerette soil locations, respectively. Cane yield was determined on the inside row of each plot using a field wagon fitted with three load sensors that determined weight to the nearest 0.45 kg. Twenty stalks were randomly selected from the center row just prior to harvest and subsequently used to determine theoretical recoverable sugar (TRS) and stalk weight. TRS was converted to commercially recoverable (CRS) sugar using a standard formula (Birkett, 1998). The product of CRS and cane yield was used to estimate sugar yield. Cane and sugar yields were converted to a hectare basis. The cane weighing wagon broke at the Jeanerette site, and therefore cane yield was estimated based on stalk weight and stalk population data for that location.

Statistical Analysis

All statistical analyses were performed using the Proc GLM procedure with SAS statistical software package version 8.02 (SAS Institute, 1999).

RESULTS AND DISCUSSION

Soil Characteristics and Soil-Test Zn Levels

The soils at the two sites were different in terms of soil pH and other physical and chemical properties (Table 1). The Dundee, acidic soil site, had low clay content and CEC, whereas the Jeanerette, calcareous soil site, exhibited high clay content and high soil CEC. The two soils also had different inherent P and K fertility status, which was adjusted in this study based on recommendations from the LSU AgCenter Soil Testing Laboratory and Plant Analysis Laboratory. The two soils had similar organic matter contents. The two soils exhibited comparably low Zn content as extracted by DTPA-TEA (Table 1). Little information is available on critical soil Zn test levels for sugarcane production. For many crops, a DTPA-extractable Zn level of 0.5-0.8 mg/kg has been regarded as a soil critical level below which crop production would be limited by Zn deficiency (Martins and Lindsay, 1990). Besides low Zn content, the two soils also exhibited low S contents (< 8 mg/kg) according to the LSU AgCenter Soil Testing and Plant Analysis Laboratory.

Leaf Tissue Analysis

The leaf tissue analysis results from the Dundee soil were variable, but both locations produced values similar to those found in the earlier work of Golden (1977) that did not correspond to a yield increase. We did not find Zn concentration in leaf tissue to be in the critical range, as previously reported (15 mg/kg) (Evans, 1967; El Wali and Gascho, 1984) (Fig. 1). In addition, we did not find significant differences in leaf tissue S content among the Zn and S treatments (data not shown). Possible reasons for this lack of validation could be the variety used and/or the sampling time. According to Kumar and Verma (1997), certain sugarcane genotypes could exhibit poor relationships between tissue Zn contents and cane yields. Furthermore, the cultivar, LCP 85-384, has been shown to have a higher critical value for leaf N compared to earlier varieties grown in Louisiana (Kennedy and Arceneaux, 2003). This may also occur for other nutrients as well. Sampling time in this study (August) was slightly later than sampling time for previously published values.

Stalk Population and Stalk Weight

Results for these yield components varied among locations. On the Dundee soil, stalk population did not differ among treatments (Fig. 2), and stalk weight for the untreated check was equal to or slightly better than treatments (Fig. 3). Results on the Jeanerette soil showed a 12 % increase in stalk population when 4.4 kg/ha Zn was applied. All other treatments were numerically, but not significantly ($P \leq 0.05$) higher than the control. Likewise, stalk weight for all treatments was also numerically, but not significantly, higher than the control.

Yields

On both the acidic and calcareous soils, sugar and cane yields were improved relative to the control by one or more treatments (Figs. 4 and 5). On the Dundee soil, yields were significantly ($P \leq 0.05$) improved over the control by about 23 % when 8.9 kg/ha Zn or 20.2 kg/ha S was applied. On the Jeanerette soil, both 4.4 and 8.9 kg/ha Zn applications increased cane yield by an average 24.8 % above the control (Fig. 4). Differences in CRS among treatments at either location were not statistically significant, but averaged higher than the control in all cases (data not presented). Because of this, sugar yields were significantly higher than the control in both soils when either 4.4 or 8.9 kg/ha Zn, or 20.2 kg/ha S was applied (Fig. 5). The foliar application of 1.3 kg/ha Zn produced significantly greater sugar yields than the control on the Jeanerette soil and averaged numerically higher yields on the Dundee soil.

The higher application rates of 17.9 and 35.8 kg/ha Zn resulted in yields that declined from the maximum obtained at the lower application rates. This could indicate minor toxicity brought about by the higher application rates. Zinc is an essential micronutrient, but, like many essential metals, it can be the toxic at higher levels (Foy et al., 1978; Wang and Evangelou, 1994). Because the counter ion to Zn in this study was SO_4^{-2}, and there was a yield response to S application, we cannot completely exclude the possibility that the obtained response to Zn application could have been contributed, in all or in part, by the S counter ion. This is highly unlikely, however, since the amount of S involved at those application rates totaled 2.5 to 4 kg/ha, an amount which is much smaller than the commonly recommended commercial application rate for S (26.9 kg/ha) for sugarcane production on Louisiana soils (Golden, 1979). Nonetheless, our results could not rule out possible Zn x S interactions and further study is needed to determine if such interactions exist. A recent study also indicated that the efficiency of Zn application could be greatly affected by components of other fertilizer amendments (Wang and Harrell, 2005).

CONCLUSIONS

The results of one year's testing at two locations differing widely in soil pH and other properties indicated that sugarcane production on soils low in DTPA-extractable Zn benefited from soil applications of 4.5 to 8.9 kg/ha Zn as $ZnSO_4$ applied in the offbar furrow in April. These results also suggest that sugarcane cultivar LCP 85-384 is sensitive to soil Zn deficiency. The DTPA-extraction method, commonly used on calcareous soil conditions, also worked on acidic soil conditions for predicting Zn deficiency. The low sulfur condition of these medium-textured soils also resulted in a response in sugarcane production when 20.2 kg/ha S was applied as $CaSO_4$. Additional studies have been initiated to determine the level of interaction between Zn and S for sugarcane yield on these soils and to confirm these initial findings.

ACKNOWLEDGMENTS

This work was supported in part by the American Sugar Cane League and is published as the Manuscript No. 05-14-0206 of the Louisiana Agricultural Experiment Station.

REFERENCES

1. Birkett, H.S. 1998. Core sampling recommended procedures. Audubon Sugar Institute, Louisiana State University Agricultural Center. Baton Rouge, LA.

2. Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59:39-45.

3. Cox., F.R., and J.I. Wear. 1977. Diagnosis and correction of Zn problems in corn and rice production. North Carolina State Univ. Southern Coop. Ser. Bull. 222.

4. El Wali, A.M.O., and G.J. Gascho. 1984. Fertilization of sugarcane using critical nutrient levels. Sugar J. 46:9-11.

5. Evans, H. 1967. Tissue diagnostic analyses and their interpretation in sugarcane. Proc. Int. Soc. Sugar Cane Technol. 12:156-180.

6. Foy, C.D., R.L. Chaney, and M.C. White. 1978. The physiology of metal toxicity in plants. Annu. Rev. Plant Phyiol. 29:511-566.

7. Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. Pages 383-412. In: Methods of Soil Analysis: Physical and Mineralogy Methods, Part 1. Second ed., A. Klute, ed. ASA and SSSA, Madison, WI.

8. Golden, L.E. 1977. Micronutrient studies with sugarcane in Louisiana. J. Amer. Soc. Sugar Cane Technol. 6:88-92.

9. Golden, L.E. 1979. Some relationships of soil, fertilizer, and leaf-blade sulphur to sugarcane yields in Louisiana. La. Agr. Exp. Sta. Bull. 723. Louisiana State Univ. Agricultural Center, Baton Rouge, LA.

10. Huang, C.L., and E.E. Schulte. 1985. Digestion of plant tissue for analysis by ICP emission spectroscopy. Commun. Soil Sci. Plant Anal. 16:943-958.

11. Kennedy, C., and A. Arceneaux. 2003. Critical Leaf Nitrogen Concentration for the Sugarcane Variety LCP 85-384. Am. Soc. Agron. Abstr. ASA annual meeting, Denver, CO.

12. Kumar, R., and P.P. Singh. 1997. Effect of phosphorus and zinc nutrition on yield and yield attributes of sugarcane (*Saccharum officinarum*) in calcareous soil of foothill region of Uttar Pradesh. Indian J. Agron. 42:702-704.

13. Kumar, V., and K.S. Verma. 1997. Relationship between nutrient element content of the index and cane yield and juice quality of sugarcane genotypes. Commun. Soil Sci. Plant Anal. 28:1021-1032.

14. Martins, D.C., and W.L. Lindsay. 1990. Testing soils for copper, iron, manganese, and zinc. Pages 229-264. In: Soil Testing and Plant Analysis, 3rd ed., R.L. Westerman, ed. Soil Sci. Soc. Amer., Madison, WI.

15. Lindsay, W.L., and W.A. Norvell. 1978. Development of a DTPA test for zinc, iron, manganese, and copper. Soil Sci. Soc. Amer. J. 42:421-428.

16. SAS Institute, 1999. SAS for Windows. Version 8.02. SAS Institute, Cary, NC.

17. Soil Survey Laboratory Methods Manual. 1996. Soil survey investigations report No. 42 Version 3.0. USDA-NRCS. Gov. Print. Office, Washington, D.C.

18. Tabatabai, M.A. 1982. Sulfur. Pages 501-538. In: Methods of Soil Analysis: Chemical and Microbiological Properties, Part 2., 2nd ed., A.L. Page, ed. ASA and SSSA, Madison, WI.

19. Thomas, G.W. 1982. Exchangeable cations. Pages 159-166. In: Methods of Soil Analysis: Chemical and Microbiological Properties, Part 2., 2nd ed. A.L. Page, ed. ASA and SSSA, Madison, WI.

20. Walkley, A. 1947. A critical examination of a rapid method for determining soil organic mater and a proposed modification of the chromic acid titration method. Soil Sci. Soc. Amer. Proc. 63:251-263.

21. Wang, J.J., and V.P. Evangelou. 1995. Metal tolerance aspects of plant cell walls and vacuoles. Pages 695-717. In: Handbook of Plant and Crop Physiology, M. Pessarakli, ed. Marcel Dekker, Inc. New York.

22. Wang, J.J., and D.H. Harrell. 2005. Effect of ammonium, potassium, sodium cations and phosphate, nitrate, chloride anions on zinc sorption and lability in selected acid and calcareous soils. Soil Sci. Soc. Amer. J. 69 (in Press).

23. Wang, J.J., D.H. Harrell, R.E. Henderson, and P.E. Bell. 2004. Comparison of soil-test extractants for phosphorus, potassium, calcium, magnesium, sodium, zinc, copper, manganese, and iron in Louisiana soils. Commun. Soil Sci. Plant Anal. 35:145-160.

24. Walkley, A. 1947. A critical examination of a rapid method for determining soil organic mater and a proposed modification of the chromic acid titration method. Soil Sci. Soc. Amer. Proc. 63:251-263.

25. Wear, J.I., and A.L. Sommer. 1948. Acid-extractable zinc of soils in relation to the occurrence of zinc deficiency symptoms of corn: A method of analysis. Soil Sci. Soc. Amer. Proc. 12:143-144.

Table 1. Soil physical and chemical properties of the two study sites.

Soil	pH	Clay	Sand	Silt	OM	CEC	Bray 2 P	NH_4OAc K	DTPA Zn	NH_4OAc-HOAc S
		--------------%-------------			%	$cmol_c\ kg^{-1}$	-------------------- $mg\ kg^{-1}$ ----------------			
Dundee	5.4	16	21	63	1.0	5.8	51	131	0.4	5.8
Jeanerette	8.1	31	8	61	1.0	17.0	228	86	0.3	7.3

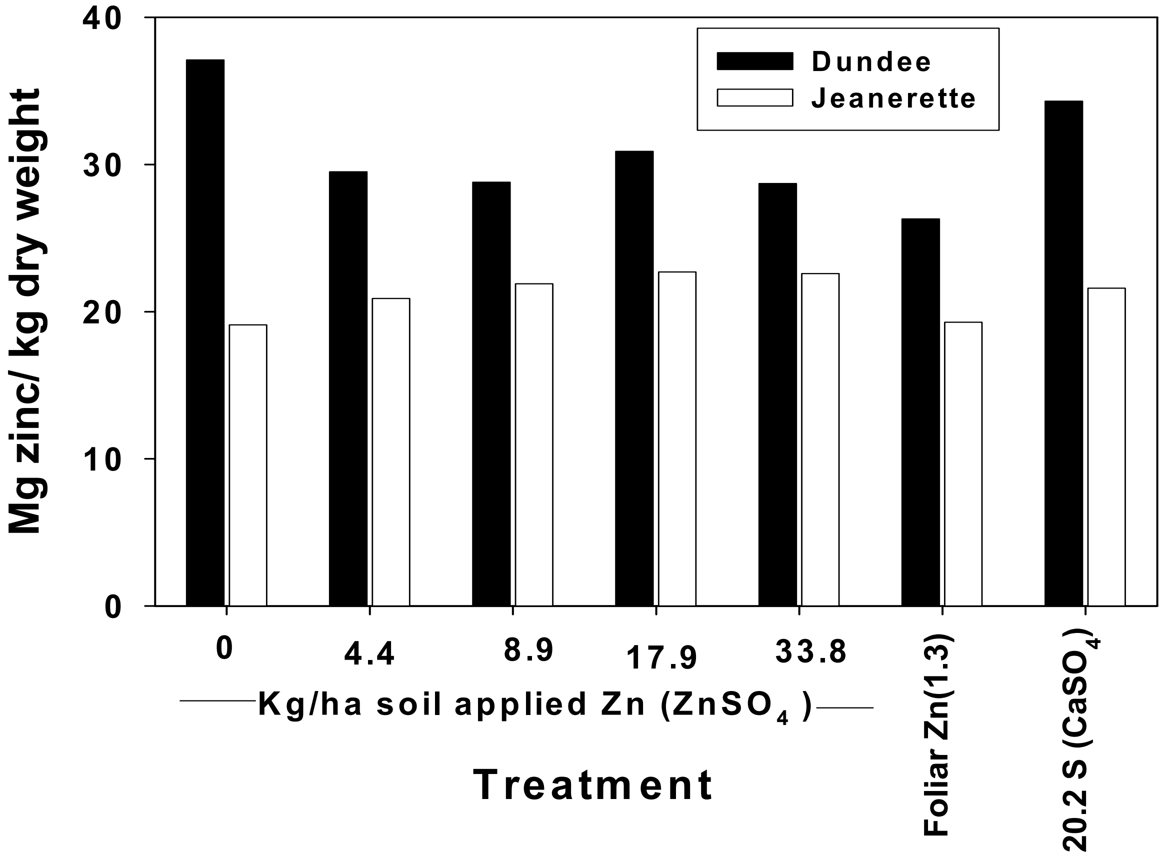

Figure 1. Zinc concentration of the leaf below TVD (top visible dewlap) of ratoon LCP 85-384 in response to zinc and/or sulfur application.

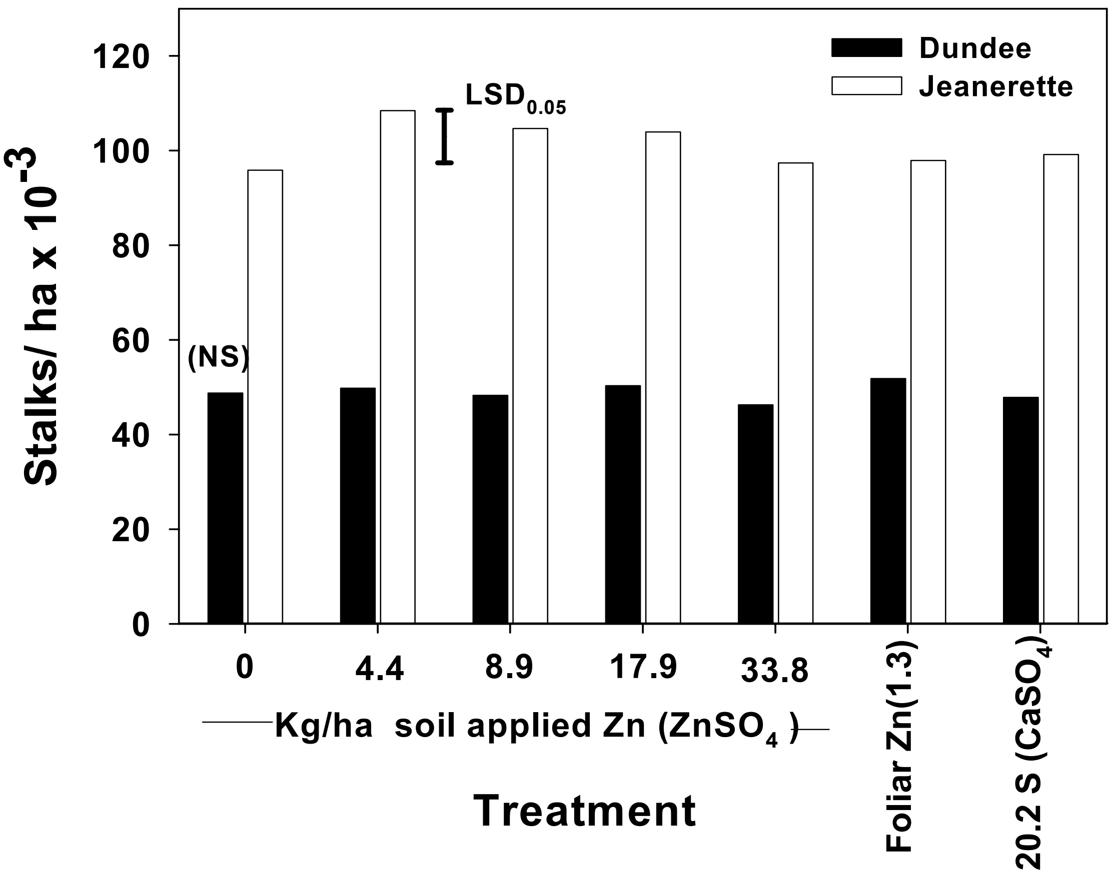

Figure 2. The population response of ratoon LCP 85-384 to zinc and sulfur applications.

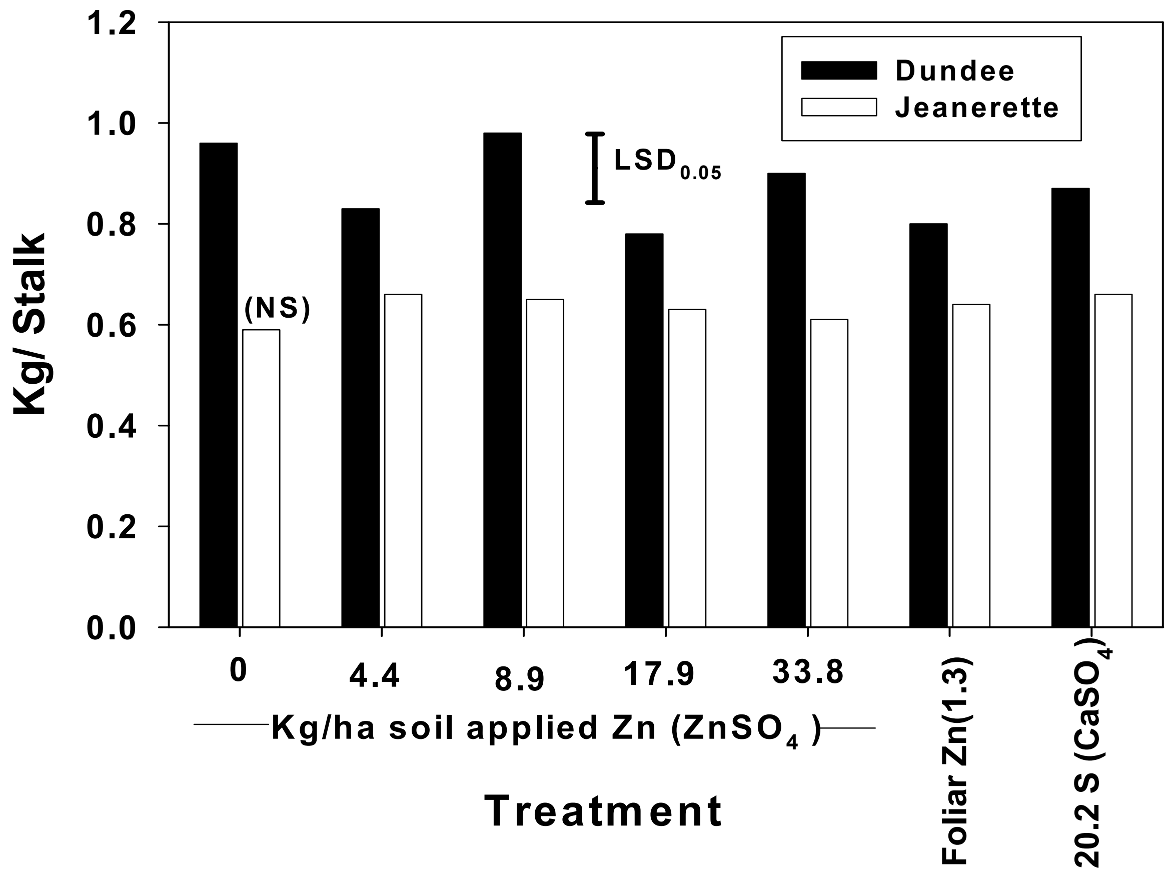

Figure 3. Stalk weight response of ratoon LCP 85-384 to zinc and sulfur applications.

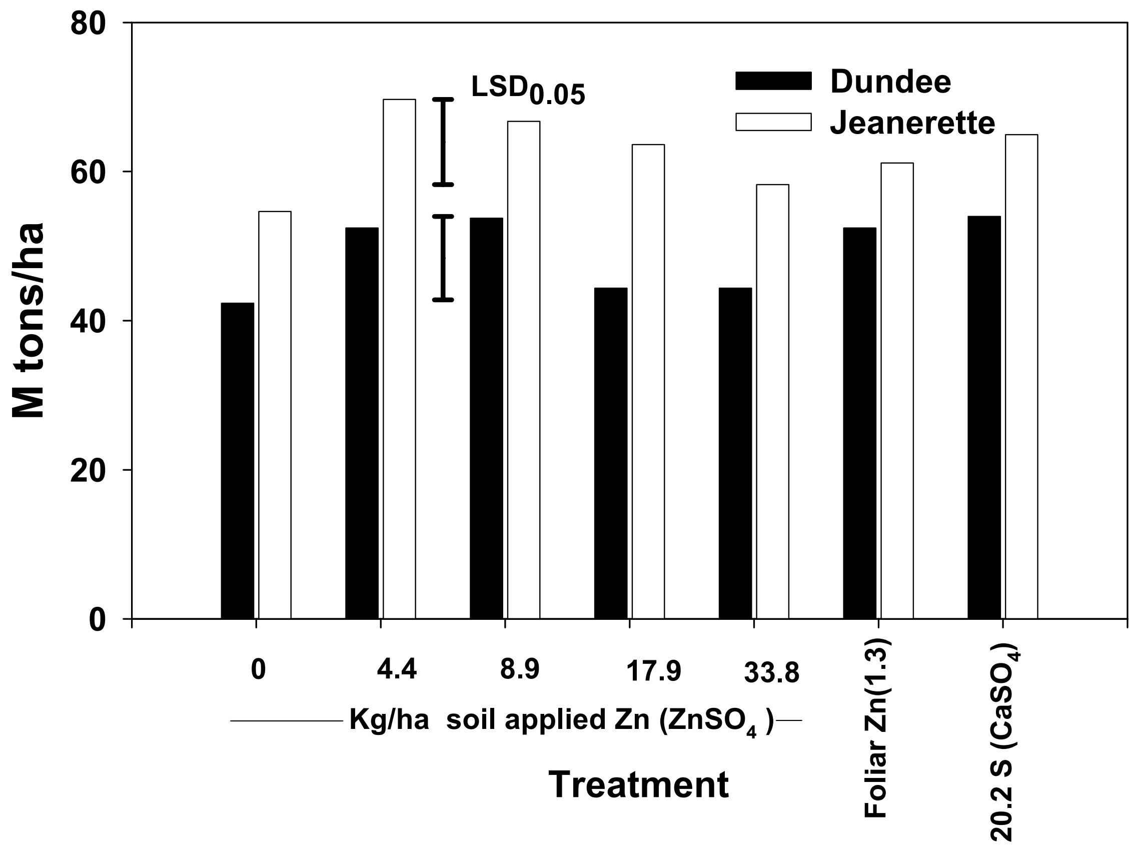

Figure 4. Cane yield response of ratoon LCP 85-384 to zinc and sulfur applications.

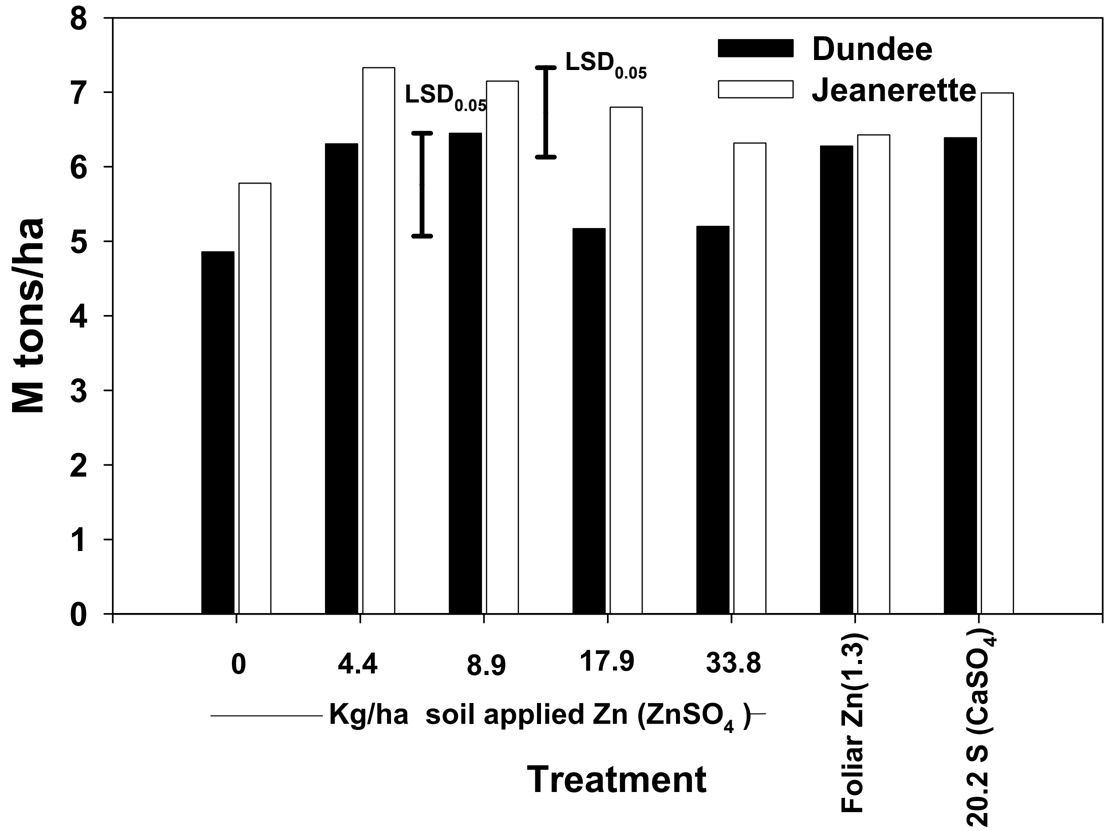

Figure 5. Sugar yield response of ratoon LCP 85-384 to zinc and sulfur applications.