# RELATIVE BORON TOLERANCE OF SOME WESTERN REVEGETATION SPECIES[1]

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**Abstract**. Boron toxicity studies have been carried out since the 1920's. Almost without exception, these investigations emphasized agricultural crops. The results of these studies should not be extrapolated to arid land minesoils without confirmation from research in semiarid regions using native plant species. This solution culture study revealed a wide range of boron tolerance in common western range species. Two saltbushes and greasewood revealed tolerances for very high boron concentrations in the root media. Two wheatgrasses revealed lower but relatively high boron tolerances. Big sagebrush, Rubber rabbitbrush, Indian ricegrass, and Silky lupine revealed low tolerance for this element.

**Additional Key Words:** boron excess, boron tolerance, revegetation, minesoils, Northern Great Plains

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## Introduction

The revegetation of Northern Great Plains grasslands disturbed for natural resource extraction or other violent disruptions can be accomplished. Several widespread problems remain, however, such as development of diverse plant communities, establishment of shrubs and trees from seed, and agricultural crop production but most areas of concern are local or restricted to a few mines. Boron (B) phytotoxicity is such a problem; it is limited in extent but impedes revegetation when elevated levels of the element are present in plant root zones. This solution culture study was designed to generate information about the relative sensitivity of Great Plains revegetation species to excess B.

Boron phytotoxicity is encountered in many western areas but is normally associated with irrigation water rather than soils (Gupta 1979). Numerous studies of the effects of B in irrigation water on plants may be found in the literature (Bingham 1971, Wilcox 1955), but the most thorough investigations are to be found in Eaton's classic experiments reported in 1944. He investigated the response of 58 varieties of plants to B deficiency and excess. Unfortunately, of those plant species, only *Poa pratensis*, *Avena sativa*, *Melilotus officinalis*, and *Medicago sativa* have any relevance to semiarid land reclamation.

Boron research utilizing native rangeland species has been more recent. Roundy (1995) reported that B concentrations up to 200 mg $l^{-1}$ had no significant effect on germination of *Agropyron elongatum* or *Elymus cinereus*. In his experiments, growth of both species was more sensitive than germination to B. Jackson and his associates (1995) reported than visible symptoms of toxicity were observed in *Buchloe dactyloides*, another western revegetation species, at B solution concentrations of 10 $mgl^{-1}$. Schuman (1969) noted than *Agropyron elongatum* revealed reductions in dry weight yield at around 20 mg B $l^{-1}$. Marquis et al. (1984) conducted a study of B as a selective herbicide. They found that B solutions up to 600 m $l^{-1}$ were required to produce a 50% reduction in *Distichlis stricta* growth.

State regulatory agencies have established "suspect" (DEQ 1981) B concentrations in minesoils in the range of 5 to 10 mg $1^{-1}$ in the water-soluble soil extract. Like many of the parameters by which regulatory agencies describe undesirable soil surface or rootzone materials, the B suspect level is based upon irrigation studies in arid regions or agricultural research in more mesic areas. These investigations were adequate for preliminary estimates of standards, but as Becic (1983) pointed out, they must be followed by more careful studies of plant response to the parameter in question in the climatic zone of the disturbance and with plant species native to the site.

## Methods

The nine plant species (Table 1) evaluated for relative B tolerance were initially seeded in trays containing 50% Bozeman silt loam and 50% sand. After germination and development of adequate root systems, 3 to 5 leaf stage for the grasses and 2 to 6 cm for the shrubs, ten representatives of each species were transferred to growth tanks containing 22 liters of half-strength Hoaglund's solution (Hoaglund and Arnon 1950). These tanks measured 61 x 37 x

15 cm and contained a support rack for individual plants. The 90 plants in each tank were suspended by cotton collars so that their roots were submerged in the nutrient solution. Solutions in each tank were replenished from individual reservoirs by a constant drip valve metering one liter of nutrient solution every 24 hours. An overflow device removed any excess solution. Tanks were also aerated by pumping air through a glass filter into the tanks.

Table 1. Plant species* evaluated in this study.

| **Scientific Name** | **Common Name** |
|---|---|
| Artemisia tridentata (Nutt.) | Big sagebrush |
| Atriplex gardneri (Mog.) D. Dietr. | Gardner saltbush |
| *Chrysothamnus nauseosus* (Pallas ex Pursh) Britton | Rubber rabbitbrush |
| *Elymus lanceolatus* (Scribn. & J.G. Smith) Gould | Thickspike wheatgrass |
| *Lupinus sericeus* Pursh | Silky lupine |
| *Oryzopsis hymenoides*(Roem. & J.A. Schultes) Ricker & Piper | Indian ricegrass |
| *Pseudoroegeneria spicatum inerme* (Scribn. & J.G. Smith) A. Love | Beardless wheatgrass |
| *Sarcobatus vermiculatus* (Hook.) Torr. | Greasewood |

* Nomenclature from Barkworth & Dewey 1985 or S.C.S. 1982.

After the plants adjusted to the nutrient solution as evidenced by plant turgor, extra B (as boric acid) was added in increasing amounts from the control tank level of 0.5 mg $1^{-1}$ to concentrations of 5, 7.5, 10, 12.5, 15, 20, 40, 60, 80, and 100 mg $1^{-1}$. Nutrient solution B concentrations were chemically determined (Standard Methods 1975) at 10-day intervals and adjustments were made to maintain the predetermined concentration levels. The pH of the solution was also monitored and maintained in the range 6.5 to 7.5. Each B level was replicated in three randomly arranged tanks, providing a total of 33 growth tanks with 10 plants of each of the nine species in each tank. The growth period in the greenhouse extended for 14 weeks from the time of B addition. Light and dark periods were approximately 10.5 and 13.5 hours, respectively. Temperature was maintained in the range of 25 to 35° C during the light period and 18 to 24° C during the dark period.

At the end of the growth period, the surviving plants were counted, weighed, and evaluated for injury. Boron concentrations in the plants were determined by the curcumin colormetric method (Dible et al. 1954), after the tissues were oven-dried and ground to pass a 40 mesh screen. Each species in a replicated tank was harvested and manipulated separately from other species and replicates of the same species in other tanks so that B plant levels and other parameters measured in this research were based on N = 3 for each species.

Plant response was based upon three physical measurements and a subjective evaluation of the color and appearance of the plants at harvest. The measurements included number of surviving plants, total biomass, and tissue B levels. Biomass was determined for oven-dried roots, stems, and leaves of living plants. The subjective evaluation or injury index was the sum of two scores, one for color or tip burn and another for growth or vigor. Scores for both criteria ranged from 1 - very poor to 5 - excellent. A vigorous plant with good color would score 10 on the injury index, whereas a plant that was almost dead and severely discolored would score 1.

Statistical analyses included analysis of variance and mean separation for each of the four plant response measurements by individual plant species. Simple correlation coefficients were computed between plant weight and nutrient solution B concentrations for each species. A significance level of $p < 0.05$ was chosen for all statistical tests.

## Results and Discussion

Because of the multitude of factors which influence plant response to B (i.e., growth stage, calcium level, pH of root media, etc.), it is rather difficult to state a concentration at which maximum growth occurs. Furthermore, as Eaton (1944) reported injury may occur below the concentration contributing to maximum growth, therefore, to simplify this study, each species was evaluated separately. Furthermore, no attempt was made to arrive at a deficiency concentration; rather, a range of adequate B in solution culture was determined for each species investigated.

### *Artemisia tridentata*

A statistically significant number of plants of this species died at B concentrations above 10 mg $1^{-1}$, and simple correlations revealed a significant decrease in mean weight of surviving plants with increasing B concentrations in nutrient solution (Table 2). Plants surviving in 5 mg B $1^{-1}$ or more revealed extensive marginal burn of all fully expanded leaves.

### *Atriplex canescens*

Survival of this species in all growth solutions from control to 100 mg B $1^{-1}$ was excellent although reduced at 7.5, 40, and 100 mg $1^{-1}$. The survival of almost all of these plants (2, 3, and 2 dead plants at 7.5, 40 and 100 mg $1^{-1}$, respectively), indicated a strong B tolerance by this species. Plant weights revealed differences but the distribution of weight reductions was suggestive of a random effect and not B toxicity. For example, maximum average biomass production occurred at 0.5, 20, and 80 mg B $1^{-1}$, whereas minimum biomass was produced by plants in 7.5, 12.5, 15, and 60 mg B $1^{-1}$ solution. Mean elemental concentration in tissues of Fourwing saltbush was only 272 Φg $g^{-1}$ in 20 mg B $1^{-1}$ solution (Table 2). A slight discoloration and subsequent death of older leaves was observed on plants growing in 80 and 100 mg B $1^{-1}$.

### *Atriplex gardneri*

As in *A. canescens*, there was a death of plants of this species in various growth tanks. There were 1, 2, 1, and 7 dead plants in 12.5, 20, 60, and 80 mg B $1^{-1}$ solution, respectively. Plant weights revealed no significant differences over all B concentrations. Plant B levels were rather low.  Average plant tissue B concentrations ranged from the controls at 43 Φg B $g^{-1}$ to 345 Φg B $g^{-1}$ in 60 mg B $1^{-1}$ (Table 2).  There was no indication of injury until nutrient solution B concentrations exceeded 60 mg $1^{-1}$.  Even at 80 and 100 mg B $1^{-1}$, plants were not discolored but simply reduced in size.

**Table 2.   Plant responses to increasing B concentrations in the nutrient solution.**

| Plant Species | Nutrient Solution (mg $l^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **and Response** | **0.5** | **5.0** | **7.5** | **10** | **12.5** | **15** | **20** | **40** | **60** | **80** | **100** |
| *Artemisia tridentata* | | | | | | | | | | | |
| Weight (g $plant^{-1}$) | 0.5 | 0.3 | 0.3 | 0.3 | 0.2 | 0.4 | 0.3 | 0.1 | 0.2 | 0 | 0 |
| Plant B (Φg $g^{-1}$) | 99 | 381 | 526 | 676 | 767 | 809 | 1150 | — | 1680 | — | — |
| Survival Rate (%) | 100 | 100 | 90 | 93 | 83 | 83 | 73 | 30 | 17 | 0 | 0 |
| Injury Index | 8.0 | 7.7 | 6.3 | 6.0 | 4.7 | 3.7 | 4.0 | 2.0 | 2.0 | 0 | 0 |
| *Atriplex canescens* | | | | | | | | | | | |
| Weight (g $plant^{-1}$) | 2.5 | 1.1 | 1.0 | 1.1 | 0.8 | 0.8 | 3.2 | 1.5 | 0.7 | 2.0 | 1.2 |
| Plant B (Φg $g^{-1}$) | 46 | 92 | 169 | 179 | 174 | 205 | 272 | — | 352 | — | — |
| Survival Rate (%) | 100 | 100 | 93 | 100 | 100 | 100 | 100 | 90 | 100 | 100 | 93 |
| Injury Index | 9.0 | 8.7 | 8.8 | 8.0 | 8.1 | 6.7 | 8.7 | 8.7 | 7.0 | 6.0 | 5.3 |
| *Atriplex gardneri* | | | | | | | | | | | |
| Weight (g $plant^{-1}$) | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.1 | 0.2 | 0.2 |
| Plant B (Φg $g^{-1}$) | 43 | 94 | 146 | 150 | 210 | 245 | 314 | — | 345 | — | — |
| Survival Rate (%) | 100 | 100 | 100 | 100 | 97 | 100 | 93 | 100 | 97 | 77 | 100 |
| Injury Index | 9.0 | 9.0 | 8.1 | 9.3 | 8.2 | 8.0 | 8.0 | 8.7 | 7.7 | 7.3 | 6.7 |
| *Chrysothamnus nauseosus* | | | | | | | | | | | |
| Weight (g $plant^{-1}$) | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.3 | 0.1 | 0.1 | 0 | 0.1 |
| Plant B (Φg $g^{-1}$) | 123 | 310 | 475 | 728 | 756 | 676 | 666 | — | 1210 | — | — |
| Survival Rate (%) | 93 | 100 | 80 | 97 | 70 | 77 | 23 | 53 | 60 | 0 | 2 |
| Injury Index | 8.3 | 8.0 | 7.3 | 7.3 | 7.3 | 5.0 | 4.0 | 5.3 | 5.3 | 0 | 1.0 |
| *Elymus lanceolatus* | | | | | | | | | | | |
| Weight (g $plant^{-1}$) | 3.3 | 4.0 | 2.0 | 3.0 | 2.1 | 2.4 | 0.5 | 1.4 | 0.7 | 0.3 | 0.3 |
| Plant B (Φg $g^{-1}$) | 68 | 254 | 585 | 749 | 755 | 1170 | 1730 | — | 2350 | — | — |
| Survival Rate (%) | 97 | 100 | 100 | 100 | 100 | 100 | 93 | 93 | 100 | 57 | 50 |
| Injury Index | 8.3 | 9.7 | 8.3 | 9.3 | 8.7 | 7.8 | 4.0 | 8.3 | 3.8 | 2.0 | 2.0 |
| *Lupinus sericeus* | | | | | | | | | | | |
| Weight (g $plant^{-1}$) | 0.7 | 0.3 | 0.2 | 0.4 | 0.3 | 0.4 | 0.2 | 0.1 | 0 | 0 | 0 |
| Plant B (Φg $g^{-1}$) | 73 | 501 | 1330 | 1050 | 1310 | 1990 | 1990 | — | — | — | — |
| Survival Rate (%) | 70 | 30 | 7 | 13 | 13 | 20 | 10 | 3 | 0 | 0 | 0 |
| Injury Index | 6.3 | 5.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0 | 0 | 0 |

**Table 2. Plant responses to increasing B concentrations in the nutrient solution.**

| Plant Species and Response | Nutrient Solution (mg l$^{-1}$) 0.5 | 5.0 | 7.5 | 10 | 12.5 | 15 | 20 | 40 | 60 | 80 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Oryzopsis hymenoides* | | | | | | | | | | | |
| Weight (g plant$^{-1}$) | 0.9 | 0.8 | 0.5 | 0.4 | 0.5 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 |
| Plant B (Φg g$^{-1}$) | 88 | 474 | 953 | 951 | 1200 | 1660 | 2010 | — | 3510 | — | — |
| Survival Rate (%) | 90 | 97 | 90 | 80 | 90 | 97 | 87 | 83 | 63 | 57 | 30 |
| Injury Index | 8.0 | 8.9 | 8.3 | 6.0 | 6.7 | 5.7 | 5.7 | 4.3 | 3.0 | 2.0 | 2.0 |
| *Pseudoroegeneria spicatum inerme* | | | | | | | | | | | |
| Weight (g plant$^{-1}$) | 1.2 | 1.2 | 1.0 | 1.0 | 1.5 | 1.1 | 0.4 | 0.7 | 0.4 | 0.4 | 0.1 |
| Plant B (Φg g$^{-1}$) | 92 | 525 | 935 | 1220 | 1580 | 1310 | 2100 | — | 4960 | — | — |
| Survival Rate (%) | 90 | 87 | 93 | 80 | 93 | 90 | 93 | 33 | 43 | 27 | 23 |
| Injury Index | 7.5 | 8.5 | 6.2 | 5.5 | 6.3 | 5.5 | 4.3 | 2.6 | 3.3 | 2.0 | 2.0 |
| *Sarcobatus vermiculatus* | | | | | | | | | | | |
| | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 |
| Weight (g plant$^{-1}$) | 81 | 170 | 333 | 368 | 391 | 300 | 424 | — | 1030 | — | — |
| Plant B (Φg g$^{-1}$) | 90 | 93 | 93 | 97 | 100 | 100 | 90 | 93 | 73 | 30 | 23 |
| Survival Rate (%) | 7.2 | 8.3 | 6.8 | 4.3 | 4.3 | 6.7 | 6.7 | 4.0 | 5.3 | 2.0 | 2.0 |
| Injury Index | | | | | | | | | | | |

1 Not analyzed for B concentration.

<u>*Chrysothamnus nauseosus*</u>

A large number of these plants died at most B concentrations greater than 10 mg 1$^{-1}$. Weight of plants was reduced in those individuals growing in 7.5 or higher B concentrations. Tip and marginal burning of all but the youngest leaves occurred at concentrations greater than 5 mg B 1$^{-1}$. Plant tissue B levels exceeded 300 Φg g$^{-1}$ in those plants growing in the nutrient solution containing 5 mg B 1$^{-1}$ (Table 2).

<u>*Elymus lanceolatus*</u>

This species was the most tolerant of the three grasses studied. More than 10% of the plants did not die until nutrient solution B concentrations exceeded 60 mg 1$^{-1}$, but average plant weights were reduced in all solutions above 15 mg 1$^{-1}$. Plant tissue B levels exceeded 250 Φg g$^{-1}$ when grown in 5 mg B 1$^{-1}$ solution (Table 2). The grasses did not have the marginal brown discoloration typical of B excess in shrubs and trees but their color faded from green to pale green to yellow with increasing B levels in the root zone. Thickspike wheatgrass did not reveal marginal discoloration until the root media B level reached 20 mg 1$^{-1}$.

<u>*Lupinus sericeus*</u>

This species revealed striking symptoms of toxicity in all tanks other than the controls. All mature leaves were dead and marginal burning became acute as the young leaves expanded. Survival of this species was severely restricted in all B levels greater than the control, with 70% of the plants dead in nutrient solutions containing 5 mg B $1^{-1}$ or more. Silky lupine was the most sensitive species studied in this investigation.

*Oryzopsis hymenoides*

Mortality of this species in nutrient solutions containing elevated B levels was greater than 20% when the solutions contained over 40 mg B $1^{-1}$. However, plants in nutrient solutions containing 10 mg B $1^{-1}$ or more were distinctly yellow-green. Reduction of plant weight was significant at 15 mg $1^{-1}$. Tissue B levels exceeded 470 Φg $g^{-1}$ when grown in nutrient solution containing 5 mg B $1^{-1}$.

*Pseudoroegneria spicata* subsp. *inermis*

Drastic reduction in the survival of this species occurred at nutrient solution levels of 40 mg B $l^{-1}$ and higher. Mean plant weights were reduced in growth tanks containing more than 15 mg $1^{-1}$. Mean plant B concentrations were 525 Φg $g^{-1}$ or twice as high as *Elymus lanceolatus* in plants growing in 5 mg B $1^{-1}$ solution (Table 2). These plants rapidly lost color as the root media B level exceeded 12.5 mg $1^{-1}$. Beardless wheatgrass consistently produced smaller biomass in comparable nutrient solutions than *Elymus lanceolatus*, but greater biomass than *Oryzopsis hymenoides*.

*Sarcobatus vermiculatus*

A mortality rate greater than 20% occurred in Greasewood only at B levels of 60, 80, and 100 mg $1^{-1}$ but biomass peaked in plants grown in 20 mg $1^{-1}$. Minimum production occurred in 7.5, 10, 12.5, and 100 mg B $1^{-1}$ solutions. The slight growth of this species in any of the nutrient solutions confused the definition of an upper tolerance limit. Boron tissue levels were unique in greasewood; they averaged 333 Φg $g^{-1}$ in plants grown in 7.5 mg B $1^{-1}$ and remained near that level in plants grown in nutrient solutions containing 10, 12.5, and 15 mg $1^{-1}$. At 20 mg B $1^{-1}$ in the growth tanks the plant B levels rose to 420 Φg $g^{-1}$. The lack of a significant relationship between plant weight and solution culture B concentration indicated a strong tolerance for this element in greasewood.

## Conclusions

Simple correlations between plant weight and solution B concentrations indicated significant negative relationships for six of the nine species (Table 3). Plant weight was also negatively correlated to the concentration of B in the nutrient solutions. The absence of correlations between plant weight and solution B in greasewood and the two saltbushes was an indication of their tolerance to excess B. This tolerance was demonstrated by lack of visual injury, low mortality, and lower accumulation of B in plant tissues.

In another nutrient study (Oertli et al. 1961) several turfgrasses were grown in solutions containing B concentrations to 10 mg $1^{-1}$. Boron injury was observed and correlated with B concentrations in the plant tissues. Plants that were rapid accumulators showed injury first. Sensitivity to excess B was related more closely to uptake rates than differences in tissue tolerance when comparing tolerant and sensitive grass species. While most species in our study support this conclusion, *Pseudoroegeneria spicatum inerme* was a rapid B accumulator but did not show injury at a comparable rate. Apparently Beardless wheatgrass is more tolerant of elevated B in tissues than the other grass species investigated. The sensitivity of *Lupine sericeus* was clearly indicated by the death of most plants in all growth tanks other than the controls and by the rapid accumulation of B by the survivors.

Table 3. Simple correlations (r) between plant weight and plant B concentrations and plant weight and nutrient solution B concentrations.

| **Species** | **Wt (g plant$^{-1}$) vs. Plant B Concentrations (Φg g$^{-1}$)** | **Wt (g plant$^{-1}$) vs. Solution Concentration (mg l$^{-1}$)** |
|---|---|---|
| *Artemisia tridentata* | -0.73* | -0.89* |
| *Atriplex canescens* | 0.13 | 0.06 |
| *Atriplex gardneri* | 0.02 | 0.24 |
| *Chrysothamnus nauseosus* | -0.74* | -0.69* |
| *Elymus lanceolatus* | -0.87* | -0.89* |
| *Lupinus sericeus* | -0.64 | -0.78* |
| *Oryzopsis hymenoides* | -0.85* | -0.70* |
| *Pseudoroegeneria spicatum inerme* | -0.70* | -0.84* |
| *Sarcobatus vermiculatus* | -0.01 | -0.24 |

* Significant at $p \leq 0.05$.

In a sand culture study (Davis et al. 1978), barley tissue B levels were 80 Φg g$^{-1}$ when plants were irrigated with 2 mg B 1$^{-1}$ in the nutrient solution. The authors concluded that 80 Φg B g$^{-1}$ tissue weight was the "critical level" for this species since a 10 percent reduction in plant biomass occurred at this tissue concentration. Eaton (1944) found injury occurring in root media concentrations from 1 to 25 mg B 1$^{-1}$ varying with the species. He also reported tissue levels at injury ranging from 22 Φg g$^{-1}$ in Kentucky bluegrass to over 1,000 Φg g$^{-1}$ in sweetclover. Our study was not designed to detect such a critical level but B concentrations in controls were usually greater than 80 Φg B g$^{-1}$. Furthermore, tissue levels which showed injury tended to be greater than 300 Φg B g$^{-1}$.

Solution culture B tolerance ranges for the nine species in this study are shown in Table 4.

They fall into four relative tolerance groups: very sensitive, sensitive, semi-tolerant, and tolerant. While plant injury tended to occur when plant tissue B levels exceeded 300 Φg $g^{-1}$, no indication of injury was observed in the more tolerant species even at this level. The sensitive species absorbed B very rapidly and exceeded 300 Φg B $g^{-1}$ in their tissues at low concentrations in the root media.

Vegetation revealed species-specific tolerance to B and species-specific absorption capacity which was independent of the plants' sensitivity to B. But, in general, sensitive species absorbed B more readily than tolerant species and exhibited higher tissue levels than tolerant species in comparable rootzone B concentrations.

Table 4. Boron tolerance ranges in solution culture for species studied.

| **Species** | **Tolerance Range (mg $1^{-1}$)** | **Relative Tolerance** |
|---|---|---|
| *Artemisia tridentata* | 0.5 to 5 | sensitive |
| *Atriplex canescens* | 0.5 to 60 | tolerant |
| *Atriplex gardneri* | 0.5 to 60 | tolerant |
| *Chrysothamnus nauseosus* | 0.5 to 5 | sensitive |
| *Elymus lanceolatus* | 0.5 to 15 | semi-tolerant |
| *Lupinus sericeus* | 0.5[1] | Very sensitive |
| *Oryzopsis hymenoides* | 0.5 to 5 | sensitive |
| *Pseudoroegeneria spicatum inerme* | 0.5 to 12.5 | semi-tolerant |
| *Sarcobatus vermiculatus* | 0.5 to 20 | tolerant |

[1] Upper limit 0.5 mg $1^{-1}$.

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