Northern NY Agricultural Development Program
2005-2006 Project Report

The effect of $CuSO_4$ from dairy manure on the growth, and composition of cool season forage grasses and corn

Project Leaders:

S. A. Flis — William H. Miner Agricultural Research Institute
E. D. Thomas — P.O. Box 90
C. S. Ballard — Chazy, NY 12921
H. M. Dann — 518-846-7121
K. W. Cotanch

Introduction

The use of copper sulfate ($CuSO_4$) in footbaths as a preventative maintenance for foot health has been a common practice on dairy farms for the last 10 years. In general the waste material from footbaths ends up in the manure storage system and is then applied to fields. At Miner Institute, before $CuSO_4$ footbaths were employed, the manure slurry concentration of Cu was 4.8 g/1000 L. After $CuSO_4$ footbath use, the concentration of Cu reached a high of 88.6 g/1000 L in 2000. Records for manure analysis and application rates for Miner Institute over the last 10 years show single year application rates of Cu as high as 31.7 kg/ha, with 18% of annual applications of liquid manure above 4.54 kg Cu /ha. Spreading of manure slurry with high Cu concentrations may adversely impact crop growth and quality. Additionally, crop removal of Cu is less then 0.1 kg/ha. In 2001 on average 1.93 ± 1.28 kg Cu/ha was imported on to farms surveyed in Vermont and New York (Flis *et al*., 2006). This decreased to 1.35 ± 0.75 kg Cu/ha in 2004 (Flis *et al*., 2006). For these farms the concentration of Cu (ppm) was higher in 2001 than in 2004 for both corn silage (P = 0.04) and haylage (P = 0.009, Table 1, Flis *et al*., 2006). Copper is not highly mobile in plants and toxicity affects root growth first, resulting in decreased root growth. Finally, when this excess Cu is applied to the soil it binds tightly to negatively charged soil particles, resulting in accumulation of Cu in the soil.

Therefore, the objectives of this study were to determine:

1. the effects of rate of application of copper sulfate from dairy manure on the establishment, growth, and quality of cool season forage grasses and corn
2. the fate of Cu applied from dairy manure containing copper sulfate in the soil.

Table 1. Copper tissue concentration from surveyed farms for 2001 and 2004.

	Cu concentration (ppm)			
Forage	**2001**	**Standard Deviation**	**2004**	**Standard Deviation**
Corn Silage	11.97	6.94	6.56	2.24
Haylage	21.17	9.48	9.17	7.62

Materials and Methods – Greenhouse Grass

Soil

Bulk soils were collected by removing the top 15 cm of soil from the edges of fields with Trout River gravelly loamy sand (**sand**) and Roundabout silt loam (**silt**) as the soil types. The Trout River series is very deep, somewhat excessively well-drained soil formed in water-sorted deposits (USDA-NRCS). The Roundabout series is very deep, and somewhat poorly drained soils that formed in glaciolacustrine and glaciomarine deposits on lake or marine plains (USDA-NRCS). The total volume of soil collected was 0.42 m^3 for each type. After collection soil was dried at 105°C for 24 h and sifted to remove large rocks and debris. Pre-trial soil analysis was done at the UVM Agriculture and Environmental Testing Labs (Burlington, VT) on a dried soil sample. Soil was stored dry until potted.

Species

Three cool season forage grasses were used; orchardgrass (*Dactylis glomerata* L.), timothy (*Phleum pretense* L.), and reed canarygrass (*Phalaris arundinacea* L.). The seeding rate used was 9, 6, and 10 lbs/acre (10, 6.7, and 11.2 kg/ha) for the orchardgrass, timothy, and reed canarygrass, respectively. After adjusting the seeding rates for the purity and germination, the seeding rate per pot was determined to be 0.037, 0.022, and 0.039 g/pot for the orchardgrass, timothy, and reed canarygrass, respectively. These seeding rates result in 35, 54, and 33 seeds per pot for the orchardgrass, timothy, and reed canarygrass, respectively.

Treatments

For the 2 soil types there were 3 treatment levels with 6 replications for each of the 3 cultivars for a total of 108 pots. Treatments were 0 (**Control**), 5.61 (**Medium**), and 11.22 (**High**) kg of Cu/ha from $CuSO_4$. Soil was mixed by cultivar by treatment. Manure was added to treatments based on P requirement for establishment of a grass based on the soil test available P.

Manure

Manure was colleted 1-week prior to mixing with soil and the treatment level of $CuSO_4$ was added. Copper sulfate was mixed with water at the same rate as used in the Miner Institute Dairy Barn footbaths (25 lbs $CuSO_4$ / 45 gallons water) and mixed with manure. After 1-week manure mixes were sampled and analyzed at the UVM Agriculture and Environmental Testing Labs (Burlington, VT).

Pots

Soil and manure were mixed and transported to the greenhouse at Plattsburgh State University (Plattsburgh, NY). Pots were filled with 0.005 m^3 of the correct mixture. Seeding was done in the greenhouse and seeds were covered with 0.64 cm of the soil mixture and watered.

Watering, Temperature and Lighting

Pots received water twice daily as needed. Temperature was maintained above 13°C. Lighting was provided for a 12 h photoperiod. Due to differences in light intensity and temperature in the greenhouse, pots were rotated once a week.

Monitoring and Harvesting
Percent germination of the pots was measured for two consecutive weeks after seedlings emerged. Growth was measured once weekly for each pot and recorded. Shoots were harvested when one treatment for that species and soil type reached 40.6 cm of growth or at least 7 weeks of growth after planting. Grasses were cut to leave 5.1 cm of stubble for re-growth and were allowed to re-grow until one treatment reached 40.6 cm at which time the entire plant was harvested and the number of days after planting and height of each treatment was recorded. Roots were washed to remove soil, weighed, and dried at 55°C for 24 h to determine dry matter (**DM**) and mineral concentration. Shoots were harvested from each pot and dried at 55°C for 18-24 h to determine DM. Samples were ground to 2 mm and used to determine ash, crude protein (**CP**), neutral detergent fiber (**NDF**), acid detergent fiber (**ADF**), lignin (Miner Institute Forage Lab, Chazy, NY) and mineral analysis (UVM Agriculture and Environmental Testing labs, Burlington, VT). Soil tests were repeated at the end of the trial.

Statistical Analysis
Analysis was performed for a treatment effect, species effect, the treatment by species interaction, and the linear effect of Cu treatment level. Differences were significant at $P \leq 0.05$ and tendencies at $P \leq 0.15$.

Materials and Methods – Corn Plots

Location, Plot size, Treatments, and Corn Hybrids
Plots were located at The William H. Miner Agricultural Research Institute (Chazy, NY). Plots were 3.68 m (12', 4 rows of corn) wide and 7.62 m (25') long. Treatments were control, medium (8.1 lbs/acre or 9.12 kg/ha), and high (16.3 lbs/acre or 18.23 kg/ha). Additionally, the 3 treatment levels were tested on two corn hybrids, a short day corn (39D81 Pioneer Seeds, 84 DRM) and a long day corn (36M28 Pioneer Seeds, 103 DRM,). Each corn hybrid at each Cu level was replicated 4 times for a total of 24 plots.

Manure Collection, Application, and Planting
Approximately 105.9 L (28 gal) of manure was applied to each plot. Manure was hand applied and incorporated with a roto-tiller immediately following application. Corn was planted on May 9, 2006 in 72.6 cm (30") rows with plants within rows spaced at 17.15 cm (6.75"). At planting, 302.7 kg/ha (270 lbs/acre) of 14 – 21 – 21 + Zn was applied. Additionally, Force 3G (Syngenta) was applied for protection of early-season insect pests, including: corn rootworms, cutworms, wireworms, white grubs and seedcorn maggots. Approximately 45.7 cm 100 lbs/acre of N was also applied.

Measurement and Harvest – Soil
A soil sample was taken on the harvest day for analysis of total P, K, Mg, Al, Ca, Zn, Na, Fe, B, Mn, Cu, and S.

Corn
Number of plants per plot was counted at the V1 stage to determine the plant population per plot. Corn height was measured at 5 different stages (V3: 9- 12 days after emergence, V5: 14 to 21 days after emergence, V6: 21 to 25 days after emergence, V13: 42 to 49 days after emergence,

and R1 or silking: 63 to 68 days after emergence). At these times, days after planting, height, number of leaves, and stalk diameter were measured. Additionally, at R1, 4 plants were harvested from each plot in the center 2 rows. These plants were used for counts and measurements. At 1/3 milk line, 4 plants were harvested from each plot for dry matter determination. Corn was harvested at approximately 70 % moisture. At harvest, 10' (3.1 m) of length from the 2 center rows were hand harvested and weighed. From the plants harvested, 6 were chopped with a wood chipper and samples taken for chemical analysis of DM, NDF, ADF, lignin and CP (Miner Institute Forage Lab, Chazy, NY) and mineral analysis (UVM Agriculture and Environmental Testing labs, Burlington, VT).

Statistical Analysis

Analysis was performed for a treatment effect, hybrid effect, the treatment by hybrid interaction, and the linear effect of Cu treatment level. Differences were significant at $P \leq 0.05$ and tendencies at $P \leq 0.15$.

Results and Discussion

Greenhouse Grass

The method for seeding the pots resulted in poor germination and growth in the silt loam soil regardless of Cu treatment level. Based on this result, the silt loam treatments were repeated beginning in November of 2006. Additionally, the reed canarygrass grown in the sand soil was cut too short at the first harvest and did not re-grow for the second harvest. Therefore, results are the comparison of the orchard grass and the timothy grown in the sandy loam soil only.

Grass Growth Measurements and Counts

There were no species by treatment interactions for timothy and orchard grass for any growth measurements or counts. However, there were overall species differences. The timothy had significantly higher number of seedlings and number of shoots at first harvest (Table 2). This was likely due to more seeds planted for the timothy, due to seeding rate and seed weight differences for the species. At the second harvest the orchard grass had significantly more shoots, a higher tillering rate and shoot dry weight (Table 2). This influenced a higher re-growth rate (g/d) for the orchard grass (Table 2). However, there was not a significant difference in the shoot weight per plant or the root dry weight by species.

There was a tendency for a treatment effect on the number of seedlings and the number of shoots. Specifically, at first harvest the high Cu rate had the lowest number of seedlings and shoots (Table 3). A linear treatment effect was observed for harvest 2 number of shoots and the tillering rate from harvest 1 to harvest 2 (Table 3, Figure 1a). The linear effect suggests that there is a decrease in the number of shoots at second harvest and the tillering rate between harvests as the Cu treatment level increased. Additionally, there was a tendency for a treatment effect on the harvest 2 shoot dry weight, with the highest Cu concentration having the lowest yield (Table 3). There was also a tendency for a linear effect of Cu treatment level on the harvest 2 shoot dry weight ($P = 0.13$), with final shoot dry weight decreasing by 1.12 g from the control to the high treatment. The re-growth rate also tended to decrease as the Cu treatment level increased with a difference of 0.03 g/d from the control to the high treatment ($P = 0.12$) (Table 3). Finally, there was a significant linear treatment effect on root dry weight (Table 3). The linear effect suggests that there is a decrease in the root dry weight as the Cu treatment level increased (Figure 1b).

Quality and Mineral Measurement of Shoots and Roots

There were no species by treatment interactions for timothy and orchard grass for any quality or mineral measurement of the shoots and the roots. Again, there were overall species differences. The orchard grass had a significantly higher NDF (% DM), but significantly lower ADF and lignin (% DM) than in the timothy grass (Table 4). Orchard grass is generally higher in fiber concentration and intermediate to high in lignin concentration compared to other cool season forage grasses (Van Saten and Sleper, 1996). The differences observed here are likely due to differences in harvest date and plant maturity.

Calcium (% DM) and Cu (ppm) were both significantly lower in the orchard grass than in the timothy grass (Table 4). However, P, K, S, and Mg (% DM) were all significantly higher in the orchard grass than in the timothy grass (Table 4). In the roots, K and S (% DM) and Mn (ppm) were significantly higher in the orchard grass than the timothy (Table 5), this is the same as seen in the shoots, because all three minerals are mobile in the xylem of the plant. In the roots the Al concentration (ppm) was significantly higher in the timothy than the orchard grass, the same as in the shoots (Table 5). The concentrations of Ca and Mg (% DM) and Cu (ppm) were opposite of the differences in the concentrations of the shoots for the two species (Tables 4 and 5). The concentration of Mg and Cu was higher in the roots of the timothy than the roots of the orchard grass, while the concentration of Ca was higher in the orchard grass roots than the timothy roots.

There was a tendency for an effect of the treatment level of Cu on ADF and K (% DM) and Cu (ppm) in the shoots of the grasses (Table 6). However, the differences in ADF and K are likely not biologically significant. There was a tendency for a linear treatment effect of Cu on K (% DM, P = 0.11, (Table 6). The K concentration in the shoots increased as the Cu treatment level increased. Again, these are not likely to be biologically significant effects as the concentrations fall in the normal range for grass K concentration.

There was a tendency for a treatment effect of Cu level on the Cu concentration in the shoots (Table 6). This tendency is further explained by a significant linear effect of Cu treatment level on Cu concentration in the shoots, with Cu concentration in the shoots increasing as Cu treatment level increases (P =0.06). However, these concentrations are with in the normal range for crop plant Cu concentration (0 – 50 ppm, Epstein and Bloom, 2005).

There was a significant effect of Cu treatment level on the ash (% DM) in the roots, which is further explained by a liner effect of Cu treatment level on ash, % DM (P = 0.01, Table 7). The linear effect suggests that as Cu treatment level increases, ash concentration decreases. However, the only significant difference in mineral concentration in the roots was K (% DM, Table 6). There was a linear effect of Cu treatment level on K (% DM) of the roots (P = 0.04). The observed linear effect suggests that increasing Cu treatment level will increase the K concentration in the roots. This is the same as the linear effect in the shoots and occurs because of the high mobility of K in the xylem, phloem, and cytoplasm of plants (Epstein and Bloom, 2005).

In the roots, there was not a significant effect of Cu treatment level on Cu ppm. There was a numerical increase in the Cu concentration in the roots between treatment levels (Table 7). Overall, the Cu concentration in the shoots was lower than in the roots, 33.2 vs. 66.6 ppm, respectively. This is expected because Cu is a mineral that is generally sequestered in the roots. The shoot concentration of Cu was 32, 32, and 36 % of the whole plant concentration of Cu for the control, medium and high Cu treatment levels, respectively. This may indicate that as Cu availability in the soil increases, the root Cu concentration will only go so high before the excess Cu is moved up into the shoots.

Greenhouse Grass Conclusions

Tillering rate and re-growth rate both decreased as copper application level increased regardless of grass species. Additionally, there was a decreased shoot yield and dry root weight with increased copper application level. These effects may result in a decrease in the longevity of the stand and an overall decrease in yield. There may be concern for a larger decrease in re-growth rate and yield in drought conditions due to the decrease in root dry matter with increased Cu application rate. The Cu concentration of the shoots tended to increase in copper concentration with increased Cu application, however these values were still within expected range for crop plants. There was only a numerical increase in the Cu concentration in the roots with increased Cu application. Finally, as expected the Cu concentration was higher in the roots than in the shoots.

Corn Results – Plants

There was no effect of copper treatment level on plant number per plot, total harvest weight, number of plants harvested, or the weight per plant harvested (Table 8). Long-term studies with the application of high Cu swine manure have consistently reported no effect of the level of Cu application on corn grain or silage yields (Mullins et al., 1982; Sutton et al., 1983; Payne et al., 1988a; and Payne et al., 1988b). As expected there was a significant difference between the two hybrids for total harvest weight (42.0 and 51.3 for the short and long day hybrids, respectively $P = 0.0005$) and weight per plant (1.31 and 1.51 for the short and long day hybrids, respectively $P = 0.002$). There were no hybrid by treatment interactions; both hybrids responded the same to the copper treatments.

There was no effect of Cu treatment level on harvest DM (Table 9). Dry matter at harvest was significantly different between the two hybrids (34.1 and 38.7 for the short and long day hybrids, respectively $P < 0.0001$). Treatment also had no effect on NDF, ADF, lignin, or CP (% DM, Table 9). The two hybrids were significantly different in ADF (23.7 and 25.3 % DM for the short and long day hybrids, respectively $P = 0.003$) and lignin concentration (3.7 and 3.9 % DM for the short and long day hybrids, respectively $P = 0.02$). Additionally, there was a significant difference in CP (% DM) between the two hybrids (7.8 and 6.4 for the short and long day hybrids, respectively $P < 0.0001$).

There was a significant effect of Cu treatment on the boron concentration in the plant (Table 9). The boron concentration was significantly lower in medium treatment than in the high treatment, but not different from the low treatment. Additionally, there was a tendency for copper treatment to affect the aluminum concentration in the plant (Table 9) with the aluminum concentration significantly lower in medium than high treatment, but not different from the low treatment.

There was no effect of Cu treatment level on the Cu concentration of the plants and were within the normal range for crop plants (Table 9). Studies with long-term application of high Cu swine manure have consistently reported leaf or grain Cu concentrations that were not outside expected values (Mullins et al., 1982; Sutton et al., 1983; Payne et al., 1988a; and Payne et al., 1988b). Additionally, the corn plant Cu concentrations were much lower than the grass shoot Cu concentrations.

Corn Results- Soil Total Mineral Analysis

The total Ca concentration was significantly lower in the medium than the low and high copper treatments (Table 11). Additionally, the total P, Mg, and S concentration tended to be lower in the medium than the low and the high copper treatments (Table 11). There was a significant effect of copper treatment on total soil Cu concentration (Table 11). This effect is further explained by a significant linear effect of treatment on soil Cu concentration (Figure 2.). As expected the total soil Cu concentration increased as the copper treatment level increased. The difference in the Cu applied per acre and the difference of the soil test lbs/acre is approximately the removal of Cu in the shoots of the corn (3.7 and 1.9 lbs/acre removal from the soil for the medium and high Cu treatments, respectively, Tables 9 and 12). This indicates that the only loss of Cu from the soil is from plant removal and with one application at these rates there is no leaching of Cu. There were no significant hybrid by treatment interactions or hybrid effects on the soil mineral analysis.

Conclusions from Corn Plot study

From the results reported here it appears that one year of application of at least 16 lbs/acre of Cu from dairy manure is not a concern for growth, yield, or plant Cu concentration. Additionally, when soil was analyzed for total Cu concentration the only loss appears to be from plant removal.

Overall Conclusions and Further Research

A single high application of Cu appears to have greater effect on grass growth and yield than corn growth and yield. However, continued research is needed on the effect of multiple high application rates on corn since a single application of dairy manure to corn land is not a common practice.

Additionally, the method of soil analysis for Cu needs further examination. Differences in soil Cu concentration were observed in the corn soil samples when total mineral digestion was performed, but the typical test for soil is an extraction on available minerals which may not be showing the correct increases in soil Cu concentrations.

Education and Outreach Plan. Results of this research will be published in the monthly Miner Institute Farm Report, with readership of over 10,000. This newsletter is not copyrighted, and articles are often used by farm newspapers and county Cooperative Extension publications. Sally

Flis presented these results on December 20, 2006 at a producer meeting for Carovail, Inc. (Salem, NY).

References

Epstein and Bloom. Mineral Nutrition of Plants: Principles and Perspectives 2005. Sinauer Assoc.

Flis, S. A., C. S. Ballard, M. A. LeVitre, R. M. Conant, and E.D. Thomas. 2006. Changes in Copper Sulfate Use on Northeastern New York and Vermont Farms Between 2002 and 2005. Abstr. #T76. J. Dairy Sci. Suppl. 1 vol. 89.

Mullins, G. L., D. C. Martens, S. W. Gettier, and W. P. Miller. 1982. Form and availability of copper and zinc in a Rhodic Paleudult following long-term $CuSO_4$ and $ZnSO_4$ applications. J. Environ. Qual. 11(4):573-577.

Payne, G. G., D. C. Mertens, E. T. Kornegay, and M. D. Lindemann. 1988a. Availability and from of copper in three soils following eight annual applications of copper-enriched swine manure. J. Environ. Qual. 17(4):740-746.

Payne, G. G., D. C. Martens, C. Winarko, nad N. F. Perera. 1988b. Form and availability of copper and zinc following long-term copper sulfate and zinc sulfate applications. J. Environ. Qual. 17(4):707-711.

Sutton, A. L., D. W. Nelson, V. B. Mayrose, and D. T. Kelly. 1983. Effect of copper levels in swine manure on corn and soil. J. Environ Qual. 12(2):198-203.

Van Saten, E and D. A. Sleper. 1996. Orchardgrass. Cool-Season Forage Grasses. Agronomy. Monograph no. 34. American Society of Agronomy. Madison, WI.

Table 2. Growth measurements for Timothy and Orchard Grass grown in Trout River Gravelly Sandy Loam.

Item	**Timothy**	**Orchard Grass**	**SE**	***P*- value**
Number of seedlings	42.8	25.9	0.72	<0.01
Harvest 1 number of shoots	43.5	25.1	0.84	<0.01
Harvest 2 number of shoots	64.2	101.9	3.71	<0.01
Harvest 2 – Harvest 1 number of shoots	20.7	76.9	3.78	<0.01
Final shoot dry weight (g)	5.12	7.58	0.41	<0.01
Shoot weight per plant (g)	0.079	0.075	0.003	0.41
Re-growth rate (g/d)	0.14	0.20	0.01	<0.01
Root dry weight (g)	2.97	2.96	0.30	0.98

Table 3. Copper treatment effects on growth measurements.

	Copper Treatment Level				**Treatment**
Item	**Control**	**Medium**	**High**	**SE**	***P*-value**
Number of seedlings	34.5	35.8	32.8	0.87	0.08
Harvest 1 number of shoots	34.9	35.7	32.5	1.03	0.06
Harvest 2 number of shoots	87.6	90.3	71.3	4.55	0.01
Tillering rate from Harvest 1 to Harvest 2	52.7	54.7	39.1	4.63	0.05
Harvest 2 shoot dry weight (g)	6.57	7.04	5.45	0.50	0.09
Shoot weight per plant (g)	0.076	0.079	0.075	0.004	0.81
Re-growth rate (g/d)	0.18	0.19	0.15	0.013	0.08
Root dry weight (g)	3.25	3.44	2.19	0.37	0.05

Table 4. Shoot chemical and mineral analysis for Timothy and Orchard Grass grown in Trout River Gravelly Sandy Loam.

Item	Timothy	Orchard Grass	SE	*P*-value
NDF, % DM	45.9	48.2	0.50	<0.01
ADF, % DM	40.4	36.4	0.50	<0.01
Lignin, % DM	14.8	12.8	0.60	0.03
CP, % DM	21.3	21.4	0.80	0.90
Ca, % DM	0.81	0.65	0.02	<0.01
P, % DM	0.33	0.41	0.02	0.01
K, % DM	4.40	5.79	0.21	<0.01
Mg, % DM	0.33	0.40	0.01	<0.01
Na, % DM	0.022	0.024	0.002	0.48
Al, ppm	1264	996	134.6	0.17
Fe, ppm	1444	1100	140.8	0.10
Mn, ppm	396	699	24.9	<0.01
B, ppm	13.3	12.7	1.51	0.80
Cu, ppm	29.7	36.8	2.71	0.07
Zn, ppm	46.9	42.8	2.36	0.22
S, % DM	0.27	0.31	0.008	<0.01

Table 5. Root mineral concentration for Timothy and Orchard Grass grown in Trout River Gravelly Sandy Loam.

Item	Timothy	Orchard Grass	SE	*P*-value
Ash, % DM	15.8	20.2	1.50	0.05
Ca, % DM	0.42	0.50	0.01	<0.01
P, % DM	0.20	0.22	0.009	0.21
K, % DM	1.82	2.36	0.09	<0.01
Mg, % DM	0.25	0.18	0.006	<0.01
Na, % DM	0.09	0.15	0.008	<0.01
Al, ppm	3218	2397	229	0.02
Fe, ppm	4574	4292	447	0.66
Mn, ppm	1148	1479	85.8	0.01
B, ppm	21.9	25.2	1.94	0.25
Cu, ppm	71.6	61.5	4.34	0.11
Zn, ppm	77.0	104.5	8.91	0.04
S, % DM	0.19	0.21	0.009	0.10

Table 6. Shoot chemical and mineral analysis by copper treatment level for Timothy and Orchard Grass grown in Trout River Gravelly Sandy Loam.

	Copper Treatment Level				*P*-value
Item	**0**	**5**	**10**	**SE**	**Trt**
NDF, % DM	47.7	46.2	47.3	0.58	0.21
ADF, % DM	38.2	37.5	39.4	0.59	0.14
Lignin, % DM	13.1	13.5	14.8	0.67	0.29
CP, % DM	20.3	21.7	21.9	0.95	0.44
Ca, % DM	0.72	0.75	0.72	0.03	0.76
P, % DM	0.34	0.36	0.40	0.03	0.35
K, % DM	4.64	5.39	5.25	0.26	0.11
Mg, % DM	0.37	0.38	0.35	0.01	0.26
Na, % DM	0.02	0.02	0.03	0.003	0.55
Al, ppm	1146	914	1329	165	0.22
Fe, ppm	1298	1039	1477	172	0.21
Mn, ppm	554	548	542	30.5	0.96
B, ppm	12.9	14.0	12.2	1.84	0.77
Cu, ppm	29.8	30.9	39.0	3.32	0.12
Zn, ppm	41.9	46.1	46.8	2.89	0.44
S, % DM	0.28	0.29	0.29	0.009	0.51

Table 7. Root mineral concentration by copper treatment level for Timothy and Orchard Grass grown in Trout River Gravelly Sandy Loam.

	Copper Treatment Level				*P*-value
Item	**0**	**5**	**10**	**SE**	**Trt**
Ash, % DM	22.7	16.9	14.4	1.92	0.01
Ca, % DM	0.46	0.46	0.47	0.02	0.97
P, % DM	0.20	0.21	0.22	0.01	0.31
K, % DM	1.94	2.05	2.28	0.11	0.10
Mg, % DM	0.21	0.22	0.21	0.008	0.92
Na, % DM	0.12	0.12	0.13	0.01	0.77
Al, ppm	2878	2905	2640	281	0.77
Fe, ppm	4568	4181	4550	548	0.85
Mn, ppm	1243	1321	1377	105	0.67
B, ppm	24.6	21.4	24.7	2.37	0.56
Cu, ppm	63.3	65.6	70.9	5.32	0.59
Zn, ppm	82.6	92.9	96.7	10.9	0.64
S, % DM	0.19	0.20	0.21	0.01	0.29

Table 8. Plant population and harvest data for corn grown with three different levels of Cu application in dairy manure.

	Cu Treatment Level				
Item	**Control**	**Medium**	**High**	**SE**	***P*-Value**
Plant Number	160.25	159.38	161.0	5.96	0.98
Total Harvest Weight (kg)	45.5	47.63	46.75	1.93	0.74
Number of Plants Harvested	33.5	32.88	32.88	1.50	0.94
Weight per Plant at Harvest (kg)	1.37	1.45	1.41	0.05	0.48

Table 9. Chemical and mineral analysis of corn grown with three different levels of Cu application from dairy manure.

	Cu Treatment Level				
Item	**Control**	**Medium**	**High**	**SE**	***P*-Value**
DM	36.1	36.6	36.5	0.35	0.58
NDF, % DM	44.27	43.38	41.81	1.46	0.49
ADF, % DM	24.71	24.44	24.29	0.41	0.77
Lignin, % DM	3.77	3.88	3.79	0.07	0.52
CP, % DM	7.10	7.19	7.04	0.14	0.73
Ca, % DM	0.17	0.16	0.17	0.003	0.45
P, % DM	0.21	0.21	0.21	0.007	0.95
K, % DM	0.61	0.59	0.61	0.02	0.71
Mg, % DM	0.15	0.15	0.15	0.004	0.72
Na, % DM	0.008	0.006	0.007	0.002	0.47
Al, ppm	56.90	46.30	61.46	5.08	0.12
Fe, ppm	74.98	72.73	78.79	5.46	0.73
Mn, ppm	12.09	11.16	11.95	0.95	0.76
B, ppm	5.96	4.94	8.10	0.91	0.07
Cu, ppm	3.22	2.76	3.37	0.36	0.49
Zn, ppm	12.68	12.10	12.84	0.96	0.85
S, % DM	0.08	0.08	0.08	0.003	0.97

Table 10. Mineral analysis of corn hybrids.

	Hybrid			
Item	**Short**	**Long**	**SE**	***P*-value**
Ca, % DM	0.16	0.17	0.003	0.14
P, % DM	0.24	0.19	0.006	<0.0001
K, % DM	0.62	0.58	0.01	0.05
Mg, % DM	0.15	0.14	0.003	0.06
Na, % DM	0.007	0.007	0.001	0.82
Al, ppm	59.8	50.0	4.15	0.11
Fe, ppm	88.0	63.0	4.46	0.0008
Mn, ppm	13.5	10.0	0.77	0.005
B, ppm	6.78	5.89	0.74	0.40
Cu, ppm	2.75	3.48	0.30	0.10
Zn, ppm	14.2	10.9	0.79	0.007
S, % DM	0.10	0.07	0.003	<0.0001

Table 11. Soil mineral analysis for corn plots (ppm).

	Cu Treatment Level				
Item	**Control**	**Medium**	**High**	**SE**	***P*-Value**
Ca, % DM	3422	3292	3462	52.37	0.08
P, % DM	583	547	578	12.7	0.13
K, % DM	891.7	765.6	829.9	46.6	0.18
Mg, % DM	224.9	2016.4	2191.2	58.04	0.13
Na, % DM	140.9	121.1	130.9	9.78	0.38
Al, ppm	11454	10408	11074	397.3	0.19
Fe, ppm	14797	13694	14582	472.8	0.24
Mn, ppm	158.5	150.9	158.8	5.06	0.47
B, ppm	35.01	34.69	30.48	2.53	0.38
Cu, ppm	10.98	13.18	18.19	0.78	<0.0001
Zn, ppm	31.81	30.01	32.03	0.76	0.14
S, % DM	189.5	184.5	192.6	6.44	0.67

Table 12. Changes in soil Cu concentration compared to Cu application rate.

Treatment	**Lbs/acre applied**	**Soil Test lbs/acre**	**Difference from Control**
Control	0	21.96	-
Medium	8.1	26.36	4.4
High	16.3	36.38	14.42

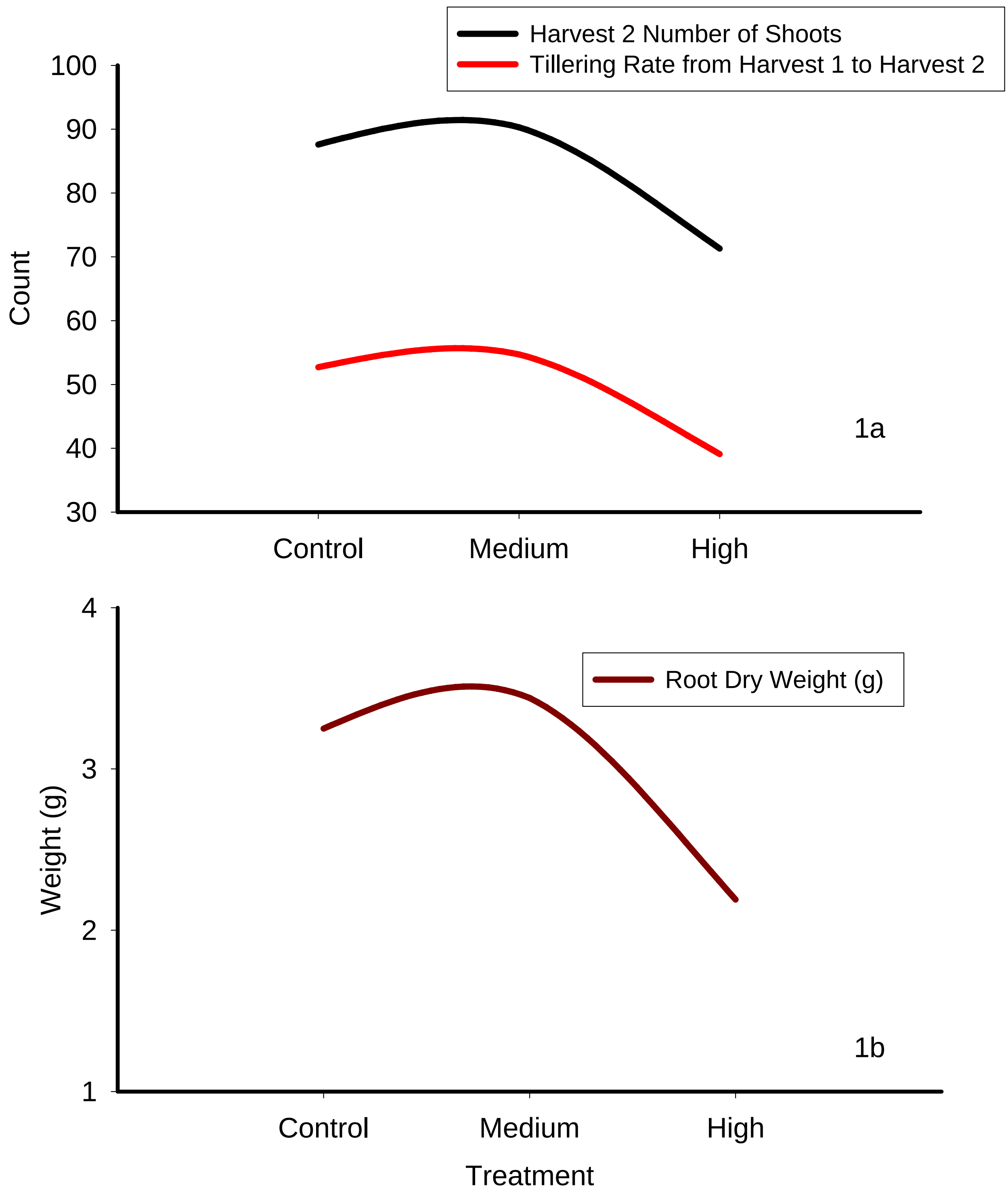

Figure 1a,b. Linear effect of Cu treatment level on harvest 2 number of shoots, tillering rate from harvest 1 to harvst 2, and root dry weight (g).

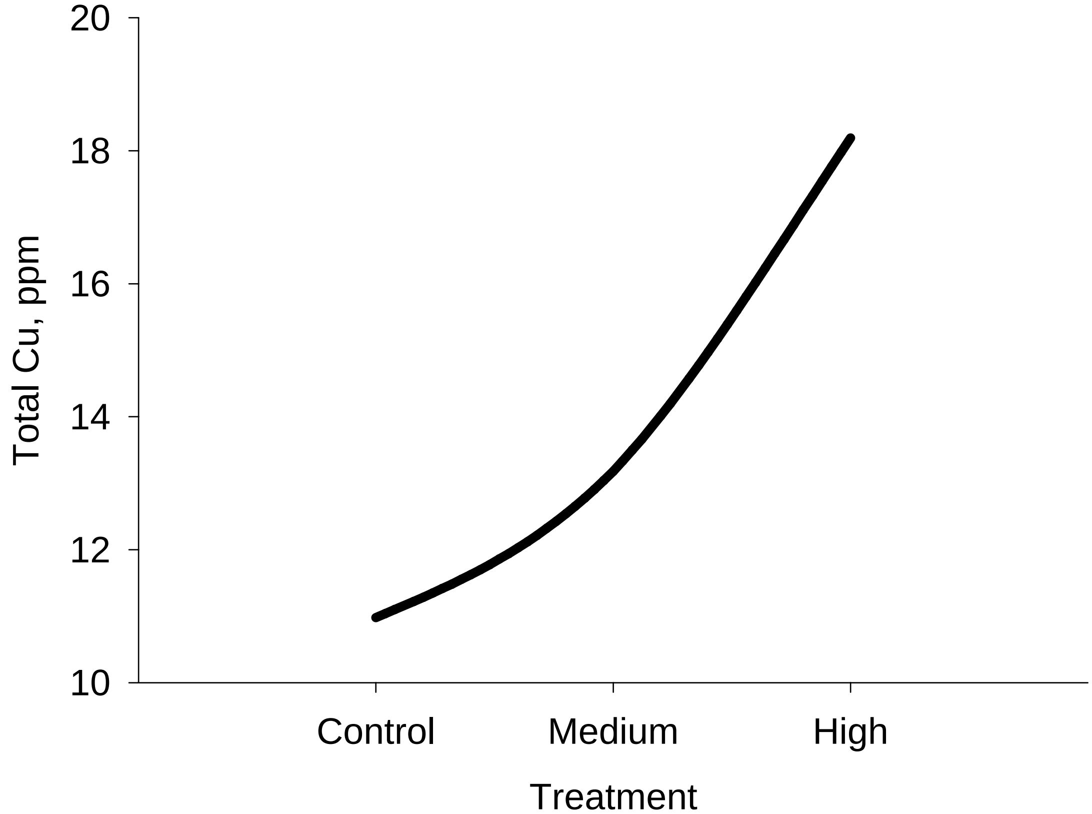

Figure 2. Linear effect of Cu treatment level on total soil test Cu (ppm).