Blue grama response to Zn source and rates

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Abstract

Surface-applied zinc (Zn) in range with claypan soils could increase herbage production, but the Zn concentration could become toxic to the crown and roots of blue grama *(Bouteloua gracilis)*. Metallic Zn, $ZnCl_2$, and Zn chelate were applied in the greenhouse to the soil surface of pots with blue grama to determine the rate that would be toxic and the effect of Zn source on toxicity and herbage Zn content. Metallic Zn (dust, 30- and 40-mesh) was not toxic at rates below 0.40 g Zn kg-soil^{-1}, but Zn chelate was toxic and $ZnCl_2$ at the 0.40 g Zn rate was toxic initially. After 2 years growth, salt was leached and herbage yields were not significantly different for different sources. Herbage Zn increased with increasing application up to about 0.9 g Zn kg^{-1}. $ZnCl_2$, applied to plants that were not Zn deficient, decreased growth; and half the plants died at rates of 2 g Zn kg-soil^{-1}. Herbage from the 2-gm rate had 7.4 g Zn kg^{-1}. DTPA-extracted soil Zn increased with increasing applications but not at the same rate for different sources. Metallic Zn or $ZnCl_2$, if applied at reasonable rates, is a satisfactory Zn source, but high rates of Zn chelate cause soil dispersion initially and should not be used on soil that disperses readily.

Key Words: ***Bouteloua gracilis,*** **Zn toxicity, soil-DTPA Zn, herbage Zn-P interaction**

Zinc applied in Hoagland-type solutions (Hoagland and Arnon 1938, Jacobson 1950) increased blue grama *(Bouteloua gracilis)* growth on claypan soils in the greenhouse (White and Gartner 1986). Each application of the solution contains a small amount of Zn. Surface applications of Zn on rangeland increase the concentration around blue grama roots to a level where it could become toxic. Beneficial and toxic effects of Zn on plants have been summarized by Knezek and Ellis (1980). Fertilization with acidic phosphates can solubilize soil Zn (Shuman 1988). Lindsay (1979) reported Zn and P can interact in the soil, and Tisdale et al. (1988) reported low Zn causes toxic P accumulations in the plant although the Zn content will appear normal. Wheat shoot weights are reduced by a Zn deficiency but the P contents are increased (Webb and Loneragan 1988) with the greatest increase being in older leaves. Zn deficiency in barley increases the shoot content of B, P, NO_3, S, Ca, Mg, K, and Cu but not Fe (Graham et al. 1987). Rauzi et al. (1969) reported blue grama herbage collected in rangeland had 15 mg Zn kg^{-1} in early summer, which decreased to about 8 mg in the fall. This amount is less than the 20 to 40 mg Zn kg-herbage^{-1} needed in feed for beef cattle (Nat. Research Council 1984). The effects of Zn source and application rates on blue grama growth were studied to determine if Zn toxicity is likely to be a problem where range is fertilized with surface-applied Zn.

Materials and Methods

Cedar Butte loam (fine, montmorillonitic mesic Ustollic Natrargids) was used in the greenhouse to grow blue grama in the following experiments. Cedar Butte loam has a 11-cm-thick E horizon with a pH of 5.7 to 5.8 and a very slowly permeable clay upper B horizon with a pH of 5.6. Cedar Butte and related soils support nonvigorous shortgrasses even in climatic cycles with above normal precipitation. Ten to 20% of the soils of central and western South Dakota have claypan dispersed by exchangeable sodium. These claypans prevent or reduce water infiltration into the lower subsoil, which in turn reduces root growth. Thus, shortgrasses on these areas are dependent on water and fertilizer elements in the upper soil layers. Fertilizer elements including Zn have been removed from these areas by prehistoric grazing, wind and water erosion, and likely in air-borne plant ash during prairie fires. Zn gradually has been depleted from the upper part of these soils which have pH's that are in the critical pH 5.5 to 6.5 range where soil Zn is not released as readily to plants as at more acid pH's (Thorne 1957).

Experiment 1

The purpose was to determine if previous applications of minor elements to claypan-surface-soil in the greenhouse had a residual effect on bluegrama response to additional Zn applications. Soil used for a previous study (White and Gartner 1986) was crushed, and the replications of each treatment were composited and used to fill 5 plastic pots with 1.5 kg of soil. Thirty-mesh Zn metal was added at rates of 0, 0.10, 0.20, 0.30, and 0.40 g kg^{-1}. Thus, 5 Zn rates were superimposed across the 9 treatments used previously. These previous 9 were: water plus, additively in succession, NPK, B, Zn, Mn, Fe, Cu, Mo, and Co (White and Gartner 1986). Residual effects of the original minor elements on additions of more Zn as well as the Zn rate needed to maximize growth were studied in this experiment. The Zn rate on a pot area basis would be 97, 195, 284, and 390 kg ha^{-1} (87 to 348 lbs acre^{-1}). These rates far exceed the 5–15 kg Zn ha^{-1} rates usually used (Murphy and Walsh 1972), but plant roots may be in contact with a high concentration around Zn granules. Thirty blue grama seeds were planted in pots and, after seedlings became established, culms were counted and herbage was harvested 5 times, dried, and weighed. Harvest periods were considered as replications. Inflorescences developed on some plants before herbage was harvested. Blue grama growth is controlled more by greenhouse temperature than by day length so harvest date is less important than growth stage.

Experiment 2

The purpose was to determine if Zn is deficient in the subsoil from blue grama and if Zn added to the subsoil would increase blue grama growth. The 0.1–0.3 m layer of the claypan soil was placed in plastic pots (1.5 kg soil, 0.44 g NH_4NO_3, 0.13 g KH_2PO_4, 0.2 g $CaHPO_4$) and $ZnCl_2$ to supply 0, 0.1, 0.2, 0.4, or 0.8 g Zn kg^{-1} soil in 4 replications. Blue grama was planted and the herbage harvested 5 times when some plants developed inflorescences. Plants became N-deficient and chlorotic after the second harvest and were watered with a solution containing NPK (Hoagland and Arnon 1938).

Experiment 3

The purpose was to determine if 1 Zn source and rate was better than another. Claypan surface soil (0–0.1 m) that had not been used previously was crushed, mixed, and 1.5 kg placed in plastic pots. Five replications were used for 17 treatments. The 17 were untreated check, surface-applied NPK, and surface-applied NPK with 0.10, 0.20, or 0.40 g Zn kg^{-1} soil from 5 sources. The Zn sources were dust-, 40-mesh-, or 30-mesh-metallic Zn, Zn chelate

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(EDTA), or Zn chloride. The NPK amounts were respectively 0.10, 0.50, and 0.02 g kg^{-1} soil. Thirty blue grama seeds were planted per pot, culms were counted after seedlings were established, and herbage was harvested 5 times, dried, and weighed after inflorescences developed on some plants.

The soil in the pots was allowed to dry after the fifth harvest, and blue grama was reseeded in the pots. Many seedlings died, possibly from Zn toxicity and/or salt accumulation (White and Gartner 1987). Salt was leached from the pots with distilled water, and 30 blue grama seeds were planted with subsequent establishment of an adequate number of plants. Herbage was harvested once, dried (60–70° C), weighed, and ground. The herbage ash, Zn, and P contents were determined for 3 of the 5 replications. Ash, determined gravimetrically, was solubilized in 2M HCl and Zn and P contents determined, respectively, by atomic absorption and with the ascorbic acid procedure (Watanabe and Olsen 1965). Soil from the 3 replications used for herbage Zn and P contents was sampled from the upper 0.05 m layer of the pots and DTPA-extracted Zn (Lindsay and Norvell 1978) was determined by atomic absorption.

Experiment 4

Pots with soil and blue grama plants used in Experiment 1 were used to determine the amount of Zn that would decrease growth of blue grama. Four replications of pots that received increasing amounts of Zn initially were further treated with 0, 0.2, 0.4, 0.8, and 1.6 g Zn as $ZnCl_2$ kg^{-1} soil. The total Zn added from both treatments was 0, 0.3, 0.6, 1.1, and 2.0 g kg^{-1} soil. Because chloride could be a factor, it was added as $CaCl_2$ in the same amounts as in the $ZnCl_2$ to 2 additional replications of pots. The herbage was harvested once, dried (60–70° C), weighed, ground, and analyzed for Zn and P as described previously.

Experiment 5:

The purpose was to determine if small Zn applications ($ZnCl_2$) are fixed in the soil and if larger amounts remain in solution where they could be toxic. A 0.09 l solution containing 0, 1.44, 14.4, or 144 mg Zn (as $ZnCl_2$) was equilibrated with 18 g of the claypan surface soil for 1, 168, and 336 hr, centrifuged, and the supernatant Zn concentration was determined by atomic absorption. The centrifugate soil was allowed to dry without further treatment, crushed, extracted with DTPA (Lindsey and Norvell 1978), and the extracted Zn determined by atomic absorption. Solution occluded in the centrifugate soil cake was not considered because most of the free salt should be excluded (Wiklander 1964).

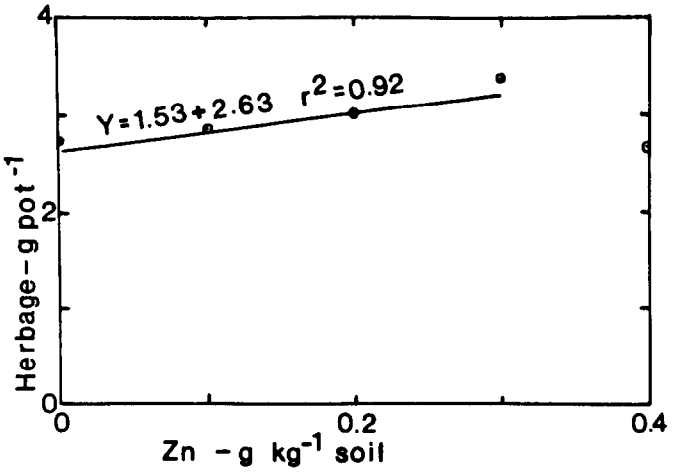

Fig. 1. Linear increase in blue grama herbage with Zn applications from 0 to 0.3 g kg^{-1} soil and a decrease at 0.4 g kg^{-1} soil.

Results and Discussion

Experiment 1

The mean herbage weights pot^{-1} for the 5 harvests were 2.7, 2.8, 3.0, 3.4, and 2.7 g pot^{-1}, respectively, for Zn application rates of 0, 0.10, 0.20, 0.30, and 0.40 g Zn kg^{-1} soil. The herbage weight was positively related to Zn application rates up to 0.40 g Zn kg^{-1} soil (Fig. 1). The 0.40 g Zn rate reduced the herbage weight, presumably because Zn became toxic. When the successively added elements in the Hoagland solutions are considered (Fig. 2), Zn did not improve herbage yield significantly over the untreated soil although herbage from the B treatment was significantly greater. However,

Table 1. Effect of Zn source and application rate on seedling establishment, herbage weight, herbage-ash, -Zn, and -P contents, and DTPA-extracted soil Zn amounts (Experiment 3).

Treat.[2] Zn Source	Zn g kg^{-1} soil	1986 Plant No.	1986 Herbage g/pot harvest	1987 Plant No	1988 Plant No.	1988 Herbage g/pot harvest	1988 Herbage[2] Ash	1988 Herbage[2] Zn mg kg^{-1}	1988 Herbage[2] P	Soil DTPA Zn mg kg^{-1}
1. None	0.00	12.4	3.66	10.8	18.2	6.91	82	11	1.59	6
2. NPK	0.00	17.2	3.99	8.8	21.0	7.10	85	13	1.76	2
3. Dust	0.10	11.4	3.78	9.6	22.6	6.83	80	44	1.65	44
4.	0.20	6.0	3.45	9.0	17.6	7.41	82	71	1.87	103
5.	0.40	9.0	3.71	7.6	19.0	7.51	76	132	1.67	184
6. 30 mesh	0.10	9.4	3.54	8.8	20.4	6.81	83	39	1.78	52
7.	0.20	9.0	3.37	6.8	19.4	7.68	71	86	1.63	80
8.	0.40	10.0	3.48	9.8	22.2	7.20	77	167	1.80	124
9. 40 mesh	0.10	11.2	3.71	8.8	18.4	6.80	85	42	1.62	63
10.	0.20	13.2	3.62	10.2	20.4	7.50	76	74	1.66	94
11.	0.40	10.0	3.62	7.4	20.8	8.55	75	183	1.76	234
12. Chelate	0.10	1.8	1.55	6.2	21.2	7.41	72	121	1.86	35
13.	0.20	0.0	0.00	5.4	18.0	7.90	67	365	1.66	62
14.	0.40	0.0	0.00	0.8	15.8	7.71	75	905	2.08	111
15. Chloride	0.10	14.2	3.73	9.8	22.4	8.33	77	60	1.84	42
16.	0.32	19.2	3.68	9.2	20.6	8.44	73	242	1.81	78
17.	0.40	8.8	2.31	2.6	20.8	6.76	81	418	1.98	157
l.s.d. (p=0.05)		6.6	0.75	7.8	6.8	1.81	13	187	0.28	50

[1]NPK added to all Zn rates.
[2]Herbage and DTPA analysis for 3 of the 5 replications.

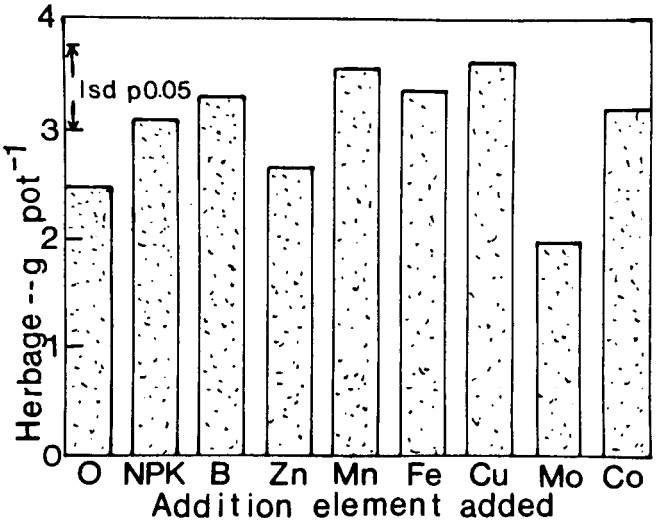

Fig. 2. Blue grama herbage weight as successively more elements are added to the watering solution.

the B and Zn treatments were not significantly different. The Mn and Cu treatments significantly increased herbage relative to the Zn treatment. Effects of adding Zn to soils previously treated with minor elements are not clear, but some synergistic relationship may occur between Zn and Mn, Cu, Fe, or Co. Soils that received Zn previously apparently contained sufficient residual Zn to supply the needs of the plants and possibly may be toxic if Mn, Cu, Fe, and/or Co are not added. Possibly B, as borate, and Mo, as molybdate, acted respectively to stimulate or reduce herbage weights either by interacting with phosphate or Zn and other minor elements in the plant.

Experiment 2

The mean herbage weights of the 5 blue grama harvests from the $ZnCl_2$ fertilization of claypan subsoil were: 0 gm Zn kg^{-1} soil—3.2 g herbage, 0.1—2.8, 0.2—2.6, 0.4—2.0, and 0.8—0.1 The mean herbage weights were negatively correlated ($r = 0.99$, $Y = -3.87X + 3.28$) to the Zn rate amounts. Applications of $ZnCl_2$ to subsoil decreased blue grama herbage relative to plants that received only NPK. Fertilization of the pot soils with KH_2PO_4 and $CaHPO_4$ probably increased available Zn (Shuman 1988) so that further Zn additions caused toxicity. The toxicity increased with increasing Zn application.

Experiment 3

The mean herbage from 5 harvests in 1986 (Table 1) was related more to the number of plants pot^{-1} than to the treatment applied. For the Zn chelate treatment, the low seedling survival in 1986 and 1987 may have been caused by poor soil structure which reduced water infiltration and root penetration. Polyvalent cations which promote flocculation may have been complexed (chelated) so that the soil could disperse. Leaching with distilled water improved water infiltration and seedling survival for the Zn-chelate treatments in 1988. Use of chelates in soils which tend to have poor structure may be ill advised. Except for the chelate, the Zn source had little, if any, effect on seedling survival within any of the 3 years.

Herbage yields were not significantly different for any of the treatments in 1988 (Table 1). The herbage Zn content increased as the Zn application rate increased for each of the sources. The largest herbage Zn content was 905 mg kg^{-1} and herbage yield was not reduced. Although not evident from the means, the herbage Zn and P contents were positively correlated ($r = 0.54$, $p = 0.05$). The Zn contents of plants treated with $ZnCl_2$ were intermediate to those treated with the same amount of Zn in chelate or metallic material.

The DTPA-extracted soil Zn amount increased as the amount applied increased. The herbage Zn content and DTPA-extracted soil Zn tended to be related for any Zn source, but DTPA-Zn was less than would be expected relative to the herbage amount for the chelate and chloride sources (Table 1). Lindsay and Norvell (1978) indicated the DTPA-extraction solution could complex up to 654 mg Zn kg-$soil^{-1}$ so the complexing capacity of the solution was not exceeded. Zn absorbed by the plant apparently came from slowly available forms, which implied that very soluble chelate and chloride Zn is complexed by the soil. If greenhouse data can be extrapolated to the field, a large application of Zn would be needed to increase the concentration of Zn in blue grama herbage to the 20–40 mg Zn kg-$herbage^{-1}$ that cattle may need. Herbage from the untreated and NPK treatments contained similar amounts of Zn, and increased solubilization of Zn by the application of acidic phosphates (Shuman 1988) did not have an effect, at least in the third season. However, Zn concentrations in the DTPA-extracted soil was less for the NPK treatment in comparison to the untreated soil. If Zn solubilization did occur, phosphate may have reacted with Zn subsequently to reduce the amount of DTPA-extracted Zn.

Experiment 4

Blue grama herbage weight decreased and herbage Zn content increased as the Zn application increased from 0.3 to 2.0 g Zn kg^{-1} soil (Table 2). Plants in 2 of the 4 replications died at the highest Zn rate. Plant vigor decreased and herbage became temporarily more chlorotic as added Zn increased. The decrease in vigor was not caused by the chloride ion because yields were not significantly different for the different $CaCl_2$ application rates. The herbage P contents were not significantly different ($p = 0.05$) for plants treated with $ZnCl_2$ or $CaCl_2$. The ash content increased as the Zn rate increased. Apparently chloride does not have a detrimental effect on blue grama growth so that $ZnCl_2$ is a satisfactory source at reasonable application rates.

Table 2. Mean weight of blue grama herbage and its ash, Zn, and P content from plants treated with different amounts of $ZnCl_2$ or $CaCl_2$ (Experiment 4).

	Grams Zn ($ZnCl_2$) in kg^{-1} soil					
	0	0.30	0.60	1.10	2.0	r^2†
Herbage g pot^{-1}	5.4	6.2	4.8	3.7	2.2	0.68
Ash mg g^{-1}	57	59	60	85	111	0.69
Zn mg kg^{-1}	8	21	32	405	7412	0.39
P mg kg^{-1}	1442	1291	1195	1695	1307	0.00
Chloride added as $CaCl_2$ to equal amount in $ZnCl_2$						
Herbage g pot^{-1}	5.0	7.6	5.4	5.3	5.6	0.02
Ash mg g^{-1}	73	58	59	60	60	0.14
Zn mg kg^{-1}	25	7	19	5	10	0.17
P mg kg^{-1}	1440	1220	1395	1380	1275	0.06

†Regression dependent on Zn or Cl applied is significant ($p = 0.05$) if $r^2 > 0.40$.

Experiment 5

The Zn absorbed increased as the solution Zn concentration increased. After 336 h with 1.44, 14.4, and 144 mg Zn in the equilibration solution, 98, 88, and 28% of the Zn was absorbed by 18 g soil. Zn fixation into relatively insoluble forms may occur. About half the Zn absorbed at each initial concentration was released to DTPA after 336 h. The surface area with absorbed or precipitated Zn may increase with increasing initial concentrations and control the release to DTPA. $ZnCl_2$ applied to the soil surface that is not absorbed could move downward in the solution phase and be absorbed in deeper layers for eventual release to plants.

Table 3. Effect of solution Zn concentration and time on mean-equilibration-solution concentration, sorbed Zn, and subsequent DTPA-extracted soil Zn (Experiment 5).

Initial 0.098 Zn Cl_2-solution Zn	Equilibration Solution		Soil Zinc	
	Time	Zn	Sorbed	DTPA
mg	hours	mg		mg/18 g
0.00	1	0.006	nd	0.02
	168	0.005	nd	0.03
	336	0.005	nd	0.02
1.44	1	0.019	1.43	1.18
	168	0.054	1.38	0.86
	336	0.025	1.41	0.62
14.40	1	2.53	11.8	9.07
	168	2.05	12.4	8.33
	336	1.73	12.7	7.65
144.00	1	106	38.3	26.6
	168	114	30.0	20.2
	336	104	40.0	19.5
Source	Means			
Time (hr)	1	27.3	17.2	8.73
	168	29.0	14.6	7.34
	336	26.0	18.0	6.95
	mg (Zn)			
mg (Zn)	0	0.006	nd	0.02
	1.44	0.033	1.4	0.88
	14.4	2.10	12.3	8.35
	144.0	108.0	30.1	21.43

nd—not determined

Applied $ZnCl_2$ might be toxic for a short time to plants in direct contact, but the toxicity should dissipate rapidly.

Summary and Conclusions

Metallic Zn, applied at rates from 0 to 0.40 g Zn^{-1} claypan-surface soil in the greenhouse, increased blue-grama-herbage Zn in proportion to the amount applied. Zn chelate at all rates and chloride at the higher rate were initially detrimental to herbage production. After equilibration for 2 years and excess salt was leached, herbage production was not significantly different for the different Zn sources or from soil fertilized with acidic phosphate with Zn. Long-term effects of acidic phosphates on Zn deficient soils are not known, but presumably Zn would again become deficient eventually. At Zn rates up to 4 g Zn kg^{-1} soil, herbage Zn ranged from 11 to 900 mg kg^{-1} but, with $ZnCl_2$ applied at 0.30 to 2.0 g Zn kg^{-1} soil, Zn increased from 21 to 7,400 mg kg^{-1}. If 0.6, 1.10, and 2.0 g Zn kg^{-1} soil were applied as $ZnCl_2$, the mature plants became initially chlorotic; and at the highest rate, half the plants died. A normal color developed in all remaining plants in a few weeks. Plants treated with an equivalent amount of chloride as $CaCl_2$ did not become chlorotic. Blue grama apparently would adjust rapidly to very high surface applications of Zn. Soil absorption and fixation may occur to decrease toxic effects. Generalizing from the different experiments, Zn decreases herbage at rates equal or greater than 0.40 g Zn kg^{-1} soil.

DTPA-extracted soil Zn ranged from about 1 to 1,100 mg kg^{-1} (0.2 to 20 mg 18-g-$soil^{-1}$) as the equilibration solution increased from 0 to 144 mg Zn 18-g-$soil^{-1}$. For any single Zn source, herbage Zn increased with increasing DTPA soil Zn, but Zn-chelate- and Zn-chloride-treated blue grama had higher herbage Zn contents relative to DTPA soil Zn. Presumably, some applied Zn is fixed into forms that are available to plants but not to short-term DTPA extractions. Moderate applications of Zn on range would not be detrimental to blue grama and might increase the blue-grama-herbage Zn to the 20-40 mg kg^{-1} level needed for beef cattle (Nat. Research Council 1984) although feeding of mineral supplements would likely be more economical.

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