Effect of Oil Well Brine on Germination and Seedling Growth of Several Crops[1]

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ABSTRACT. Large quantities of oil and gas well brines are produced annually in Ohio. This paper presents chemical parameters measured for a Wayne County, Ohio, oil well brine and reports the effects of several incremental brine concentrations on the germination and seedling development of soft red winter wheat (Triticum aestivum), soybeans (Glycine max), tall fescue (Festuca arundinacea), garden peas (Pisum sativum), and oats (Avena sativa). Chemical tests of two brine samples collected at the same well site showed large quantities of total solids (83 and 96 g/L), very high electrical conductivity (124 and 145 dS/m), and the presence of several elements at levels reported in the literature to be capable of causing crop injury or toxicity (Cl^- 55 and 57 g/L, Na^+ 14.8 and 15.8 g/L, B 11 and 9 mg/L). The dominant ions present were Na^+ and Cl^-. Germination studies indicated that increasing the volume percentage of brine reduced the germination of tall fescue and soybeans more than wheat or garden peas. Increasing the volume percentage of brine caused the greatest reduction in plumule/hypocotyl enlargement in the following order: tall fescue > peas > wheat. In a 21-day greenhouse study, soybean dry matter yields were reduced more than those of oats by increasing the levels of brine in the water used to water the plants without leaching.

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INTRODUCTION

Large volumes of oil and gas well brines are produced annually nationwide. A 1984 Task Force estimated 160,000 barrels are produced per day in Ohio alone (Beeker 1984). Under the provisions of Ohio Substitute House Bill 572, June 1985 (Hoffman 1986), brine may be disposed of only by annular disposal (trickling brine down nonproducing well casings), deep well injection (the most environmentally desirable technique), or by spreading on roads if this practice is in compliance with county and township guidelines. The disposal of such brines may be more or less stringently regulated in other states.

Since brine can contaminate surface waters or soils (during handling and/or surface spreading), the following question should be raised: What impacts do these brines have on crops, vegetation, and soils?

Objectives of this study were:

1. To chemically characterize a Wayne County, Ohio, oil well brine.
2. To assess the effect of brine concentration on germination percentage and early seedling growth of soybeans, wheat, oats, tall fescue and garden peas.

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MATERIALS AND METHODS

BRINE COLLECTION AND CHARACTERIZATION.

1. Brine was collected by a well service crew during drilling in East Union Township, Wayne County, Ohio, in April 1986. The well was drilled 3,700 feet deep into the Clinton sand formation (Conroy 1921).
2. Two 20-liter carboys of brine were collected over time, hereafter identified as brines #1 and #2.
3. Four replicate measurements of pH, electrical conductivity, total solids by evaporation to dryness of 100 ml samples, solution density, and Cl^- concentration were made on each brine. The Cl^- concentrations were measured with an ion-specific electrode.
4. Samples were tested by the Ohio Research and Development Center (OARDC) Research Extension Analytical Laboratory for K^+, Ca^{+2}, Mg^{+2}, Na^+, Fe, Mn, and B by inductively coupled plasma emission (ICP) spectroscopy.

SEED GERMINATION AND EARLY GROWTH. Crops and varieties used were "Hillsdale" soft red winter wheat (Woods' Seed Farm, Deerfield, MI), "Little Marvel" garden peas (Goldstar Store, Wooster, OH), "Sparks" soybeans (OARDC Agronomy Dept.), and "Chesapeake" tall fescue, a "turf-type" (Donley Seed Company, Ashland, OH). Brine concentrations in the water used to moisten the germinating paper were 0, 1%, 2%, and 10% calculated as (Vol. brine × 100)/Total Volume, with the balance of the volume being distilled water. Germination was tested by placing 50 seeds of each crop between two pieces of germination paper, rolling into a cylinder, and immersing the base of the cylinder in water in a plastic bucket. Temperature was 16°C ± 2°C for the seven-day test. After seven days, the number of seeds that had radicle protrusions were counted and length of each plumule for grasses or hypocotyl for peas and soybeans was measured.

SEEDLING GROWTH IN GREENHOUSE POTS. Thirty plastic pots that contained 750 g of air-dried Canfield silt loam soil and 50 g of

TABLE 1
*Characteristics of Two Brine Samples**

Test	Brine #1	Brine #2
pH	6.01 ± 0.17	5.38 ± 0.23
Electrical Conductivity (dS/m)	124.0	145.0
Solution Density (g/cm^3)	1.032 ± 0.0010	1.033 ± 0.0015
Total Solids (g/L)	83.0 ± 11	96.0 ± 5.7
Cl (g/L)	55.1 ± 6.2	57.4 ± 10.3
Elements by ICP Spectroscopy (mg/L)		
K^+	643.0	572.0
Ca^{+2}	7,560.0	8,421.0
Mg^{+2}	1,135.0	1,190.0
Na^+	14,847.0	15,843.0
Fe	224.0	279.0
Mn	18.0	18.0
B	11.0	9.0
SAR calculated from Na, Ca, Mg	42.0	43.0

*The first five tests are means of four replicates reported ± standard deviation. The ICP spectroscopy results were not replicated. There are several possible chemical species present for Fe, Mn and B that are not differentiated in ICP analyses, so ionic status is not represented.

perlite for aeration were used to plant "Pioneer 2480" soybeans and "Porter" oats at 2 cm depth. They were planted on 17 April 1986, and on 21 April 1986, respectively. Three soybean and 15 oat plants were achieved by overseeding and thinning to the desired number of plants in each pot upon emergence. Five treatments, distilled water, 1%, 2%, 10% (volume percentage), and straight brine, were replicated three times for each crop. Plants were grown in a controlled greenhouse environment and maintained at approximately 20% soil moisture. Plants in pots were assigned to the available greenhouse bench space in a completely randomized design. Chemical parameters measured in the soil and plant dry weights were analyzed statistically by one-way analysis of variance.

At the conclusion of the growth study, five core samples were obtained from each pot for pH and soluble salt tests. The soil samples were shaken with distilled water for 30 minutes to prepare 1:2 weight/volume extracts which were filtered through Whatman #1 paper and analyzed for pH and electrical conductivity.

RESULTS AND DISCUSSION

The two samples of brine collected over several days by the drilling crew were similar in electrical conductivity, pH, density of solution, and total solids by evaporation to dryness (Table 1). Brine #1 was chosen for further work. The brines were found to possess dissolved salts (electrical conductivity [EC] 124-145 dS/m), Cl^- (55-57 g/L), B (9-11 mg/L) and Na^+ levels (sodium adsorption ratio [SAR]), all of which far exceed the highest acceptable levels in irrigation water or soil saturation extracts (Venne 1984, U.S. Salinity Laboratory Staff 1954, Hoffman 1986, Hawkes 1985). The literature suggests that soluble salts content expressed as ECW > 3 dSm/m, SAR > 9, B > 2.0 mg/L, and Cl^- > 350 mg/L may be injurious to plants (Avers 1977, Cera et al. 1985).

In terms of germination, 100% brine #1 completely inhibited germination of each crop species tested in common brown towel medium tests. Ten percent (volume/volume) brine in brown towel medium tests dramatically reduced germination of "Sparks" soybeans and "Chesapeake" tall fescue, but did not reduce the germination of "Hillsdale" wheat or "Little Marvel" peas (Table 2). This reduced germination in the presence of 10% or straight brine may be attributed to high B, total salts, Cl^- or Na^+ relative to other cations. In terms of seedling top development during germination (Table 3), tall fescue showed the greatest reduction in

TABLE 2
Effect of % Brine (Vol/Vol) on Germination.

Treatment (Volume % Brine)	Percentage Seeds Germinated in 7 Days: Soybeans	Peas	Wheat	Tall Fescue
0%	66	68	100	64
1%	70	70	100	44
2%	72	66	96	47
10%	30	70	100	44

TABLE 3
Effect of Brine Concentration on Plumule or Hypocotyl Length in Seven Day Test.

	Tall Fescue Plumule (mm)			Soft Red Wheat Plumule (mm)			Garden Peas Hypocotyl (mm)		
Treatment	Mean	Std. Dev.	Ratio*	Mean	Std. Dev.	Ratio*	Mean	Std. Dev.	Ratio*
Control	15.3	8.8	1.00	40.2	13.1	1.00	18.4	9.7	1.00
1%	8.7	7.9	0.57	56.7	7.2	1.41	22.0	13.2	1.20
2%	3.5	3.6	0.23	44.1	13.7	1.10	8.7	7.8	0.47
10%	1.4	2.5	0.09	25.6	9.2	0.64	7.2	5.7	0.39

$$^*\text{Ratio is } \frac{\text{Top Length for 1\%, 2\%, or 10\%}}{\text{Top Length Control (Distilled Water)}}$$

plumule length, garden pea hypocotyl reduction was intermediate, and wheat growth was reduced the least. In fact, both wheat and peas showed enhanced top elongation at 1% brine, compared to a control of distilled water, and wheat plumule length was slightly enhanced by 2% brine. These findings suggest that Ca^{+2} and/or B from the brine may be enhancing cell division and growth compared to a distilled water control (Epstein 1972).

In the oat and soybean seedling growth studies, where several volume percentages of brine were used as the sole source of water for 21 days, straight brine prevented germination and 10% brine reduced growth as measured by dry matter production (Tables 4 and 5). The pots were watered with the appropriate brine dilution (100%, 10%, 2%, 1%, or 0) without leaching, and in 21 days salt buildup was tremendous, as evidenced by the EC of 1:2 soil distilled water extracts (Tables 4 and 5).

In reclaiming a brine-contaminated soil, the question arises as to how much leaching would be required to grow many common crops (Hoffman 1986). These preliminary studies suggest that a soil saturated with brine would need at least 100-fold dilution with low salt water to bring the level of salts (Na^+, Cl^-, and B) down to levels that would permit satisfactory crop growth. The retention of large amounts of B from the brine by Ohio soils and the possible adverse impact of high Na^+ levels on soil structure and hydraulic conductivity rates need to be examined in further work.

TABLE 4
Effect of Brine Treatment on Oat Seedling Dry Weight and Soil Properties.

	Volume % Brine Concentrations						
	100	10	2	1	0	LSD (0.05)	LSD (0.01)
Seedling Dry Weight (g)	0.00	0.74	0.84	1.03	0.97	0.13	0.22
Soil Extractable Soluble Salts EC (1:2) dS/M	40.0	6.6	1.5	0.8	<0.1	1.9	2.6
pH (1:2)	5.3	6.6	6.2	5.4	6.7	0.4	0.5

TABLE 5
Effect of Brine on Soybean Seedling Dry Weight and Soil Properties.

	Volume % Brine Concentrations						
	100	10	2	1	0	LSD (0.05)	LSD (0.01)
Seedling Dry Weight (g)	0.00	0.37	1.19	1.07	1.12	0.13	0.22
Soil Extractable Soluble Salts EC (1:2) dS/M	45.6	5.7	1.3	0.7	<0.1	3.0	2.6
pH (1:2)	5.3	6.5	6.5	6.2	6.7	0.2	0.3

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