Agronomic and Environmental Issues with Foot Bath Solution Land Spreading

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Key Summary Points

- Copper is an essential element for plant function and health but is removed from the soil in extremely small amounts.
- Copper has a strong affinity to be bound by soil or manure organic matter and soil minerals. Hence, much of the copper found in soil is unavailable for plant uptake.
- Instances of plant or livestock (especially dairy) copper toxicity from high soil copper levels are rare. Sandy soils need to be monitored more closely than clay based soils.
- Once soil copper levels become excessive to the point of causing toxicity, the situation is essentially irreversible.
- Most dairy farms using copper sulfate for hoof health are not land applying copper in amounts that we would expect to encounter plant or livestock toxicity problems in the short to mid-term.
- Copper acts as a bactericide in both manure lagoons and digesters if concentrations become too high.
- In most states, environmental regulations addressing copper handling and land spreading on dairy farms do not constrain current management practices. However, this situation may change in the future.

Introduction

During recent years, there have been several articles in the popular farm press addressing the potential problem of increased soil copper (Cu) levels from land spreading spent copper sulfate ($CuSO_4{\cdot}5H_2O$) foot bath solutions with liquid manure. This occurs, of course, because the used $CuSO_4$ solution is often pumped into the manure storage unit, which significantly raises the Cu concentration of the manure. The concerns center on several issues:

- Increased soil Cu concentrations and the effects on crop health
- Increased Cu concentrations of harvested crops and the effects on livestock health
- Environmental impacts of high soil Cu concentrations
- Regulatory constraints associated with Cu land spreading

Basic Copper Agronomics

Copper is an essential element for plant growth and is important for several physiological functions, but like most micronutrients it is needed in very small amounts. Most crops remove less than 0.1 lb/a of copper per year from the soil. The copper ion (Cu^{++}) is held very tightly by soil minerals and organic matter and most soil Cu remains unavailable for plant uptake. In Wisconsin, the Cu content of soil ranges from 2 to 100 parts per million (ppm) with an average value of about 30 ppm (Schulte and Kelling, 1999).

Several important soil properties affect the availability of Cu in the soil. These include soil texture, organic matter content, pH, and interactions with other soil elements such as nitrogen, phosphorus, calcium, aluminum, iron, and zinc (Tinsdale et al., 1985). Copper availability is reduced in soils containing high amounts of organic matter or having a high pH. Organic matter binds Cu more strongly than any other micronutrient. Further, fine-textured soils (e.g. clays) contain relatively less plant-available Cu than sandy soils because more of the Cu is bound by soil mineral, organic matter, and clay fractions.

Once soil Cu concentrations are increased by land applications of high Cu containing materials, soil test Cu levels will remain high for a long time. This is because very little Cu is leached through the soil profile and plants remove minimal amounts of Cu over time.

Copper Toxicity and Deficiency

Plants

Instances of plant Cu toxicity and deficiency have historically been rare in the midwestern United States. Toxicity symptoms are usually induced by unique situations such as soils with high naturally occurring available Cu, the routine addition of Cu containing fungicides to vegetable crops grown on sandy soils, or the addition of high Cu containing biosolids or mine wastes. Toxic levels of Cu reduce plant shoot vigor, cause poor root development, and result in leaf chlorosis. Copper is relatively immobile in plant tissue and tends to accumulate in the roots.

Plant Cu deficiency is also rare. Deficiency symptoms are most common on intensively cropped peat and muck soils, which are high in organic matter. Table 1 provides the University of Wisconsin's sufficiency ranges of plant tissue Cu concentrations for several field crops (Schulte et al., 2000). The sufficiency range is defined as the range in concentration that results in 95 to 100 percent of maximum yield.

Table 1. Copper sufficiency ranges for several common field crops (University of Wisconsin).

CROP	PLANT PART SAMPLED	TIME OF SAMPLING	SUFFICIENCY RANGE
Alfalfa	Top 6 inches	Bud	3.0-30.0
Corn, pre-tassel	Leaf below whorl	Pre-tassel	3.0-15.0
Corn, tassel to silk	Earleaf	Silking	3.0-7.5
Oat/Wheat	Top leaves	Boot stage	5.0-20.0
Soybean	Newest developed leaf	By early flowering	6.0-15.0

Livestock

Copper toxicity in dairy cattle has been documented but most often is caused by an error in mineral supplementation. Of all the minerals, Cu is the most likely to become toxic if over-supplemented (NRC for dairy cattle, 2001). There have been no known cases in dairy cattle where Cu toxicity was caused by high Cu concentrations in forage. Copper is stored and accumulated in the liver of livestock. Sheep are extremely sensitive to Cu in feeds. In fact, feeding forage that is over 20 ppm Cu to sheep can result in animal death. Average Cu concentrations for common forage feeds are presented in Table 2.

Table 2. Average copper concentration of selected forages as reported in the NRC Nutrient Requirements of Dairy Cattle (2001) and Dairyland Labs, Arcadia, WI (2003)

	NRC, 2001				**Dairyland Labs, 2003**		
FORAGE TYPE	**N**	**SD**	**Cu**		**N**	**SD**	**Cu**
			ppm				ppm
Mid-maturity legume hay	56	2	9		31	1.7	12
Mid-maturity legume silage	607	3	9		24	6.0	12
Mid-maturity grass hay	23	4	9		14	3.0	13
Mid-maturity grass silage	35	2	9		--	--	--
Corn silage	912	7	6		85	5.8	10
Managed grass pasture	13	3	10		--	--	--

The Miner Institute Experience

Thomas (2001) reported on the Miner Institute's (Chazy, N.Y.) experience with land applications of spent $CuSO_4$ foot bath solutions in an article that appeared in *Hoard's Dairyman* magazine. As a result, many producers and consultants began to raise questions about the practice of both using and land applying the $CuSO_4$ solutions with manure. In 1998, the Miner Institute was using about 254 of $CuSO_4$ per week for their 160 cow herd. This translates into the farm pumping about 3300 lbs. of Cu into their manure pit each year. The manure was then spread on 470 acres of cropland annually. This resulted in about 7 lbs. of copper being applied per acre on an annual basis.

After noticing an increase in Cu concentrations of their manure and forage crops, the farm reduced from five to three the number of days per week that $CuSO_4$ was used. They also reduced the concentration of the foot bath solution. Further, they used alternative treatments (tetracycline) in alternate weeks. The change in management reduced the amount of Cu being applied to cropland to about 1000 lbs. per year, or slightly over 2 lbs. per acre.

Calculating Copper Application Rates

How much $CuSO_4$ is currently being used and applied to agricultural land on Midwest dairy farms? In a 2003 herd hoof health survey of 27 Fond du Lac County, WI dairy farm operators, $CuSO_4$ used per week averaged about 77 lbs. with a range of 12 to 200 lbs (Irv Possin, personal communication). Of course that is only part of the story because we need to know how many acres that the solution is being applied to and how often an individual field receives manure. Table 3 shows calculations from several Wisconsin dairy farms based on the fact that $CuSO_4$ contains 25 percent Cu.

Table 3. Calculated soil copper loading from the use of $CuSO_4$ foot bath solutions for four Wisconsin dairy farms.

	A	B	C	D	E
Farm	**Amount $CuSO_4$ used per week**	**Amount of $CuSO_4$ used per year (A x 52)**	**Total Cu applied per year (B x 0.25)**	**Crop acres receiving manure annually**	**Cu applied lbs/ac/year (D/C)**
1	175	9,100	2275	295	7.7
2	250	13,000	3250	400	8.1
3	200	10,400	2600	560	4.6
4	80	4,160	1040	100	10.4

Clearly there can be a wide variation in the amount of Cu applied to agricultural land depending on the hoof care management employed and the number of acres where manure and $CuSO_4$ solutions are annually applied. Four dairies checked in Pennsylvania had Cu land applications ranging from 2 to 11 lbs. per acre (Stehouwer and Roth, 2004). Knowing how much Cu is being applied per acre is an important number for dairy producers to calculate. Indications are that it is not uncommon for rates to fall between 5 and 10 lbs. of Cu per acre per year. Table 4 can be used to roughly estimate annual Cu loading on a per acre basis. These estimates do not include the normal background amount of Cu found in manure without any $CuSO_4$ additions (about 150 ppm d.m. or 0.06 lb./1000 gal).

Some Perspective

Combs et al. (1998) reported on the trace element content of manure samples submitted to soil testing labs in the NCR-13, SERA-6, and NEC-67 regions. The Cu concentrations for dairy, swine, and poultry manure are presented in Table 5. The average Cu concentration for liquid dairy manure was 191 ppm (dry weight basis) with a range of 16 to 1320 ppm. The study did not distinguish farms adding spent $CuSO_4$ solution to the manure. Nevertheless, it is interesting to note that liquid swine manure was over three times greater and poultry manure was over twice greater in Cu content than dairy manure. Swine are routinely fed higher levels of Cu in the diet. Several research studies have been done evaluating high soil Cu loading rates with swine manure (Anderson et al., 1991, Payne et al., 1988, Sutton et al., 1983). In some cases, up to 250 lb. Cu per acre were added to the soil with no crop yield decreases and only a small increase in plant Cu concentration. It was indicated that a significant amount of the Cu applied was converted to an unavailable form.

Table 4. Estimated average annual copper loads per acre based on weekly $CuSO_4$ use and crop acres spread with manure (excludes background manure Cu)

Lbs. of CuSO4 used per week	Number of crop acres spread per year: 100	200	300	400	500	600	700	800
20	**2.6**	**1.3**	**0.9**	**0.7**	**0.5**	**0.4**	**0.4**	**0.3**
40	**5.2**	**2.6**	**1.7**	**1.3**	**1.0**	**0.9**	**0.7**	**0.7**
60	**7.8**	**3.9**	**2.6**	**2.0**	**1.6**	**1.3**	**1.1**	**1.0**
80	**10.4**	**5.2**	**3.5**	**2.6**	**2.1**	**1.7**	**1.5**	**1.3**
100	**13.0**	**6.5**	**4.3**	**3.3**	**2.6**	**2.2**	**1.9**	**1.6**
120	**15.6**	**7.8**	**5.2**	**3.9**	**3.1**	**2.6**	**2.2**	**2.0**
140	**18.2**	**9.1**	**6.1**	**4.6**	**3.6**	**3.0**	**2.6**	**2.3**
160	**20.8**	**10.4**	**6.9**	**5.2**	**4.2**	**3.5**	**3.0**	**2.6**
180	**23.4**	**11.7**	**7.8**	**5.9**	**4.7**	**3.9**	**3.3**	**2.9**
200	**26.0**	**13.0**	**8.7**	**6.5**	**5.2**	**4.3**	**3.7**	**3.3**
220	**28.6**	**14.3**	**9.5**	**7.2**	**5.7**	**4.8**	**4.1**	**3.6**
240	**31.2**	**15.6**	**10.4**	**7.8**	**6.2**	**5.2**	**4.5**	**3.9**
260	**33.8**	**16.9**	**11.3**	**8.5**	**6.8**	**5.6**	**4.8**	**4.2**

Table 5. Summary of copper content in selected dairy, swine, and poultry manure samples (Combs et al., 1998)

Type	**n**	**min**	**max**	**mean**	**Cu load @ 160 lb. N/ac/yr**
		---------ppm d.m.----------			lb/ac/yr
Dairy solid	63	12	200	27	0.6
Dairy liquid	24	16	1320	191	2.4
Swine solid	5	270	515	381	11.1
Swine liquid	5	146	1923	673	4.9
Poultry solid	24	35	1350	438	3.7

When $CuSO_4$ solutions are added to the manure slurry, over 90 percent of the Cu is bound by organic matter and made less available for plant uptake. This makes it very unlikely that a plant toxicity situation will exist where recommended rates of manure are applied to cropland. Stehouwer and Roth (2004) reported checking the Cu content of corn silage from fields with 3-5 times normal total soil Cu, but finding no increase in the forage Cu concentrations. Even so, total soil Cu concentrations will build-up over time and are virtually irreversible. Further, it is not recommended that spent $CuSO_4$ solutions be disposed of in short term holding structures and then spread on a small land area. At this point in time, dilution is the best solution for the disposal of the spent foot bath effluent.

Sewage sludge is perhaps another reasonable comparison to make given its historically high content of certain heavy metals. A review of several published sludge nutrient content sources indicates a wide variability in Cu content ranging from about 200 to over 1300 ppm (Combs et al., 1998, Stehouwer, 1999). Again, these concentrations are generally above those found in liquid dairy manure, with or without spent $CuSO_4$, but applications are made less frequently to the same field. Additionally, application of sludge is regulated by local state and/or federal government agencies.

Copper as a bactericide

Copper is sometimes used as an algicide in ponds, fungicide for plants, herbicide, and is a known bactericide. The latter has implications for dairy producers. First, if soil Cu concentrations are too high, there may be a negative impact on soil microorganisms. High Cu manure concentrations have been shown to have a detrimental effect on the operation of anaerobic manure digesters, which depend on bacteria for the digestion process. Finally, Cu has been linked to having an impact on the amount and type of microbe growth in anaerobic manure lagoons (Gilley et al., 2000).

Regulation of Copper Land Applications

The Environmental Protection Agency (EPA) has guidelines for Cu loading to agricultural land when sewage sludge (biosolids) is applied. Although most state enforcement agencies do not monitor Cu applications from dairy manure, standards set for sludge offer a guide and perhaps an indication of future regulations. The EPA is beginning to take a more in depth look at practices and procedures followed on dairy farms (especially CAFO's), which includes the use of $CuSO_4$ (Arnie Leder, Region 5 EPA, personal communication). Recently, a New Mexico CAFO dairy farm was cited as being in violation of their NPDES permit by Region 6 EPA for discharging $CuSO_4$ into a manure storage unit (Dairy Producers of New Mexico, 2004). The citation stated that "*discharges to containment structures must be composed entirely of wastewater from the proper operation and maintenance of the animal feeding operation*."

The EPA 503 standard for application of biosolids to agricultural land cites a maximum lifetime loading limit for Cu as 1339 lbs. per acre and an annual application limit of 66 lbs. per acre. Neither of these guidelines is severely limiting for typical manure applications even where above average amounts of spent $CuSO_4$ are added to the manure slurry. It should be noted that specific states may have more restrictive regulations. For example, Thomas (2001) reported New York has a lifetime cumulative loading limit of 75 lbs. per acre. By comparison, Illinois has a lifetime application limit of 250 lbs. per acre while Wisconsin, Minnesota, and Iowa follow the previously mentioned EPA standards.

Management Recommendations

- Seek ways to reduce $CuSO_4$ use without sacrificing herd hoof health. These include:
  - Reducing the concentration of $CuSO_4$ in the foot bath solution.
  - Reducing the frequency of $CuSO_4$ foot bath use by cattle.
  - Substituting non-Cu containing hoof care products either in part or entirety.
  - Using a clean water foot wash bath ahead of the $CuSO_4$ bath to extend the useful life of the latter.
- Know your situation in terms of the amount of Cu being applied per acre and soil types.
- Analyze manure, soil, and feed Cu levels to set a benchmark. Where high amounts of Cu are being applied to land (>10 lbs per acre), continue to monitor Cu levels every few years.
- Don't concentrate spent $CuSO_4$ solutions in short term holding facilities and spread on a small land area.
- Potential Cu build-up in soil is just one more reason to write and follow a nutrient management plan.
- **It seems reasonable to assume that both herd hoof health and agronomic plant health can still be obtained with the judicious use of $CuSO_4$.**

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