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Toxic Effects of Manure, Alfalfa, and Ammonia on Emergence and Growth of Cucumber Seedlings

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Abstract. **Chopped alfalfa *(Medicago sativa* L.), alfalfa hay extract, and ammonium hydroxide produced free ammonia in media and inhibited both germination and seedling growth of cucumber *(Cucumis sativus* L.). Toxic levels of ammonia were not produced by the quantities of manure added to the media. Alfalfa extract enhanced cucumber seedling growth in sand medium while inhibiting growth in sand-soil media. This difference is attributed to a reduced level of microbial activity in the sand. With higher levels of microbial activity, rapid decomposition of the extract may have resulted in a burst of ammonia evolution that proved damaging to cucumbers. The natural buffering capacity of the soil medium apparently mitigated the effects of the ammonia. Ammonium hydroxide, which did not depend on microbiological activity to release ammonia, proved lethal to cucumbers grown in sand. A diminished effect on growth was observed as the cation exchange capacity of the medium increased. Because high levels of alfalfa hay and ammonium hydroxide were required to produce toxic levels of ammonia in soil, it is unlikely that cucumbers would be harmed under normal field usage of alfalfa hay.**

Alfalfa is widely used in crop rotations because it reduces weed populations, penetrates the subsoil, and usually has a positive effect on succeeding crops. However, alfalfa inhibited cucumber germination in laboratory tests (Ells and McSay, 1983, 1991) and prevented the re-establishment of seeded alfalfa in alfalfa fields where dead areas had occurred (Miller, 1983). Alfalfa contains saponins (Megie et al., 1967; Miller, 1983) that inhibit cotton seed germination (Megie et al., 1967). Alfalfa also releases ammonia during decomposition in the soil (Megie et al., 1967), and ammonia can be phytotoxic to cucumbers (Shenk and Wehrmann, 1979; Smith, 1964). Animal manures, which produce ammonia upon decay, also have been associated with inhibition of seed germination (Wong et al., 1983). The concentration of free ammonia in the soil is influenced by soil pH (Cox and Seeley, 1984; Warrent, 1962) and soil cation exchange capacity (CEC) (Smith, 1964).

A series of three successive field tests were conducted to determine how cucumber seed planted in soil treated with manure, alfalfa residue, or ammonium hydroxide would perform. Laboratory studies (Ells and McSay, 1983, 1991) demonstrated an inhibition of cucumber germination and growth when alfalfa residue was incorporated into the soil. Therefore, we were interested in determining whether this effect occurred in the field.

A preliminary experiment involved rototilling cattle manure and alfalfa hay into field plots. Neither manure nor alfalfa increased the levels of ammonia in the soil nor caused any inhibition of cucumber growth with rates of manure up to 100 $t \cdot ha^{-1}$ and alfalfa hay up to 50 $t \cdot ha^{-1}$ (data not presented). These results indicated that there was little danger of producing inhibitory levels of ammonia in clay loam soils by incorporating common amounts of manure or alfalfa into the soil. However, it remained to be determined whether higher levels of alfalfa or manure would generate inhibitory levels of ammonia and if soil type would affect the results.

We used 1.4-liter pots (130-mm top diameter) that were sunk to the brim into the field to accommodate large quantities of amendments and several sand–soil mixtures. Media were made by mixing air-dried builder's sand with air-dried soil from the Colorado State Univ. Horticulture Research Center. The soil was a Nunn clay loam (Aridic Argiustoll) with 30% clay, 7.75 pH, and a CEC of 48.81 meq/100 g. The CEC test was performed on 100 g of dried soil by charging all exchange sites with Na^+, then removing and measuring the Na^+ according to Page et al. (1982). Sand–soil mixtures (w/w) of 1:0, 2:1, 1:2, and 0:1 were prepared and found to have CEC values of 1.68,"8.25, 34.89, and 48.81, respectively.

These media were amended using the relationship that 0.022 $g \cdot kg^{-1}$ of an applied substance (dry-weight basis) is equal to 1 $t \cdot ha^{-1}$ on a dry-weight basis. Therefore, 1.1 $g \cdot kg^{-1}$ was used to stimulate 50 $t \cdot ha^{-1}$, and 2.2 $g \cdot kg^{-1}$ was used to simulate 100 $t \cdot ha^{-1}$, on a dry-weight basis. The amendments used were cattle manure (57.3% moisture) from a feed lot and chopped alfalfa hay (<25-mm pieces, 14.7% moisture). These were added to sand (0.5% moisture) and soil (6.1% moisture) mixtures to provide media with manure or alfalfa hay at 50 and 100 $t \cdot ha^{-1}$.

We also used ammonium hydroxide (28% NH_3) and an extract of alfalfa hay. The ammonium hydroxide stock solution was applied at 2.5, 5.0, and 7.5 $ml \cdot kg^{-1}$ of soil to attain simulated treatments of 50, 100, and 200 kg N/ha. The alfalfa extracts for 100 and 300 t alfalfa hay/ha were obtained by soaking 2.2 g and 6.6 g of alfalfa hay overnight for every kilogram of medium to be treated. In the morning, the extract was squeezed out of the hay and applied to the media.

The media mixtures were used to fill four 1.4-liter steel containers per treatment. Five 'Triple Mech' cucumber seeds were planted in each container, watered, and taken to the field. A randomized complete block design was used, with each replication being a row of containers. These containers were sunken in soil 15 cm apart in rows 1 m apart. A garden sprinkler was then used for irrigation. Soil cores (25 × 150 mm) were taken from each pot for ammonia and pH analysis twice during the experiment. The cores for the four replications were composite and a single analysis was made for each treatment. The tallest seedling in each pot was measured from the soil surface to the growing tip, then the plants were thinned to a single one. Two weeks later, the remaining plant was measured and the experiment was terminated.

The soil samples were extracted with 2 M KCl according to Page et al. (1982). The total concentration of ammonia solution species (NH_4^+ + NH3) was determined using flow injection analysis (Lachat, 1986; Ranger, 1988). The concentration of dissolved ammonia (NH_3) was calculated according to Lindsay (1979).

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Table 1. Cucumber seed germination and seedling growth as influenced by levels of manure, alfalfa hay, NH_4OH, and the CEC of the growing medium.[z]

Treatment	Rate/ha	NH_3-N (ppm)[y]		pH		Seedling ht (mm)	
		3 days[x]	10 days	3 days	10 days	10 days	21 days
		Effect due to treatment					
Manure (t)	100	0.6 b[w]	0.5 c	8.2 a	8.3 a	68 a	103 a
	200	0.5 b	0.6 c	8.2 a	8.3 a	60 b	98 ab
Alfalfa (t)	50	6.3 ab	7.6 b	8.1 a	8.1 a	5 d	8 c
	100	10.3 a	15.5 a	8.0 a	8.1 a	3 d	8 c
NH_4OH (kg N)	50	1.2 b	0.7 bc	8.1 a	8.1 a	60 b	98 ab
	100	1.7 b	0.5 c	8.1 a	8.1 a	53 c	93 ab
	200	3.6 b	1.0 bc	8.2 a	8.2 a	50 c	90 b
Control		0.5 b	0.3 c	8.0 a	8.0 a	55 c	90 b
		Effect due to medium					
Sand : soil medium (ratio)	CEC[v]						
1:0	1.7	1.0 a[u]	1.9 a	8.5 a	8.5 a	33 b	53 c
2:1	8.3	4.3 a	5.0 a	8.2 b	8.3 a	48 a	70 b
1:2	34.9	3.6 a	3.3 a	7.9 c	8.0 b	50 a	83 a
0:1	48.8	3.4 a	3.0 a	7.8 c	7.8 b	48 a	85 a
Treatment × media interaction						**	**

[z]Value in a column followed by different letters are different at $P = 0.05$.

[y]Calculated ammonia N based on $NH_3 + H^+ = NH_4 \frac{\log K^o}{9.28}$.

[x]Days after planting.

[w]Data are means of four media and four replications.

[v]CEC = cation exchange capacity, meq/100 g.

[u]Data are means of eight treatments and four replications.

**Significant at $P = 0.01$.

Table 2. Cucumber seedling height (mm) as influenced by media × treatment of Table 1.

Sand : soil ratio	CEC[y]	Seedling ht (mm)[z]							
		Manure ($t \cdot ha^{-1}$)		Alfalfa ($t \cdot ha^{-1}$)		NH_4OH (kg N/ha)			
		100	200	50	100	50	100	200	Control
		10 Days after planting							
1:0	1.7	58 b	52 b	13 a	13 a	40 c	25 b	25 b	38 b
2:1	8.3	77 a	63 ab	3 a	0 a	58 b	58 a	58 c	59 a
1:2	34.9	73 ab	69 a	0 a	0 a	70 a	63 a	56 a	61 a
0:1	48.8	59 b	58 ab	0 a	0 a	69 a	67 a	55 a	59 a
		21 Days after planting							
1:0	1.7	78 b	83 b	28 a	25 a	59 c	41 b	56 c	58 c
2:1	8.3	102 a	97 ab	0 b	0 a	95 b	94 a	86 b	91 b
1:2	34.9	116 a	111 a	0 b	0 a	111 ab	116 a	105 a	106 a
0:1	48.8	109 a	97 ab	0 b	0 a	122 a	114 a	109 a	100 ab

[z]Mean separation in columns at $P = 0.05$.

[y]CEC = cation exchange capacity, meq/100 g.

Response to low levels of soil ammonia (Expt. 1). A factorial design used four sand-soil media, eight ammonia treatments, and four replications. The treatments consisted of manure at 100 and 200 $t \cdot ha^{-1}$; chopped alfalfa at 50 and 100 $t \cdot ha^{-1}$; ammonia hydroxide at 50, 100, and 200 kg N/ha; and a control for each medium.

Relative to the control, manure at 100 $t \cdot ha^{-1}$ increased plant height. Alfalfa at 50 and 100 $t \cdot ha^{-1}$ greatly reduced plant height. Alfalfa at 100 $t \cdot ha^{-1}$ elevated the level of ammonia in the soil both 3 and 10 days after planting. This rise was associated with a reduction in seedling height at both 10 and 21 days after planting. Ammonium hydroxide treatments had no effect on ammonia level, pH, or seedling height (Table 1).

A pH increase was detected in the sand medium (1:0) 3 and 10 days after planting. This increase was associated with a reduction in seedling height after 10 and 21 days (Table 1). The low CEC may have permitted the pH to increase in the sand, while the greater CEC of the soil may have kept the pH relatively stable (Smith, 1964).

The treatment × media interaction was highly significant for cucumber seedling height at 10 and 21 days after planting (Table 2). After 10 days, sand generally proved to be the poorest medium for growing cucumbers. Cucumber seedlings in control and all the ammonium treatments performed worse in sand (1:0) than in the other media. After 21 days, sand was still the poorest medium for the ammonium treatment and the control, but the best treatment for alfalfa at 50 $t \cdot ha^{-1}$ (Table 2). Since sand also had the lowest CEC and the highest pH after 3 days (Table 1), we hypothesize that ammonia, CEC, and pH combined to produce this poor performance in the following fashion: The concentration of ammonia in the soil depends on pH, since ammonia cannot exist at pH 7 or below. However, as the soil pH increases (as it did in the sand), the reaction $NH_3 + H^+ \rightleftharpoons NH_4^+$ shifts to the left, producing free ammonia in the soil. Ammonia above 10 ppm is phytotoxic to cotton (Megie et al., 1967). Cucumber seeds germinated in the sand medium amended with alfalfa. Germination was almost totally inhibited in a soil medium containing alfalfa. Since ammonia production from alfalfa hay depends on microbial activity, we suspect that sand had lower levels of biological activity and, therefore, did not generate the high levels of ammonia that would have inhibited cucumber germination.

Response to high levels of soil ammonia (Expt. 2). The factorial design for this ex-

Table 3. Cucumber seed germination and seedling growth as influenced by levels of alfalfa hay extract (alf. ext.), NH_4OH, and the CEC of the growing medium.[z]

Treatment	Rate/ha	NH_3-N (ppm)[y] 4 days[x]	NH_3-N (ppm)[y] 11 days	pH 4 days	pH 11 days	Seedling ht (mm) 7 days	Seedling ht (mm) 18 days
		Effect due to treatment					
Alfalfa extract (t)	100	2.1 b[w]	0.6 b	8.2 a	8.2 b	35 a	49 a
	300	3.3 b	5.5 b	8.2 a	8.4 a	15 c	32 b
NH_4OH (kg N)	200	2.6 b	0.5 b	8.0 a	8.1 b	30 a	51 a
	1000	19.4 b	5.2 b	8.2 a	8.1 b	10 cd	22 c
	2000	42.9 a	26.8 a	8.6 a	8.3 b	5 d	8 d
Control		0.9 b	0.4 b	7.9 a	8.1 b	23 b	47 a
		Effect due to medium					
Sand : soil medium (ratio)	CEC[v]						
1:0	1.7	3.8 a[u]	1.6 a	8.4 a	8.6 a	20 b	43 a
2:1	8.3	15.0 a	11.5 a	8.3 a	8.3 b	15 b	25 b
1:2	34.9	16.4 a	8.9 a	8.0 a	8.0 c	15 b	29 b
0:1	48.8	12.2 a	3.9 a	7.9 a	7.8 d	25 a	42 a
Treatment × media interaction						*	**

[z]Values in a column followed by different letters are different at $P = 0.05$.

[y]Calculated NH_3-N based on $NH_3 + H^+ = NH_4^+ \frac{\log K^o}{9.28}$.

[x]Days after planting.
[w]Each value is the mean of four media and four replications.
[v]CEC = cation exchange capacity, meq/100 g.
[u]Each value is the mean of eight treatments and four replications.
*,**Significant at $P = 0.05$ and 0.01, respectively.

Table 4. Cucumber seedling height (mm) as influenced by media and treatment of Table 3.[z]

Sand : soil medium	CEC	Alfalfa extract ($t \cdot ha^{-1}$) 100	Alfalfa extract ($t \cdot ha^{-1}$) 300	NH_4OH (kg N/ha) 200	NH_4OH (kg N/ha) 1000	NH_4OH (kg N/ha) 2000	Control
			7 Days after planting				
1:0	1.7	34 a	39 a	22 b	0 b	0 a	19 b
2:1	8.3	33 a	0 c	38 a	0 b	0 a	20 b
1:2	34.9	34 a	0 c	22 b	11 ab	0 a	19 b
0:1	48.8	36 a	16 b	34 a	21 a	14 a	31 a
			18 Days after planting				
1:0	1.7	80 a	80 a	58 a	0 b	0 b	40 b
2:1	8.3	41 b	10 c	47 bc	8 b	0 b	46 ab
1:2	34.9	44 b	4 c	44 c	38 a	0 b	45 ab
0:1	48.8	29 b	35 b	55 ab	40 a	33 a	57 a

[z]Values in columns followed by different letters are different at $P = 0.05$; each value is the mean of four replications.

periment employed four sand–soil media, six ammonia treatments, and four replications. Alfalfa extract treatments were used instead of chopped alfalfa hay, since the efficacy of chopped alfalfa had already been demonstrated (Expt. 1). Manure, as in Expt. 1, was not used because little ammonia was produced. Ammonium hydroxide concentrations were increased to 200, 1000, and 2000 kg N/ha to determine the threshold of ammonia inhibition.

The alfalfa extract at 100 $t \cdot ha^{-1}$ had increased seedling height after 7 days, whereas the 300-t rate had reduced seedling height at 7 and 18 days, relative to the control. Ammonium hydroxide at 200 kg N/ha had increased seedling height after 7 days, but 1000 kg N had reduced it at 7 and 18 days, and 2000 kg N had increased ammonia in the medium after 4 and 11 days and reduced seedling height at 7 and 18 days (Table 3).

The sand medium had a high pH after 11 days, and the soil medium had the tallest seedlings after 7 days. The interaction between treatment and media for seedling height was significant (Table 3).

After 7 days, the alfalfa extract at the 300-t rate produced cucumber seedlings of above average height on the sand medium while totally inhibiting germination on the sand–soil media and greatly reducing the height of seedlings on the soil medium. After 18 days, the alfalfa extract produced the tallest seedlings on the sand medium. All levels of ammonium hydroxide were detrimental to cucumbers planted in sand, and at 1000 and 2000 kg N/ha, were inhibitory to cucumbers planted on other media (Table 4).

Ammonium hydroxide at the 200-kg N rate had little effect on cucumber growth. However, at 1000 kg N, it inhibited cucumber germination on the sand medium, and at the 2000-kg N rate, it inhibited germination in all media, except the soil (Table 4).

Alfalfa extract is probably a very nutritious fertilizer, and when nutrients are released by slow decay, as apparently was the case in the sand medium, the cucumber seedlings responded with increased growth. However, when decay is so rapid that a burst of ammonia is released, the alfalfa extract could then become toxic to cucumbers if the medium did not have a CEC great enough to keep the pH from temporarily rising. This appeared to have been the case with the soil medium (0: 1), where total inhibition was averted but seedling height was reduced. Ammonium hydroxide, which does not depend on decay for ammonia release, was most devastating on cucumber seedlings grown in sand where there was little buffering capacity to keep the pH from rising (Table 4).

The fact that seedlings belatedly appeared after 18 days in sand-soil media treated with either alfalfa extract or ammonium hydroxide indicates that ammonia can inhibit germination without killing the seed and that germination can occur when ammonia has dissipated (Table 4).

We hypothesize that inhibition was due to ammonia in both the alfalfa and NH_4OH treatments and that the difference in reaction was due to the low level of microbial activity in the sand medium.

We, therefore, have concluded that ammonia can be generated by incorporating alfalfa into soil and that, in excess, ammonia is toxic to cucumbers. However, it appears that neither manure, alfalfa, nor anhydrous ammonia, used at the proper rates, pose any danger to a crop of field cucumbers.

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