SALT THRESHOLDS FOR LIQUID MANURE APPLIED TO CORN AND SOYBEAN

C. A. Shapiro, W. L. Kranz, C. S. Wortmann

ABSTRACT. *Sprinkler application of liquid manure to growing crops is often a convenient, and agronomically acceptable, means of land application. However, manure salts can cause crop damage, and safe salt concentrations of liquid manure have not been determined. Research was conducted to better understand the relationship of salt concentration to phytotoxicity. Swine (*Sus scrofa*) manure from a below-barn storage facility was applied during the summer of 2003 to corn (*Zea mays *L.) and soybean [*Glycine max *L. (Merr.)] growing on a Kennebec silt loam (fine-silty, mixed, mesic Cumulic Hapludoll) soil under field conditions. The manure had a mean electrical conductivity (EC) of 20.3 dS m^{-1} and was diluted to EC levels of 11.7, 6.4, and 0.6 dS m^{-1}. The 20.3 dS m^{-1} and the 6.4 dS m^{-1} concentrations are typical of under-barn storage and anaerobic lagoons, respectively. The liquid manure was applied to crop canopies at a rate of 11.7 mm ha^{-1} in three increments over a 10 min period at growth stages V7 or V14 for corn, and V3 or R1 for soybean. At the 20.3 dS m^{-1} concentration, phytotoxic effects occurred for both crops, although the effects were minor for the corn with application at the V14 stage. At the 11.7 dS m^{-1} concentration, liquid manure caused leaf necrosis, stunting, and reduced leaf area in soybean, while visible phytotoxic effects were much less severe in corn. Eighty-eight percent of the soybean plants were killed by the 20.3 dS m^{-1} concentration when applied at the V3 stage. Soybean and corn yields were decreased for the V3 and V7 applications by 89% and 15%, respectively. With the later application of 20.3 dS m^{-1} concentration, soybean yield was reduced by 45%, but corn yield was not reduced. The V3 application of solutions of 11.7 and 6.4 dS m^{-1} caused an 8.5% decrease in soybean yields. Application of 11.7 dS m^{-1} liquid manure at V7 reduced corn yield by 12% but increased yield by 10% when applied at V14. Application of 6.4 dS m^{-1} liquid manure increased corn yield by 4% and 13% for the V7 and V14 applications, respectively, compared to the control. Under the conditions of this study, application of liquid manure of 6.4 dS m^{-1} or less should be safe for all stages of soybean and corn, while 11.7 dS m^{-1} should be safe for soybean after R1 and for corn after V7. Further research is needed to evaluate these results across several growing environments and to determine potential differences in plant damage threshold.*

Keywords. *Corn, Liquid manure, Phytotoxicity, Soybean, Sprinkler application.*

In-season application of liquid manure from animal feeding operations is a common practice when the liquid component is sufficiently dilute. In-season land application allows the crop producer to benefit from the water and nutrients applied at a time when the crop has a high demand (Al-Kaisi and Waskom, 2002). Occasionally, crop damage occurs with the application of liquid manure, presumably because of high salt concentration. While the liquid manure might be diluted in such cases, producers may not have fresh water, facilities for dilution, or proper environmental safeguards.

Much research has been done on the use of saline water, wastewater, and liquid manure for irrigation of crops throughout the growing season. Typically, these studies have applied liquids with EC values of less than 2 dS m^{-1} (Day et al., 1979; Day and Tucker, 1977; Hayes et al., 1990; Jordan et al., 2001), which usually resulted in little or no foliar damage. Jordan et al. (2001), however, reported damage to more sensitive species of ornamental trees that were irrigated daily during the summer months. Foliar damage and yield loss occurred with regular irrigation with less than 4 dS m^{-1} water (Busch and Turner, 1967; Bernstein and Francois, 1975). Bell pepper (*Capsicum frutescens*) yield was reduced by 50% with sprinkler irrigation with water of <4.2 dS m^{-1}, but there was no yield loss or foliar damage with drip irrigation (Bernstein and Francois, 1975).

Maas (1985) reported salinity thresholds for induced foliar injury in a number of species, noting that the thresholds vary with weather conditions. Maas (1985) concluded that since damage is caused by absorption into plant tissues, foliar application should be avoided in hot, dry, windy conditions that produce high potential evapotranspiration (PET). Species vary in their rates of foliar absorption of salts, such as: sorghum (*Sorghum bicolor* L. Moench) < cotton (*Gossypium hirsutum* L.) = sunflower (*Helianthus annus* L.) < alfalfa (*Medicago sativa* L.) = sugar beet (*Beta vulgaris* (*saccharifera*) L.) < barley (*Hordeum vulgare* L.) < potato (*Solanum tuberosum* L.), but susceptibility to injury is not related to salt absorption, as injury varied as: sugar beet < cotton < barley = sorghum < alfalfa < potato (Maas et al., 1982). Leaf

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absorption of salts may be affected by leaf age, with generally less permeability in older leaves, and by angle and position of the leaf, which may affect the time and amount of leaf salt exposure.

In the above studies, irrigation with saline or wastewater was a major source of water for the crop, and the cumulative effect of soil salinity was eventually a greater concern than crop canopy damage by salts. An approximate relationship between salts in irrigation water (EC_i) and soil salinity (EC_s) is:

$$(EC_s) = 1.5 \times (EC_i) \tag{1}$$

assuming 15% of the applied water is drained from the crop root zone (Hoffman, 1997). In addition, foliar damage is generally attributed to absorption of sodium and calcium ions (Maas et al., 1982), which may be the major ions in the saline water.

Sprinkler application of animal manure liquids to growing crops differs from the situations evaluated in the above studies. Soluble salt levels are often much higher than with saline water used for irrigation. The major cation is generally ammonium (NH_4+), which may increase the phytotoxicity of liquid manure relative to the effects of sodium. Liquid manure is generally a secondary source of water and is applied only once or twice during a growing season, with greater amounts of water coming from rainfall and irrigation with “clean” water, which will leach applied salts. In the areas of Nebraska where sprinkler-applied liquid manure is practiced, normal annual precipitation varies from 381 to 686 mm (High Plains Regional Climate Center, 2003), which is enough rainfall to flush salts below the root zone when salt is applied at moderate levels. Hence, long-term salt buildup in the soil is usually not a problem.

Crop damage due to sprinkler application of high-EC liquid manure could occur because of direct contact of salts with the plant. Damage could also occur due to a sudden increase in soil salinity, even if the saline condition is of short duration. Such a case is most likely to occur when liquid manure is applied to a sandy soil of low buffering capacity at a time surface soil water is depleted, resulting in a short-term case of high soil solution salinity in the crop root zone.

Producers need to know safe levels of soluble salt concentration for liquid manure application to avoid damage to growing crops. The objective of this study was to determine a salt concentration threshold for safe application of manure through sprinkler irrigation on corn and soybean crops. The hypothesis is that stage of growth and manure soluble salt concentration will influence the plant damage from direct application of liquid manure to corn and soybean foliage.

Materials and Methods

Data from 2728 liquid manure samples, submitted over several years to Ward Laboratories, Inc. (Kearney, Neb.), were analyzed to determine the EC distribution of samples from livestock operations. The only criterion for selecting the samples was that water content be more than 96%; therefore, samples probably represent manure from various animal types. The relationship between EC and ammonium-N (NH_4-N) concentration was also determined. The ranges of EC and NH_4-N concentrations from these samples were compared with concentrations used in this study.

The field research was conducted at the Haskell Agricultural Laboratory of the University of Nebraska located near Concord, Nebraska. The soil was a Kennebec silt loam (fine-silty, mixed, mesic Cumulic Hapludoll) with a pH of 7.3, 35 g kg^{-1} soil organic matter, 63 mg kg^{-1} Bray P1, and 51 mg kg^{-1} Olsen P, and 532 mg kg^{-1} potassium. The surface soil had 12.6 mg kg^{-1} of nitrate-N, and irrigation water was predicted to supply 35 kg N ha^{-1} during the growing season. A rate of 62 kg N ha^{-1} (55 lb N ac^{-1}) was determined to be adequate for a corn yield goal of 11.3 Mg ha^{-1} (180 bu ac^{-1}), but 168 kg N ha^{-1} (150 lb N ac^{-1}) was applied pre-plant to eliminate any potential for N deficiency, and to account for any variation in N concentration in the applied liquid manure.

The experimental area was irrigated with a lateral-move sprinkler irrigation system equipped with low-pressure spray nozzles mounted on top of the pipeline. Irrigation was applied as needed to maintain greater than 50% available water in the rooting depth. Irrigation supplied 200 mm (8 in.) of irrigation water, and precipitation supplied 366 mm (14.4 in.) between 1 May and the end of the season. Corn (cv. Pioneer Brand 34N43) was planted on 16 May 2003 at 66,690 plants ha^{-1}. Soybean (cv. Garst 2502) was planted on 28 May 2003 at 466,830 plants ha^{-1}. Experimental units were eight rows wide in 0.76 m row spacing and 10 m long.

The treatments consisted of single liquid manure applications of four soluble salt concentrations applied at one of two selected growth stages of corn and soybean. The plots were arranged in a randomized complete block design with three replications. The salt concentrations were produced by diluting liquid manure (EC = 20.3 dS m^{-1}) to 11.7 and 6.4 dS m^{-1}, and using well water with an EC of 0.6 dS m^{-1}. Swine manure from a confined feeding operation was pumped from an under-building storage pit through a 2 mm screen to sieve out large particles. The liquid manure was again sieved through a 0.4 mm screen and then pumped to transfer tanks plumbed to allow agitation. The EC of the solutions was determined using a conductivity meter (ATI Orion model 130, Analytical Technology, Inc., Boston, Mass.) calibrated with either a 1 or 10 dS m^{-1} solution. Liquid manure samples for both applications were collected from the supply tank outlet between the tank and the applicator and sent to Ward Laboratories to determine EC and nutrient concentration (table 1).

The liquid manure application system (LMAS) consisted of a modified HiBoy (Hahn 670, Hahn Manufacturing, Evansville, Ill.) (fig. 1). The boom supported a PVC pipe manifold constructed to apply uniform liquid to a 2.3 × 7 m area. Nozzles were arranged in a 3 × 7 grid. Each nozzle (model WSQ17, Spraying Systems Co., Wheaton, Ill.) produced a 0.8 m square pattern when positioned 0.5 m above the canopy and operated at 2.2 kPa. The LMAS was calibrated with liquid manure and water to apply 12 mm min^{-1}.

Corn and soybean blocks were adjacent. Alleys were cut to allow movement of the LMAS from one experimental unit to another. The LMAS was positioned over the middle four rows of the experimental unit. Manure was applied in three periods of 20 sec duration separated by 5 min with no application in order to keep leaves wet for a time period similar to a center-pivot application. The first application (AT1) was on 2 July 2003, when corn was in the V8 leaf stage

Table 1. Chemical analysis of liquid manure applied to corn and soybean at Concord, Nebraska, in 2003 (all values in kg ha^{-1}).

	EC Level ($dS\ m^{-1}$)[a]							
	0.6		6.4		11.7		20.3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Organic N	0.05	0.05	26.7	3.5	71.4	24.7	201.2	46.0
Ammonium N	0.57	0.15	88.3	10.8	191.3	6.7	410.6	17.8
P as P_2O_5	0.69	0.49	37.8	5.2	126.6	68.8	337.9	81.9
K as K_2O	1.06	0.14	68.2	6.3	146.6	9.9	316.1	29.5
S	3.90	0.53	13.7	2.0	28.6	5.1	60.0	8.0
Ca	10.00	1.12	21.8	1.8	65.0	40.6	147.7	37.0
Mg	2.26	0.16	10.0	1.0	26.0	11.9	65.0	15.1
Na	2.79	0.08	15.5	1.4	31.1	1.4	67.0	4.0
Soluble salts	41.5	1.50	463	49.0	846.0	27.2	1463.0	73.0
EC ($dS\ m^{-1}$)	0.60	0.00	6.4	0.67	11.7	0.38	20.3	1.01
pH	7.87	0.72	6.9	0.12	6.6	0.06	6.2	0.12
Dry matter (%)	0.05	0.01	0.5	0.05	1.8	0.97	4.2	0.86

[a] Mean EC levels for the fresh water used as a control treatment and liquid manure dilutions applied to corn and soybean.

and soybean in the V3 leaf stage (Ritchie and Hanway, 1984; Ritchie et al., 1996). The second application (AT2) was on 24 July 2003, when corn was in V14 and soybean was in the flowering stage (R1) with seven trifoliates. The precipitation, maximum and minimum air temperatures, relative humidity, incoming solar radiation, and estimated PET were recorded (table 2) for seven days beginning with each application date from an automated weather station located approximately 1.2 km to the northwest of the experiment (High Plains Regional Climate Center, 2003).

The same treatments were applied in a border area on 5 September, and soil samples were taken seven days later from the 0.6, 11.7, and 20.3 dS m^{-1} treatments and sent for chemical analysis. Ten cores were collected from the 0 to 50 mm depth in each treatment. Samples were analyzed for pH, NO_3-N, Mehlich III-P, and NH_4-N to evaluate potential relationships between soil nutrient levels and liquid manure rates.

Plant population was determined from 6.1 m of row before manure application (data not shown) and again at harvest for the AT1 and AT2 treatments. After application, plants were visually examined every three days until visible effects stabilized. All treatments were then rated for leaf necrosis on 28 July 2003 and 6 August 2003, and for degree of stunting on 6 August 2003. Percent necrosis (leaf tissue death) was evaluated by recording a visual estimate of the leaf material that appeared brown versus a healthy green color. Percent stunting was recorded by visually recording the height

Figure 1. Applicator used to apply liquid swine manure to corn and soybean.

Table 2. Summary of climatic conditions during and following liquid manure application at Concord, Nebraska, in 2003.

Month	Day	T_{max} (°C)	T_{min} (°C)	RH (%)	Wind Speed (m s^{-2})	Solar Radiation (Cal. m^{-2})	Precip. (mm)	PET[a] (mm)	PET[b] Mean (mm)	PET[b] SD (mm)
Application Time 1 (AT1)[c]										
7	2	32.8	18.8	67.5	6.5	596	0	9.2	6.4	2.0
7	3	33.7	20.0	69.8	3.8	599	5.9	8.1	6.6	2.2
7	4	26.7	16.6	77.4	5.5	470	5.5	6.1	6.5	2.5
7	5	27.6	15.9	82.9	3.9	293	27.8	4.0	5.9	2.0
7	6	30.2	16.3	82.2	3.7	594	0	6.5	6.7	1.7
7	7	26.3	20.4	72.6	4.7	372	0	5.7	6.6	2.0
7	8	26.7	16.0	81.9	5.6	516	14.3	6.0	6.4	2.0
7	9	27.7	18.6	77.2	4.5	463	10.1	5.9	6.2	2.1
7	10	27.8	14.4	68.9	4.9	602	0	8.1	6.1	2.0
Application Time 2 (AT2)[d]										
7	24	29.6	13.3	61.1	6.2	555	0	9.1	5.6	1.8
7	25	32.6	19.2	61.4	7.3	534	0	9.3	6.2	1.9
7	26	34.1	22.6	64.7	4.5	492	0	8.4	5.9	1.8
7	27	23.6	18.2	81.8	2.5	137	1.3	2.1	5.8	2.3
7	28	27.4	15.8	70.2	2.0	562	0.3	5.7	5.9	2.2
7	29	27.9	14.2	74.0	2.9	524	0	5.8	6.1	1.7
7	30	30.7	15.2	61.5	1.7	573	0	6.4	5.9	2.4
7	31	30.2	16.6	66.1	3.3	527	0	7.0	6.4	2.2
8	1	28.2	17.6	66.8	2.3	496	0	5.7	5.9	2.3

[a] The potential evapotranspiration was calculated using the modified Penman equation.
[b] Mean and standard deviation values of potential evapotranspiration based on 22 years of weather data recorded at the site.
[c] Application time AT1 began on 2 July.
[d] Application time AT2 began on 24 July.

difference in all treatments compared to the control treatment. Corn and soybean plant height and corn ear height were measured at the R5 stage on 26 August 2003.

Leaf area per plant was measured for AT1 and AT2 at the R5 stage in corn (beginning dent) and R5 soybean (beginning seed) using a LI3100 area meter (Li-Cor, Inc., Lincoln, Neb.) on four consecutive corn plants and 0.5 m of soybean row. Average leaf area per corn plant was multiplied by actual plant population and divided by 1 ha area to determine the leaf area index (LAI). Soybean leaf area was converted to LAI dividing the m^2 of leaf area by the sample land area (0.375 m^2).

Whole-plant samples were taken from 1 m of row from soybean at R6 on 19 September 2003 and weighed to determine biomass yield. A subsample of five plants was ground, from which a smaller subsample was taken, weighed wet, dried at 60°C, and weighed dry. The full soybean sample weight was then adjusted to 0% moisture. Soybean grain was harvested from 12.2 m of row on 17 October 2003 (Hege 125 plot combine, Colwich, Kansas), grain moisture was taken (model GAC2000 grain analysis computer, Dickey-John Corp., Auburn, Ill.), and yield was determined at 13.5% moisture.

Six corn plants were taken at random from each plot at R9 on 22 September 2003. Ears were removed, weighed, and dried separately. Corn stalks were weighed fresh and chopped, and a subsample was weighed wet, dried to constant weight, and reweighed. Dry weight reported is for whole plants without ears, husks, and cobs. Ears were harvested on 23 October 2003 from two 6.1 m rows and shelled in the field. Grain moisture was determined with the Dickey-John grain analysis computer, and grain yield was adjusted to 15.5% water content.

Statistical analysis was performed using SAS Proc Mixed (Littell et al., 1966). Replication was a random effect, and rate and timing of application were fixed effects. Type 3 tests were used for main effect and interactions. Simple effects (comparison of subplots within different whole plots) were used to compare the two times of applications within each concentration. Comparisons were considered significant at the 0.05 level.

Safety Issues

Working with and around manure can pose risk of contamination by microbes, odor, and particulates. Use of the equipment for transferring manure also has risks. Potential contamination of technical staff was minimized by supplying safety clothes including gloves, rain suits, hats, eye protection, suitable masks, and rubber boots. In order to use our LMAS, the manure had to be strained to remove large particles. In production systems, this process would be more automated, and workers would not need to have direct contact with liquid manure.

Results

Characteristics of Liquid Manure

The distribution of EC and NH_4-N concentration for samples obtained from a commercial laboratory are presented in figure 2. The EC and ammonium concentration of the 2728 liquid manure samples ranged from 0.1 to 70 dS m^{-1} and from 0.03 to 12646 mg NH_4-N kg^{-1}, with median values of 6.7 dS m^{-1} and 497 mg NH_4-N kg^{-1}, respectively (figs. 2a and 2b). The EC was less than 5 dS m^{-1} for 37% of the samples but above 15 dS m^{-1} for 15% of the samples (fig. 2a).These results indicate that the liquid manure and the dilutions used in this study are within the range of manure found in commercial livestock systems in Nebraska.

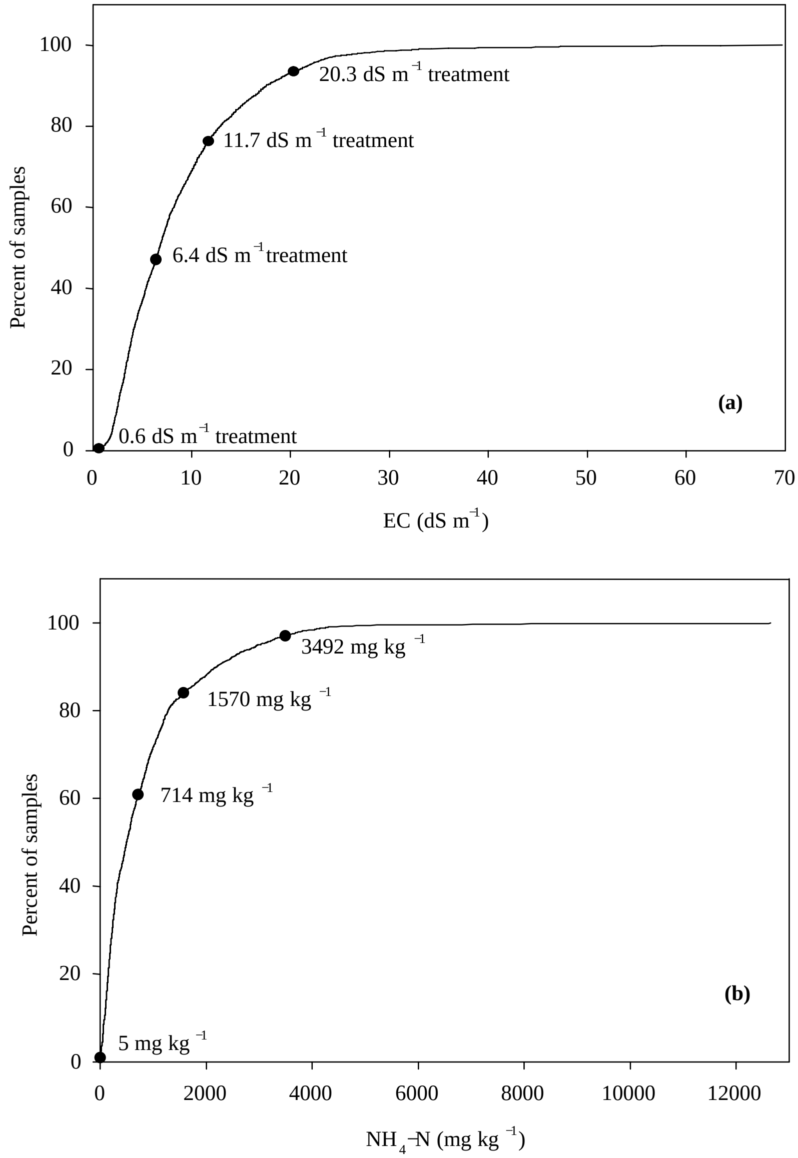

Figure 2. Cumulative distribution of electrical conductivity (a) and corresponding NH_4-N content (b) of liquid manure submitted for analysis to a commercial laboratory in Nebraska. The concentrations used in this study are also presented.

MANURE APPLICATION

The EC levels of the manure dilutions were 6.4, 11.7, and 20.3 dS m^{-1}, while the no-manure (control) treatment was 0.6 dS m^{-1}. Significant amounts of N, P, K, S, and soluble salts were applied with a liquid manure application of 12 mm, especially with the most concentrated treatment (table 1). The soil pH did not change in the 0 to 50 mm depth at seven days after application for any treatment. However, nitrate-N, Mehlich-III P, and NH_4-N increased due to liquid manure application. Soil NH_4-N was 5, 59, and 166 mg kg^{-1} for the manure EC levels of 6.4, 11.7, and 20.3 dS m^{-1}, respectively (data not shown).

SOYBEAN

Necrosis was most severe with the 28 July evaluation at four days after manure application at stage R1 (AT2) when 74% and 16% of the leaf area was necrotic in the 20.3 and 11.7 dS m^{-1} treatments, respectively (table 3). No leaf necrosis was noted for plants treated with the more dilute solutions. Due to continued leaf growth and new leaves "hiding" older and burnt leaves, the ratings on August 6 showed less damage than on 28 July. Despite severe necrosis following the R1 application, plants recovered and only 8% of the plants died with the 20.3 dS m^{-1} treatment (table 3). Stunting of plants on 6 August and the number of dead plants on 26 August followed similar trends, with 34% and 88% dead plants for the manure application at the V3 stage (AT1) with 11.7 and 20.3 dS m^{-1}, respectively. For the V3 application, plant height was reduced 82% and 31% with the 20.3 and 11.7 dS m^{-1} treatments, respectively. Plant height was reduced by 83% and 35% for the 20.3 dS m^{-1} application at the V3 and R1 stages, respectively.

Soybean plant population at harvest was less with the V3 application of 20.3 dS m^{-1} liquid manure than with the 0.6, 6.4, or 11.7 dS m^{-1} treatments, but the R1 application did not affect plant population (table 4). Leaf area per plant was greater with the V3 application than with the R1 application due to more time for the plants to recover following the V3 application and less inter-plant competition due to reduced

Table 3. Effects of liquid manure application timing on plant damage ratings, and plant height of soybean during the 2003 growing season.

	EC Level (dS m^{-1})			
	0.6	6.4	11.7	20.3
28 July, leaf necrosis[a] (% plant damage)				
V3 application[b]	NA	NA	NA	NA
R1 (V7) application[c]	0	1	16	74
6 August, leaf necrosis (% plant damage)				
V3 application	0	0	0	0
R1 (V7) application	0	0	10	58[d]
6 August, stunting of plants[e] (% plant damage)				
V3 application	0	10	43	88
R1 (V7) application	0	0	8	29
26 August, dead plants (% plant damage)				
V3 application	0	0	34	88
R1 (V7) application	0	0	3	8
Plant height at maturity[f] (m)				
V3 application	0.94	0.89	0.66	0.16
R1 (V7) application	0.91	0.88	0.73	0.59

[a] Percent of leaf material still on the plant that appeared brown versus green.
[b] V3 and R1 indicate the different application times and are comparable to AT1 and AT2 in the text.
[c] R1 was the stage of growth, but V7 indicates that seven trifoliates were on the plant at application.
[d] At this rating stage, new growth had replaced some past necrotic areas.
[e] Percent reduction in plant height compared to the control.
[f] Plant height recorded using a graduated rod.

population with the V3 application. The greater leaf area per plant with the V3 application compared to the R1 application compensated for the greater plant death with V3, so that LAI was similar for the two application times.

Leaf area per plant was decreased by the 20.3 dS m^{-1} liquid manure for both application times and by the 11.7 dS m^{-1} liquid manure for the R1 application (table 4). When compared to the control, LAI was reduced in the 11.7 and 20.3 dS m^{-1} treatments for the V3 and R1 applications.

Dry matter and grain yield were reduced with the 20.3 dS m^{-1} manure treatment for both applications as compared to the treatments with lower salt concentration. When averaged over both application timings, grain yields were the same for the 0.6, 6.4, and 11.7 dS m^{-1} manure applications, averaging 2.88 Mg ha^{-1}, as compared to 1.00 Mg ha^{-1} for the 20.3 dS m^{-1} application. Soybean with the 20.3 dS m^{-1} application at R1 had much higher dry matter (4389 kg ha^{-1}) and grain yield (1.64 Mg ha^{-1}) than with the 20.3 dS m^{-1} application at V3 (1202 kg ha^{-1} and 0.34 Mg ha^{-1}, respectively).

Corn

Corn growth was less affected than soybean, and damage was detected only with the V8 application (AT1) of 20.3 dS m^{-1} concentration (table 5). The V14 application (AT2) caused even less damage, likely due to salt tolerance of the fully developed cuticle on the corn leaves (table 5). The V8 application of 20.3 dS m^{-1} concentration caused some stunting of plants but no plant death. Ear height and plant height were shorter at maturity for the 20.3 dS m^{-1} treatment compared to the more dilute treatments.

Final plant population and leaf area per plant were not affected by liquid manure application (table 6), except for a significant unexplained interaction with the 11.7 dS m^{-1} concentration due to the V8 stage having the lowest average population and the V14 stage having the greatest average population. Dry matter yield, without the ear, was less with liquid manure of 20.3 dS m^{-1} concentration for both application times. Yield was reduced with the 20.3 dS m^{-1} concentration only with the V8 application. Dry matter yield was greater for the intermediate concentrations, and grain

Table 4. Effects of EC level of liquid manure and application time on soybean plant populations, leaf area, dry matter production, and grain yield for the 2003 growing season.

	EC Level (dS m^{-1})				Analysis of Variance[a] (P > F)		
	0.6	6.4	11.7	20.3	Time	EC Level	T × R[b]
Harvest population (plants ha^{-1})							
V3[c]	231686	253669	227240	60021	0.001*	0.003*	0.26
R1 (V7)[c]	249223	262314	253669	257868			
P > F	0.67	0.82	0.55	<0.0001*			
Leaf area (cm^2 $plant^{-1}$)							
V3	1639	1670	1578	583	0.05*	0.002*	0.57
R1 (V7)	1401	1354	881	508			
P > F	0.46	0.34	0.04*	0.82			
LAI							
V3	4.6	4.5	2.2	0.3	0.85	0.0001*	0.03*
R1 (V7)	3.5	4.1	2.5	1.5			
P > F	0.06	0.46	0.48	0.03*			
Whole-plant dry matter at physiological maturity (kg ha^{-1})							
V3	8361	8862	8303	1202	0.52	< 0.0001*	0.07
R1 (V7)	7590	8308	7908	4389			
P > F	0.50	0.63	0.73	0.01*			
Grain yield (Mg ha^{-1})							
V3	3.07	2.76	2.86	0.34	0.12	< 0.0001*	0.02*
R1 (V7)	2.96	2.92	2.66	1.64			
P > F	0.57	0.40	0.32	<0.0001*			

[a] Statistical significance of ANOVA main effects are given by the probability of the F-test (α = 0.05); significant differences are indicated by *.
[b] T × R is the timing × rate interaction.
[c] V3 and V7 are leaf stage at the time of application. R1 is the stage of growth, but V7 indicates that seven trifoliates were on the plant at the time of application.

Table 5. Effects of liquid manure application timing on plant damage ratings, ear height, and plant height of corn during the 2003 growing season.

	EC Level (dS m^{-1})			
	0.6	6.4	11.7	20.3
28 July, leaf necrosis (% plant damage)				
V8[a] application	NA	NA	NA	NA
V14[a] application	0	0	0	4[b]
6 August, leaf necrosis (% plant damage)				
V8 application	0	0	0	9
V14 application	0	0	0	1
6 August, stunting of plants (% plant damage)				
V8 application	0	0	2	18[c]
V14 application	0	0	0	0
26 August, dead plants (% plant damage)				
V8 application	0	0	0	0
V14 application	0	0	0	0
Plant height at R5[d] (m)				
V8 application	2.43	2.50	2.36	2.16
V14 application	2.46	2.47	2.50	2.38
Ear height at R5 (m)				
V8 application	0.83	0.85	0.80	0.69
V14 application	0.88	0.84	0.90	0.88

[a] V8 and V14 indicate stage of growth for different application times and are comparable to AT1 and AT2 in the text.
[b] Percent of leaf material still on the plant that appeared brown versus green.
[c] Percent reduction in plant height compared to the control.
[d] Plant height recorded using a graduated rod.

yield was greater for all liquid manures, as compared to the fresh water control (0.6 dS m^{-1} concentration) for the V14 application. Overall, the manure increased the corn yields when applied at V14 (11.2 Mg ha^{-1}) compared to V8 (10.4 Mg ha^{-1}).

Discussion

Soybean was more sensitive than corn to soluble salts in liquid manure. The V3 application of liquid manure at 20.3 dS m^{-1} to soybean caused plant damage and death, and decreased yields significantly. Application of liquid manure at approximately 11.7 dS m^{-1} at the V3 stage caused initial plant damage and reduced height and LAI; however, the vegetative growth recovered, and yield was statistically the same as with the 0.6 dS m^{-1} control. The soybean response to liquid manure application was consistent with the soybean response to hail damage because defoliation before reproductive stages does not affect soybean yield if there is no loss of nodes (Shapiro et al., 1985). Application of liquid manure with EC of 6.4 dS m^{-1} did not result in soybean plant damage or yield loss.

Application of 20.3 dS m^{-1} liquid manure to soybean at the R1 stage caused yield reduction but less reduction than with the V3 application. Soybean yields with the 11.7 dS m^{-1} liquid manure were not significantly lower than with the 0.6 dS m^{-1} control, but application of 11.7 dS m^{-1} liquid manure has potential for damage since plants were stunted and killed when liquid manure was applied at V3. The results indicate a plant damage threshold of 6.4 dS m^{-1} for liquid manure applied to soybean at all growth stages, but higher concentrations, possibly to 11.7 dS m^{-1}, can be applied beyond the V3 or V4 stage. These results support mixing manure from concentrated storage facilities with fresh water at a ratio of 1:3 or 1:4 to dilute the salt concentration safely below 11.7 dS m^{-1}.

Corn was more tolerant than soybean of soluble salts in applied liquid manure. The early application at V8 reduced yield with liquid manure of 11.7 dS m^{-1}; however, population was not reduced, and leaf area was only marginally reduced with application of the 20.3 dS m^{-1} liquid manure. When applied at the V14 stage, all liquid manure treatments had higher yield levels than the 0.6 dS m^{-1} control treatment. While excessive inorganic fertilizer N was applied and soil availability of other nutrients was found to be very high,

Table 6. Effects of EC level of liquid manure and application time on corn plant populations, leaf area, dry matter production and grain yield for the 2003 growing season.

	EC Level (dS m^{-1})				Analysis of Variance[a] (P > F)		
	0.6	6.4	11.7	20.3	Time	EC Level	T × R[b]
Plant population at physiological maturity (plants ha^{-1})							
V8[c]	58099	59534	54874	60969	0.12	0.11	0.04*
V14[c]	55590	62763	63121	60253			
P > F	0.33	0.22	0.005*	0.78			
Leaf area (cm^2 plant^{-1})							
V8	5161	5211	5149	4428	0.09	0.41	0.17
V14	4899	5667	5326	5543			
P > F	0.53	0.29	0.67	0.02*			
Whole plant without ear, husks, cob. Dry matter at physiological maturity (kg ha^{-1})							
V8	7844	8757	7728	6494	0.15	0.04*	0.35
V14	7740	8593	8919	7718			
P > F	0.89	0.82	0.11	0.11			
Grain yield (Mg ha^{-1})							
V8	10.99	11.41	9.67	9.36	0.02*	0.08	0.02*
V14	10.28	11.71	11.28	11.61			
P > F	0.28	0.65	0.02*	0.003*			

[a] Statistical significance of ANOVA main effects are given by the probability of the F-test (α = 0.05); Significant differences are indicated by *.
[b] T × R is the Timing × Rate interaction.
[c] V8 and V14 are leaf stage at the time of application.

increased availability of several nutrients with liquid manure application during times of rapid crop growth may have contributed to the increased yield. These data indicate that high rates of swine manure at high EC values can be applied to corn at the V14 stage. Yield losses from liquid manure applied at the V8 stage indicate that liquid manures less than 6.4 dS m^{-1} can be safely applied at this stage, but liquid manures more than 11.7 dS m^{-1}, and maybe higher, may be safely applied at the V14 stage.

Weather conditions following liquid manure application may be important to crop tolerance. Crop damage is expected to be more severe under dry, hot, and windy conditions (Nielson and Cannon, 1975; Maas et al., 1982) with more foliar absorption of salts at higher temperatures (Busch and Turner, 1967). Although this study was conducted during one growing season, the weather conditions were within the range of most likely conditions for the AT1 application. During the week following AT1 (table 2), daily temperatures were not excessively hot, with maximum temperature of 33.7˚C and mean daily high and of 28.3˚C and 17.3˚C. Mean relative humidity was 76.6%, and mean wind speed was 4.7 m sec^{-1}. The evaporative demand provided by the PET, which combines the factors discussed above, suggests that the weather was well within the range recorded at the site over the previous 22 years (table 2).

Weather conditions following the AT2 application were more severe than normal. During the week following AT2, temperatures were similar to the AT1 period, mean relative humidity was less (68.5%), and mean wind speed was less (3.5 m sec^{-1}). The most important difference may have been for precipitation. Precipitation amounts on days 1, 2, and 3 following the AT1 application were 5.9, 5.5, and 27.8 mm, respectively, while only 1.3 mm fell on the third day following the AT2 application. Phytotoxic effects following AT1 might have been more severe if rainfall had not washed off the salt deposited on the leaves, as this salt may have been dissolved in dew and absorbed by the leaves (Maas, 1985). The lower wind speed following AT2 compared to AT1 may have been conducive to less damage. The overall evaporative demand provided by the PET (table 2) indicates that some days during and following AT2 were more stressful than recorded at the site for the previous 22 years. Thus, studies under more controlled temperature and relative humidity conditions may be warranted.

The liquid manure applications in this study were greater than typically applied by farmers in order to induce measurable damage. Application through a center pivot may keep the foliage wet and the salts soluble longer than the approximate 10 min in our study, especially near the center of the pivot circle. Our application rate was 12 mm ha^{-1} (0.5 in.), but some pivots can apply as little as 6.5 mm ha^{-1} (0.25 in. ac^{-1}), reducing the total amount of soluble salts applied and the potential for leaf damage.

The changing tolerance to liquid manure with vegetative growth stages needs to be better understood. Risk of crop damage may be reduced with lower application rates of liquid manure with high EC. The tolerance to salts in applied liquid manures needs to be determined for other crops. The effect of a “wash-off” application of clean water following liquid manure application should be investigated, as it may reduce damage by removing salts or increase damage by dissolving salts deposited on the leaf surface. Solar radiation, temperature, and humidity effects on phytotoxicity associated with liquid manure application need to be quantified. Phytotoxicity may be less with nighttime application, as foliar absorption of salts is less at night (Busch and Turner, 1967). Absorption of applied salts through the roots may be a factor, since soluble salt concentration of the soil solution in the surface 50 mm of soil would be increased, especially on sandy soils with depleted soil water.

Summary

Several conclusions can be drawn from this research. Producers can use inexpensive EC meters to estimate the potential for damage with liquid manure application. Application of liquid manure to corn and soybean through a sprinkler system is feasible with proper management. The results support the hypothesis that growth stage and liquid manure soluble salt concentration influence plant damage. When possible, based on the conditions of this study, liquid manure with EC levels greater than 6.4 dS m^{-1} should not be applied to soybean during early vegetative growth. Liquid manure with EC levels less than 11.7 dS m^{-1} can be applied to corn and to soybean after flowering. If the soybean plants are not defoliated as a result of liquid manure application, yield is not likely to be reduced. Crop tolerance to soluble salt application is greater during the reproductive growth stages of the season than during the early vegetative stages. Applications of liquid manures that keep the foliage wet for longer periods than used in this study should be done on an experimental basis to make sure phytotoxicity is not increased by increased wetting periods.

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ABBREVIATIONS

LMAS = liquid manure application system
EC = electrical conductivity
AT = application timing
PET = potential evapotranspiration
LAI = leaf area index