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George O. Estes
University of New Hampshire

Jian Q. Zhao
University of New Hampshire

Thomas P. Ballesterio
University of New Hampshire

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**Release of Nitrate-Nitrogen and Heavy Metals from Land-Applied
Biosolids in Northern Areas**

**Dr. George O. Estes, Professor
Jian Q. Zhao, Ph.D. Candidate**

**Department of Plant Biology
University of New Hampshire
Durham, NH 03824**

**Dr. Thomas P. Ballester, Director
New Hampshire Water Resources Research Center
218 Morse Hall
University of New Hampshire
Durham, NH 03824**

ABSTRACT

Field studies at two New Hampshire sites were conducted from 1993-1995 to evaluate the effects of various rates of broadcast, soil-incorporated wastewater treatment facility (WWTF) biosolids and manure on water, crops and soil. Site I was located on corn land in the Merrimack River watershed in Boscawen, NH and compared lime-stabilized, dewatered biosolids from the Concord WWTF with dairy manure. Site II was in Lebanon and compared anaerobically digested of the Hanover WWTF with lime-stabilized biosolids from Concord as nutrient resources for corn production. The principal focus was on N release and its impact on soil and water levels of $\text{NO}_3\text{-N}$.

The chemical composition of Concord Biosolids was highly variable, ranging from 0.6-5.2% total N over a four-year period of testing by the Concord WWTF. The N content of anaerobically digested biosolids was much more uniform, ranging from 5.0-5.4% total N over the 1993-1995 period. Treatments involved "low", "intermediate" and "high" rates of application which were initially based on a 20-30% mineralization rate (MR) endorsed by USEPA; use of a 50% MR resulted in a reduced loading rate in 1995. The major area of concern with all treatments was with $\text{NO}_3\text{-N}$ losses beyond the root zone to groundwater. The N-P-K profile of biosolids showed a K deficit which requires supplemental use of fertilizer-K. Lime-stabilized biosolids supplied abundant Ca which elevated soil pH and reduced the need for lime which will also dictate the frequency of use of biosolids on a specific field.

Nitrate-N measurements were made in soil from the pre-sidedress N test (PSNT) and in water collected via suction lysimeters and in monitoring wells. The PSNT assay is

widely used by farmers in the Northeast U.S. to predict the need for supplemental sidedressed N fertilizer for corn; if the PSNT value for soil NO₃-N concentration is >25 mg kg⁻¹ when corn is at the 35-40 cm growth stage, no supplemental N is recommended. The PSNT data of both 1994 and 1995 showed greater seasonal variability in NO₃-N concentrations with biosolids compared with manure; early season NO₃-N concentrations were generally higher with biosolids. In 1995, fall concentrations of NO₃-N via PSNT assay had declined to ~5 mg kg⁻¹ for all three treatments with the “low” application rate (Control, Manure, Biosolids) and to ~10 mg kg⁻¹ for the “intermediate” rate. Water samples from suction lysimeters located four feet below the soil surface showed fugitive NO₃-N escaping beyond the root zone and moving downward in the soil profile with manure yielding the most NO₃-N. Assessment of potential N loss from biosolids and amendments must consider the relative amounts of organic and inorganic N present and recognize the distinction between N availability and N mineralization. Results of NO₃-N assay in water samples from small monitoring wells (SMW's) under field areas receiving manure and biosolids showed a range of 3.5 - 12.2 mg kg⁻¹ with slightly higher levels with biosolids. Such results suggest a slower seasonal release of N with biosolids compared with manures governed by a larger fraction of organic-N in biosolids.

Applications of biosolids or manure generally did not have significant effects on crop yield which reflects inherently high soil fertility at the two sites. Chemical analysis showed that Zn and Cu are the principal metals being added from both biosolids but that quantities are exceedingly low compared to naturally occurring concentrations in soil.

BACKGROUND AND LITERATURE REVIEW

New Hampshire communities face mounting costs of solid waste disposal particularly with biosolids (sludge) from wastewater treatment facilities. Of the three major disposal options - incineration, landfilling and landspreading - the practice of landspreading of biosolids on agricultural land is expanding due to their value as a nutrient resource which provides financial benefit to farmers through reduced costs of chemical fertilizers (as well as possible tipping fees received for accepting the biosolids) and savings for municipalities in landfilling or incineration costs.

While benefits may accrue from on-farm use of biosolids, the release of nutrients and metals to soil, crops and water may serve as a contaminant in the absence of sound management practices. Only biosolids that are nutrient-rich, stabilized to significantly reduce pathogens, and low in metals are suitable for landspreading.

Central to the issue of landspreading of N-rich organic residuals is the potential for nitrate-N ($\text{NO}_3\text{-N}$) contamination of groundwater. Nutrients are either the leading or second leading cause of pollution in waterbodies outside of the Great Lakes [1]. Identification of valid mineralization rates for N from the myriad of organic wastes represents a major effort by soil scientists since it forms the basis of sound N recommendations for crop production. If excessively low N mineralization rates are used, the potential exists for groundwater contamination due to high application rates/acre of soil amendments. Since the rate of mineralization is governed by soil moisture, temperature, and microbial activity, the quantity of $\text{NO}_3\text{-N}$ supplied from a broadcast, preplant, soil-incorporated application of biosolids is difficult to predict. Fortunately, use

of the pre-sidedress N test (PSNT) assay [2], permits a more precise determination of the need for supplemental N as a sidedress application for corn to fulfill the total seasonal N needs of the crop.

The limited acreage of cropland available for landspreading in the heavily populated Northeast is of critical importance to the stewardship of land and water resources since the region has only six percent of the land area of the continental United States, but has twenty-five percent of its population. Of the total 5,940,500 acres of land area in New Hampshire, only 107,000 are cropland [3] which precludes any long-term program of agricultural use of biosolids without jeopardizing water quality. The state municipalities produce about 45,000 wet tons (65,000 yds³) annually from its 105 wastewater treatment facilities; approximately one-half of these biosolids are landspread and the balance is landfilled [4]. In addition, significant amounts of biosolids from cities and towns outside of New Hampshire are also being spread on NH farmland. When integrated into cropping programs, the use of biosolids represents an increase to the “pool of nutrients” which are being applied to the watersheds of New Hampshire from a myriad of sources such as dairy manures, wood ash, chemical fertilizers, legume-based rotations, and composts. While the beneficial effects of biosolids to crops are usually attributed to their nutrient contribution, lime-stabilized biosolids, with a CaCO₃ equivalence as high as 25 percent, are also an excellent liming agent [5].

Municipalities with significant industry may produce biosolids with high levels of heavy metals which may make them unsuitable for land application. Heavy metals of concern include Zn, Cu, Ni, Cd, Cr, Pb, As, Hg, Se and Mo. These metals occur naturally

in all soils, crops, fertilizers, manures, and biosolids. The maximum amount of these metals that can be applied to land from biosolids is regulated by the **The Standard for the Use and Disposal of Sewage Biosolids**. This EPA standard, the so-called Part 503 rule [6], was published in the Federal Register on February 19, 1993 and became effective on March 22, 1993. Table 1 presents ranges of selected heavy metals present in typical soils, compares these elements to ranges found in typical biosolids, phosphate fertilizers, and dairy manures and presents the U.S. EPA 503 allowable ceiling concentrations and cumulative loading rates for biosolids [7].

The biosolids application rate per acre of agricultural land is usually based on the N content of the biosolids, the agronomic recommendation for N to the specific crop, and the mineralization rate of the biosolids-N. Because 50 to 90% of the N in biosolids is organic [8], information about the N mineralization rate is necessary to predict N availability during the cropping season. Magdoff and Amadon [9] reported a 54% loss of organic N in 17 weeks from aerobically digested sludge under laboratory conditions and a 55% loss under field conditions. Environmental Protection Agency guidelines recommend a relatively low mineralization rate of 20% for the first year of biosolids application [10]. Nitrogen release from biosolids is further complicated due to the types of processes used in their treatment. Aerobic and anaerobically digested biosolids vary in their mineralization rates. Serna and Pomares [11] showed that the amounts of N mineralized in a soil amended with biosolids, expressed as a percentage of total organic N added to soil, ranged from 13.8 to 45.6%; aerobically treated biosolids gave higher mineralization rates than the anaerobically treated wastes.

If public opposition [12] to landspreading of biosolids is to be surmounted, assurance must be provided that the practice is safe. This can only be achieved from an ongoing program of site-specific field research to document impact on soil, crops and water resources coupled with an effective outreach program. This paper presents results of two on-farm, field-scale studies with biosolids from Concord and Hanover, NH applied at various rates to land on which silage corn was produced. Specific objectives were (a) to determine the relationship between N loading rates and changes in $\text{NO}_3\text{-N}$ production, crop use and losses from the root zone to soil- and groundwater and (b) to identify the extent of nutrient and metal accumulation and mobility within soil profiles and their uptake by the corn crop.

METHODOLOGY

Field experiments were conducted at two sites in New Hampshire from 1993-1995 in collaboration with commercial farmers and private companies involved with landspreading of biosolids. Site I was located in Boscawen on an Ondawa fine sandy loam at a location abutting the Merrimack River which drains the largest watershed in New Hampshire. Site II was on farmland in Lebanon, NH on a Croghan loamy fine sand at a location distant from any significant waterways.

Site I (Boscawen, NH)

The experiment at Site I compared dewatered, lime-stabilized biosolids from the Concord, NH waste water treatment facility (WWTF) with manure produced by the 200-cow dairy herd at the commercial farm. The experimental design, shown with plot dimensions in Figure 1, was a randomized complete block experiment with three

replications. Three rates of each material were used each year and were considered as “low”, “intermediate” and “high” application rates; in 1993 these rates, on a wet-weight basis, were 25, 50 and 75 tons/acre. Rates were adjusted in 1994 and 1995 and these data are presented in Table 4. The current practice treatment at the farm involved manure applied at the low rate with reliance on results of the PSNT assay to determine the need for supplemental N as a sidedress application. The site had been in continuous corn and had received annual manure applications for the previous ten years. Soil parameters at Site I in 1993, prior to applying soil amendments, are given in Table 2.

Materials were applied as a pre-plant, broadcast, soil-incorporated application at four rates (Figure 1) in 1993, 1994, and 1995. Nutrient and metal composition of the biosolids and manure used at Site I are shown in Table 3. The N-P-K profile of manure is closely aligned with crop needs while the low K content of biosolids is noteworthy; Ca content of the Concord WWTF biosolids was 6-10 times higher compared to dairy manure.

The application rates in wet and dry tons per acre for the biosolids and manure at Site I are given in Table 4. The three biosolids and manure treatments received annual applications ranging from 1.0 - 27.9 dry tons/acre. Materials were trucked to the site, dumped, immediately applied to the plot areas using a calibrated, rear-discharge spreader and soil incorporated by discing to a six-inch depth. The high application rates of total N in 1993 and 1994 reflected a mineralization rate estimate of 30%. Thus, for every 100 pounds of total N applied, it was assumed that 30 pounds becomes available for crop use during the first year following application. Because of high $\text{NO}_3\text{-N}$ concentrations

observed in PSNT assays and lysimeter samples in 1993 and 1994, rates were lowered significantly in 1995 to more closely match nutrient supply with crop demand which translated to the use of a higher mineralization rate. The rapidity of change in soil/water $\text{NO}_3\text{-N}$ concentrations of the plot areas was also of key interest. Annual applications of biosolids to achieve a specific rate of total N/ was not possible due to variability in N concentration (Figure 2) and assays which was determined following the land application of the specific batch of biosolids and manure. Nutrient additions from the four application rates of biosolids and manure in 1993, 1994, and 1995 at Site I are given in Table 5; trace metal additions for these materials, rates and years at Site I are given in Table 6.

Corn was planted at a population of 26,000 plants/acre on 3 May, 4 May, and 2 May in 1993, 1994 and 1995 using recommended rates of supplemental K, starter fertilizer, and herbicide.

During the growing season, the pre-sidedress nitrate test (PSNT) was performed on soil samples collected biweekly from all plots to determine N release from the various biosolids and manure treatments. The PSNT is commonly used by farmers to estimate the availability of N to corn for the cropping season by using the $\text{NO}_3\text{-N}$ concentration of the surface 30-cm of soil when corn plants are 15- to 30-cm tall. Samples were taken by collecting a composite of three 2-cm-diameter cores from all plots. Samples were immediately refrigerated for transport to the laboratory where they were dried, screened through a 2-mm sieve and analyzed for $\text{NO}_3\text{-N}$ via a Technicon Autoanalyzer in the UNH Analytical Services Laboratory.

Loss of $\text{NO}_3\text{-N}$ beyond the root zone was measured from soil water samples collected with porous, pressure/vacuum double-port lysimeters (Soil Moisture Equipment Corp., Santa Barbara, CA) installed in selected plots in 1994. The 2.3-cm diameter ceramic cup lysimeters were installed by hand auger below the root zone (120 cm) in the vadose zone; bore holes were first packed with silica flour to prevent plugging of the porous tip. Prior to installation, lysimeters were cleaned with dilute hydrochloric acid solution. Because Site I was a field in active use for corn production, installation of lysimeters was delayed until the crop was planted. Once installed, the sampling area (containing the two coils of lysimeter tubing) was protected using four-foot lengths of 12-inch diameter PVC pipe which were positioned approximately six feet away from the lysimeter units. Removal of this PVC pipe and closure of these access ports was required each fall to permit crop harvest with the tractor-drawn equipment.

For sample collection, the double-port lysimeters were placed under approximately 50 centibars of suction. Water was collected at various intervals throughout the growing season, immediately refrigerated after collection, and analyzed for $\text{NO}_3\text{-N}$ within 24 hours by methods described above.

In 1995, six small diameter wells (SDW's) were installed to permit monitoring of groundwater levels and treatment effects on $\text{NO}_3\text{-N}$ concentrations of the water. The SDW's used 2.1 cm outside diameter steel pipe (1.57 cm ID) that was vibrated into the ground with a vibratory hammer. The well screens were vertically slotted by laser (two rows of 5.1 cm by 0.038 cm slots, each slot separated by a 1.5 cm gap where the solid pipe remains uncut) with a porosity of 1%; total screen length was 2 m. A machined steel

drive point was on the leading edge of the SDW and held in place with a Buna-N O-ring. At the top of the well, a loose fitting steel drive cap was used to transmit the energy from the vibratory hammer to the pipe.

The SDW's were completed at four feet below the soil surface to avoid disruption from tillage practices; protective plastic covers were installed over the pipe at this elevation. The SDW's contain 0.194 liters/meter, a volume which is ten times less per meter of length than traditional 5-cm wells. An obvious advantage is that purge water volumes are markedly lower when using SDW's in lieu of larger PVC wells.

Separate sampling tubing was used for each SDW. The SDW's were thoroughly purged prior to sample collection. Water samples from the SDW's were refrigerated immediately after collection and NO₃-N assays were conducted on all samples within 24 hours at the UNH Analytical Services Laboratory using a Technicon Autoanalyzer.

Soil samples were collected at a 0-6" depth from all 24 plots each year to determine treatment effects on soil pH and nutrient concentrations. Samples were dried, screened to pass a 2 mm sieve, and analyzed at the UNH Analytical Services Laboratory for available nutrients using the Mehlich III extraction procedure [13].

In the fall of 1994 and 1995, soil cores were taken from all plots to a four foot depth using a Giddings tractor-mounted soil coring unit (Model GS-T-S Hydraulic Soil Sampling Machine. Giddings Machine Co., Inc. Fort Collins, CO) to determine profile distribution of nutrients and metals.

Corn was harvested on 23 September, 8 September, and 12 September in 1993, 1994, and 1995, respectively. Harvest of the crop consisted of cutting 26 representative

whole corn plants from the center two rows of all plots (representing one-thousandth acre) and weighing to determine silage yield on a fresh-weight basis. A three-plant subsample was chosen from the above plants, weighed, dried at 80°C, and reweighed to determine percent moisture content and dry matter yield/acre.

Site II (Lebanon, NH)

The experiment at Site II in Lebanon, NH compared dewatered, lime-stabilized from the WWTF in Concord, NH with anaerobically digested biosolids from the WWTF in Hanover, NH for silage corn production on a Croghan loamy fine sand. Results of soil assays on various sampling dates, including an initial sampling on 18 May 1993 prior to applying biosolids at the site, are given in Table 17.

The experimental design was a randomized block with three replications. Treatments consisted of a control, three rates of Hanover WWTF biosolids (“Low”, “Intermediate”, and “High”) and two rates of Concord WWTF biosolids (“Low”, “Intermediate”); the specific rates applied in each year are given in Table 7. The application rate of Concord biosolids was reduced in 1995 in light of higher than expected mineralization rates in the first two years of the experiment; rates of Hanover biosolids were quite similar over the three-year period.

Nutrient and trace metal concentrations of the two biosolids used at Site II in 1993, 1994, and 1995 are given in Table 8. Hanover WWTF biosolids showed greater uniformity and nearly twice the N content of the dewatered, lime-stabilized biosolids from Concord. Conversely, the Ca concentration of Concord biosolids was about double that in Hanover biosolids.

The specific quantities of nutrients (N,P,K,Ca,Mg) applied at the various treatment levels at Site II are given in Table 9. Except for the lowest rate of application, the total nutrient load exceeded recommended rates for N and P for agronomic crops in New Hampshire. The Ca contribution from the Concord biosolids were significant and suggests that liming could likely be eliminated if soil Mg levels are found to be within recommended levels.

The quantities of trace metals supplied by the two biosolids at the various application rates in 1993 and 1995 at Site II are given in Table 10; metal assays were not conducted on the biosolids in 1994.

All materials and supplemental fertilizers were pre-plant, broadcast, soil-incorporated applications in 1993, 1994, and 1995. Corn (cv. Halsey 180) was planted at a population of 26,000 plants/acre on 18 May 1993, 19 May 1994 and 18 May 1995 using 30-inch row spacing and 200 lbs/acre of 10-20-20 starter fertilizer; the herbicide treatments were 1.5 lbs atrazine + 2 pints Dual/acre.

The sampling protocol at Site II for soils and PSNT assays were as described for Site I. Installation of lysimeters in the spring of 1994 used similar methods and materials as described earlier; sample collections, preparation and assays were also similar to those used at Site I. Specific collection dates of soil, PSNT, and lysimeter samples are given in the appropriate figure or table. Harvests of one-thousandth acre samples and three-plant subsamples of the corn crop were made on 30 September 1993, 29 September 1994 and 10 October 1995 for dry matter and tissue assay.

RESULTS AND DISCUSSION

Site I (Boscawen, NH)

Assessment of Biosolids and Manure.

The N contribution from biosolids and manure to crops constitute the principal purpose for their land application. The N concentration varied greatly in the dewatered, lime-stabilized biosolids from the Concord waste water treatment facility (WWTF). Concentration of Total Kjeldahl Nitrogen (TKN) ranged from 0.6 - 5.2 % with a mean of 2.1% over a four year period of testing by the facility (Figure 2). Such variability in N content of biosolids represents a serious problem when recommendations call for the application of precise amounts of N to satisfy crop needs without risking groundwater pollution.

As with biosolids, manure was also highly variable in its N content. Table 3 shows that the N concentration in the land-applied biosolids used over the three-year period ranged from 0.5 to 3.2% while manure-N ranged from 0.8 to 3.4 %. Results in Table 5 show the range in loading rate for nutrients from biosolids and manure at Site I for each year. The annual N load, computed from concentration values multiplied by applied rates (dry-wt basis) and expressed in pounds per acre, ranged from 0-277, 0-1071, and 0-314 in 1993, 1994, and 1994. The range of total N contributed from manure was 0-260, 0-837, and 0-346 for the three years, respectively. At the highest levels, these application rates of total N were significantly greater than commonly recognized agronomic needs of corn - normally 100 -200 lbs/A of “available” N - since a low mineralization rate of 30% was assumed for the organic-N present in the soil amendments.

Predicting the precise amount of available N which will be released to the crop from biosolids during its growing season is difficult. This mineralization rate was found to vary from 8.6-60 lbs/ton for uncomposted biosolids to -5.2 - 22 lbs/ton for uncomposted manures [20]; the negative 5.2 lbs/ton indicated N immobilization. Synchronizing N supply with crop demand is particularly difficult with the Concord biosolids due to the variability in chemical content, large/irregular particle size, and a mineralization process which is microbially mediated and thereby affected by climatic conditions.

The nutrient profile relative to crop requirements shows deficient levels of K with the Concord biosolids compared to a more balanced N-P-K content in dairy manure (Table 3). Such data suggests that any long-term usage of Concord biosolids on cropland will require supplemental applications of potassium. However, the high pH and abundant Ca in Concord biosolids (resulting from the lime-stabilization process) may permit it to serve as a substitute for limestone if soil Mg levels are adequate. Soils of New England are commonly low in Mg which is routinely corrected by broadcast applications of dolomitic limestone.

Treatment Effects on pH and Nutrient Status of Soil

The dominant effect of three annual applications of biosolids on soil properties was on soil Ca concentrations which doubled from 1993 to 1995 even at the lowest application rate; manure use led to a very modest elevation in soil Ca levels (Table 11). Soil pH increased from about 7.2 to 7.7 following biosolids use over the three-year period. The modest pH increase with biosolids suggest a strong buffering capacity in the soil, perhaps resulting from the organic matter contribution of the biosolids. An increase in about one

percent in soil organic matter occurred at the highest rates of both soil amendments (data not shown).

Concentrations of soil K remained unchanged or declined with biosolids use. Such results suggest an annual need for supplemental K to prevent a potential K deficiency in the crop. The expected contributions of K from manure use was reflected in a K accumulation from 1993 to 1995. Soil Mg concentrations paralleled those of K in that low soil Mg accompanied biosolids use. The high soil pH and Ca of biosolids treatments indicate that short-term use of the lime-stabilized material is recommended since $\text{pH} > 7.5$ can lead to nutritional problems in most agronomic species.

Treatment Effects on Trace Metal Levels in Soil

The concentrations of six trace metals in 120-cm deep soil cores collected from plots receiving the “high” rate of biosolids (26.8, 16.7 and 6.0 dry tons in 1993, 1994, and 1995, respectively) at Site I are shown in Table 12. Metal concentrations (Cr, Pb, Ni, Cu, Zn, Cd) were not significantly altered by biosolids or manure treatments in the soil profile compared to control treatments. When core segments were analyzed, the concentrations of Pb, Cu, and Zn were significantly higher in the top 0-30 cm segment of the soil profile compared to lower segments (Table 13) although the elevations were slight and within the range commonly found in soils. No significant mobility of metals was apparent beyond the zone of incorporation.

Recently, McBride [27] has challenged the safety of USEPA 503 Regulations as being too liberal, relying on metal-tolerant corn as the bioassay crop, and ignoring soil characteristics in establishing metal tolerances for land-applied biosolids. Results in Table

12 indicating modest changes in metal concentrations between control, biosolids, and manure treatments over the three-year period suggest that use of Best Management Practices (BMP's) can minimize risk from metals loading of agricultural land. This is supported by results of Peterson et al. [28] who showed that, after 15 years of biosolids application (0,3, and 6 dry tons/acre) to a field site on which corn was grown, no significant changes occurred in metal concentrations of the grain although a slight increase in Cu and Zn concentrations occurred compared to controls.

Seasonal Nitrate-N Release

The PSNT assay is widely used by farmers in the Northeast U.S. to predict the need for supplemental sidedressed N fertilizer for corn. Under NH growing conditions, if the PSNT value for soil NO₃-N concentration is >25 mg kg⁻¹ when corn is at the 35-40 cm growth stage, no supplemental N is recommended. Soil nitrate-N status was monitored throughout the 1994 and 1995 growing season at Site I using the PSNT assay. Results in Figure 3 show the seasonal NO₃-N for the control and the "low" rates of manure and biosolids for 1994; Figures 4 and 5 show corresponding data for both the "low" and "intermediate" rates of each amendment in 1995.

Results for 1994 show that both the release pattern and total quantity of NO₃-N differ between biosolids and manure. The soil NO₃-N levels from plots receiving 357 pounds of total N from biosolids remained at ~40-45 mg kg⁻¹ during the first half of the summer and declined steadily from mid-August to October. The pattern of release of N from manure in 1994 showed a relatively linear decrease following its spring application; NO₃-N values were equal to or lower than those in control plots. Peak NO₃-N

concentrations from biosolids were about twice those from manure and reflect the higher rates of total N which were applied from biosolids (357 lbs per acre, dry wt basis) compared to manure (279 lbs per acre, dry wt basis) during the spring broadcast application. Use of a 50% mineralization value translates to ~180 and 140 pounds of available N/acre from the above biosolids and manure treatments.

Data of 1994 suggest that, under conditions of this study, raising the mineralization rate to 50% for Concord biosolids is more appropriate than use of the 20-30% values endorsed by USEPA [10] and used to derive the loading rates of total N in 1994. On-farm use of the 50% value would lead to lower recommended application rates/acre for biosolids, translate to lower PSNT NO₃-N concentrations, and reduce risk to groundwater from NO₃-N contamination.

In 1995, use of the 50% mineralization rate formed the basis for reduced applications of manure and biosolids applications. The PSNT data for 1995 at the “low” and “intermediate” application rates for biosolids and manure (Figures 4,5) indicate that similar rates and patterns of seasonal decline for NO₃-N existed for both amendments as well as the control plots. Early season NO₃-N concentrations were slightly higher with biosolids compared to values with manure and exhibited a more rapid seasonal decline. By mid-October, 1995, NO₃-N concentrations, as measured by the PSNT assay, had declined to ~5 mg kg⁻¹ for all three treatments with the “low” application rate (Control, Manure, Biosolids) and to ~10 mg kg⁻¹ for the “intermediate” rate.

The “low” application rate for biosolids and manure in 1995 represented a total N application of 94 and 86 pounds/acre, respectively. If a N mineralization rate of 50% is

assumed, the amount of available N is 47 and 43 pounds/acre from each material. These quantities of N would be classified as low for the commercial production of silage corn in New Hampshire. In the above situation, $\text{NO}_3\text{-N}$ concentrations via the PSNT assay were below the threshold level of 25 mg kg^{-1} in late June and supplemental N, applied as a sidedressed application, would be recommended to achieve satisfactory crop yields [2].

On-farm usage of these amendments would not normally exceed the “intermediate” levels used at Site I. At Site I, the “intermediate” application rates of total N from biosolids and manure were 185 and 174 pounds/acre; PSNT $\text{NO}_3\text{-N}$ values peaked at 40 and 27 mg kg^{-1} on June 21 and declined steadily through the remainder of the growing season. By September 1, the $\text{NO}_3\text{-N}$ concentrations were 13 and 9 mg kg^{-1} for these “intermediate” rates of biosolids and manure, respectively.

The above PSNT data for 1995 in association with results of 1994 illustrates the extreme responsiveness of soil $\text{NO}_3\text{-N}$ levels to applied levels of total N in spring applications. When applied at agronomically acceptable rates/acre, both biosolids and manure yield $\text{NO}_3\text{-N}$ concentrations which decline linearly throughout the growing season and should pose little risk to groundwater quality.

Nitrate-N in Soil Water as Measured by Lysimetry

Suction lysimeters were installed at Site I four feet below the soil surface in control plots and plots receiving the highest rates of biosolids and manure. Nitrate-N concentrations from these lysimeters on six sampling dates in 1995 are given in Table

14. Both biosolids and manure results show fugitive $\text{NO}_3\text{-N}$ escaping beyond the root zone and moving downward in the soil profile with manure yielding the most $\text{NO}_3\text{-N}$. The total N applied on May 1, 1995 from this “high” treatment rate of biosolids and manure was 314 and 346 pounds/acre (Table 5), which translates to 157 and 173 pounds/acre of available N, assuming a 50% mineralization rate. These results, whereby approximately the same amount of total N is supplied from both sources, indicate a more rapid release of available N from manure compared to biosolids.

Capture of $\text{NO}_3\text{-N}$ before its movement beyond the root zone will reduce potential groundwater degradation. The most rapid development of corn root systems occurs during the first eight weeks after planting with growth generally continuing until silking [26]. If mineralization of N from biosolids is delayed in spring due to low temperatures or soil moisture, the “window” for peak N absorption may be missed thereby resulting in greater N losses to groundwater.

Because the amounts of organic and inorganic N varies widely in different organic N sources, a distinction is necessary between N availability and N mineralization. The microbial decomposition of organic N with the release of ammonium, or mineralization, is not a factor if the N already exists in an inorganic form. A ratio of organic N to inorganic N of 3.9 has been reported for solid dairy manure in samples analyzed in Ohio [23]. Ready et al. [24] found that published values for ammonia-N ranged from 6 to 75% of total N for different types of manures and management systems. Unique differences exist in the N profile of lime-stabilized, dewatered biosolids compared to dairy manure since the lime treatment to achieve biological stabilization adds Ca, raises pH, and results in very

low $\text{NH}_4\text{-N}$ concentrations due to volatilization losses. Results of Hormann et al. [25] show that the major N fraction of biosolids is in the organic form.

If the C:N ratio of the organic component of biosolids or manure is <30:1, it is justifiable to assume that all the inorganic N is immediately available. Thus, reliable assessment of N availability from materials such as biosolids and manure requires analysis of the total N, inorganic N, and (by difference) organic N fractions. The inorganic fraction is all potentially available to the crop in the year of application, and the remainder will be mineralized at a rate which depends primarily on temperature and moisture. Thus, the equilibrium between organic and inorganic forms of N is of crucial importance to the question of groundwater protection.

Nitrate Concentrations in Soil Core Segments

Nitrate-N concentrations in successive 30-cm segments of soil cores collected on October 20, 1994 at Site I to a 120-cm depth are given in Table 15. Interpretation of these data should recognize that spring tillage of the surface 20-cm of soil following broadcast application of the biosolids and manure has influenced the $\text{NO}_3\text{-N}$ distribution. The biosolids treatment shows more vertical fugitive $\text{NO}_3\text{-N}$ than the manure-treated plots with no effect from either treatment below 90-cm (3 ft) at this time. The depletion of $\text{NO}_3\text{-N}$ at the lower depths indicates a greater mineralization/availability of N from manure compared to biosolids. This pattern of an increased $\text{NO}_3\text{-N}$ depletion with soil depth in manured plots compared with a more uniform $\text{NO}_3\text{-N}$ distribution in plots amended with biosolids indicates a higher degree of available-N with manure compared with more mineralizable-N with biosolids. This interpretation is supported by the higher $\text{NO}_3\text{-N}$

levels from manured plots in lysimeter water (Table 14) which implies a greater seasonal loss of N.

Nitrate-N in Groundwater

The six SDW's were installed in the field adjacent to the Site I experiment on June 14, 1995 to a depth of ~16 feet below the soil surface to measure seasonal levels of NO₃-N. Two wells were installed in an area which had received annual manure applications for several years. Three wells were located approximately 200 feet apart in an area which had received recommended rates of biosolids in spring, 1995; the area had previously received annual manure applications. A control well was installed about 1000 distant from the above installations at the edge of a field which has been maintained as hayland for several years.

Results of NO₃-N assay in water samples from the six SDW's collected at three dates in 1995 showed a seasonal increase in NO₃-N concentration from the area which received biosolids. For example, average values (3 wells) of 7.6, 9.2, and 12.2 mg/l of NO₃-N were observed in this area on June 21, July 19 and August 28, respectively. The manured area showed average (2 wells) NO₃-N concentrations of 8.1, 10.3, and 3.5 mg/l for these three dates. The single control well gave values of 1.2, 0.8, and 1.4 mg/l NO₃-N for the respective dates. Such data supports a slower seasonal release of N with biosolids compared with manures. Because late season NO₃-N concentrations exceed the federal drinking water standard of 10 mg/l NO₃-N where biosolids have been applied, greater care is needed in their management.

Chemical analysis data show that Zn and Cu are the principal metals being added from the lime-stabilized (Concord, NH) and anaerobically digested (Hanover, NH) biosolids. The quantities of these metals being added to soil are relatively small, even at the highest application rate of biosolids. However, since the contamination of biosolids with heavy metals may lead to an accumulation in agricultural soils, this issue is of great concern to all stakeholders in biosolids management.

Biosolids are but only one anthropogenic source of metals in soils and waters. In spite of the vital importance of fertilizers for crop production, trace metal concentrations in N, P, and NPK fertilizers may contain concentrations of As, Cd, Cu, and Zn that clearly exceed the background levels of these metals in soils [21]. For example, the range of concentration of Pb and Zn in limestone was reported by Kabata-Pendias and Pendias [19] to be 20-1250 and 10-450 mg kg⁻¹ compared to a typical normal range of 2-300 and 10-300 for these two metals in soils. Fortunately, many properties of soil amendments can help to reduce the bioavailability of heavy metals. High Ca, Zn, Fe and P can notably impede the absorption of both Pb and Cd [22]. The high pH of lime-stabilized biosolids will reduce the solubility of most trace metals and the adsorption of metals to the organic matrix of biosolids further reduce their absorption by plants.

Treatment Effects on pH and Nutrient Status of Soil

Results shown in Table 17 show a soil with an initially high (6.9) pH which increased modestly to ~7.2 following soil incorporation of lime-stabilized biosolids from Concord biosolids and decreased to 6.3-6.8 after application of anaerobically digested biosolids from Hanover, NH.

Concentrations of plant-available Ca in soil over the 1993-1995 period following annual use of the biosolids showed a marked increase with Concord biosolids while levels of both Ca and Mg were generally stable or declined slightly with the application of Hanover biosolids. The low levels of K in biosolids was reflected in a decline in soil K over the three year period while soil P accumulations occurred with both types of biosolids.

Seasonal Nitrate-N Release

The PSNT assays at Site II for several sampling periods in 1994 and 1995 are given in Tables 18 and 19. Results show that early season $\text{NO}_3\text{-N}$ concentrations in soil were very high in 1994 for both biosolids treatments; comparable plot areas which received reduced applications in 1995 gave much lower $\text{NO}_3\text{-N}$ values. The high loading rates of total N in 1994 and 1995 assumed a rate of N mineralization of 30% and exceed recommended levels of available N for agronomic crops.

The rate of seasonal decline in soil $\text{NO}_3\text{-N}$ concentrations was more rapid with the anaerobically digested biosolids from Hanover compared to lime-stabilized, dewatered biosolids from the Concord WWTF. Assay of the Concord biosolids showed 98% of its total N was in organic form [5] while the range of organic-N in Hanover biosolids ranged between 70-90% (Table 8). The greater rate of disappearance of N from the Hanover product during the growing season may have resulted from (a) its higher concentration of inorganic N ($\text{NH}_4\text{-N} + \text{NO}_3\text{-N}$), (b) smaller particle size, or (c) a matrix which exhibited a higher mineralization rate. The sharp reduction in PSNT $\text{NO}_3\text{-N}$ concentrations in 1995

compared to 1994 for plots treated with Concord biosolids indicates a soil which is highly responsive to a reduced N loading.

Nitrate-N in Soil Water Via Lysimetry Sampling

The NO₃-N concentrations in soil water derived from lysimeters located four feet below the soil surface in 1995 at Site II are given in Table 20; missing data from malfunctioning lysimeters is denoted as NA.

Results indicate very high residual fertility at the site as evidenced by NO₃-N concentrations of 58-98 mg kg⁻¹ in control plots. Late season readings in soil from plots receiving Hanover biosolids were much lower than from comparable plots amended with Concord biosolids. While the Concord biosolids plots had received ~25% greater load of total N in 1995 compared to Hanover biosolids plots, their late-season NO₃-N concentrations via PSNT assay were many times higher (Table 19). These data confirm that Concord biosolids degrade at a slower rate than anaerobically digested material which yields higher later-season readings in lysimetry NO₃-N levels.

Treatment Effects on Crop Yields

Results of biosolids treatments on corn yields at Site II in 1993, 1994, and 1995 are given in Table 21. No significant effects on yields were noted in 1993 or 1995 while yield improvements occurred with higher rates of both Concord and Hanover biosolids in 1994. No yield penalty accrued from high amendment rates in any year. The marked year-to-year variation in yield was principally due to differences in rainfall.

Treatment Effects on Trace Metal Accumulation in Soil

Of the six trace metals tested, significant increases occurred only with Cu and Zn concentrations in surface soil following annual applications of both Hanover and Concord biosolids at Site II (Table 22). These data correspond to the relatively high loading rates for these metals (Table 10) which predominate in the Hanover and Concord biosolids. While increases in Cu and Zn did increase with biosolids use, the total concentration of either metal at any treatment rate was extremely low relative to reported ranges in soil (Table 1). The amount of acid extractable metal correlated strongly with application rate of both types of biosolids.

These data, illustrating modest changes in trace metal levels following application of biosolids, should provide reassurance about the safety of biosolids for several reasons. First, the actual amount of metal addition is small when agronomic rates of biosolids are used. Second, nutrient-rich and low-metal biosolids are most suitable for agricultural land. Lastly, when lime-stabilized materials are involved, their agricultural use on a specific site will likely be short-term due to rapid pH increases. Once a “target pH” is achieved, further use of biosolids would be curtailed for agronomic crops.

CONCLUSION

Field studies at two sites in New Hampshire compared landspreading of biosolids from two wastewater treatment facilities (WWTF) with dairy manure on water, crops, and soils. Chemical analysis of lime-stabilized, dewatered biosolids from the Concord WWTF showed significant variability, particularly in N, compared to the more uniform N levels in

anaerobically digested biosolids from the Hanover WWTF. Application of these amendments at low, intermediate, and high rates indicated that the major concern in their proper management will necessarily have to be with avoidance of $\text{NO}_3\text{-N}$ losses to groundwater. Their nutrient profile showed a K deficit which will require the use of supplemental fertilizer K for balanced crop nutrition. Lime-stabilized biosolids supplied abundant Ca which elevated soil pH following their land application which will dictate the frequency of usage on specific fields. Trace metal contributions to land from biosolids applied at agronomically acceptable rates will be minimal; Cu and Zn were the dominant metals in the biosolids used in this project.

Nitrate-N measurements made using the pre-sidedress N test (PSNT) and in water collected via suction lysimeters and in monitoring wells showed greater seasonal variability with biosolids compared with manure. Water samples from lysimeters located four feet below the soil surface showed greater quantities of fugitive $\text{NO}_3\text{-N}$ escaping beyond the root zone from manure-treated plots in the early summer. Results suggested a slower seasonal release of N with biosolids compared with manures which is likely due to a larger fraction of organic-N in biosolids. Nitrate-N assay in water from small monitoring wells under field areas receiving manure and biosolids showed a range of 3.5 - 12.2 mg kg^{-1} with slightly higher levels with biosolids. Use of a 50% mineralization rate (MR) with biosolids is recommended rather than risk excessive N loading by using the 20% MR endorsed by USEPA; routine use of the PSNT will assure that N needs of crops will be met without risk of degrading water quality. Reducing the variability in chemical analysis

and odor from biosolids along with modifying process engineering to create a more uniform particle for agricultural use should be goals of WWTF in the region.

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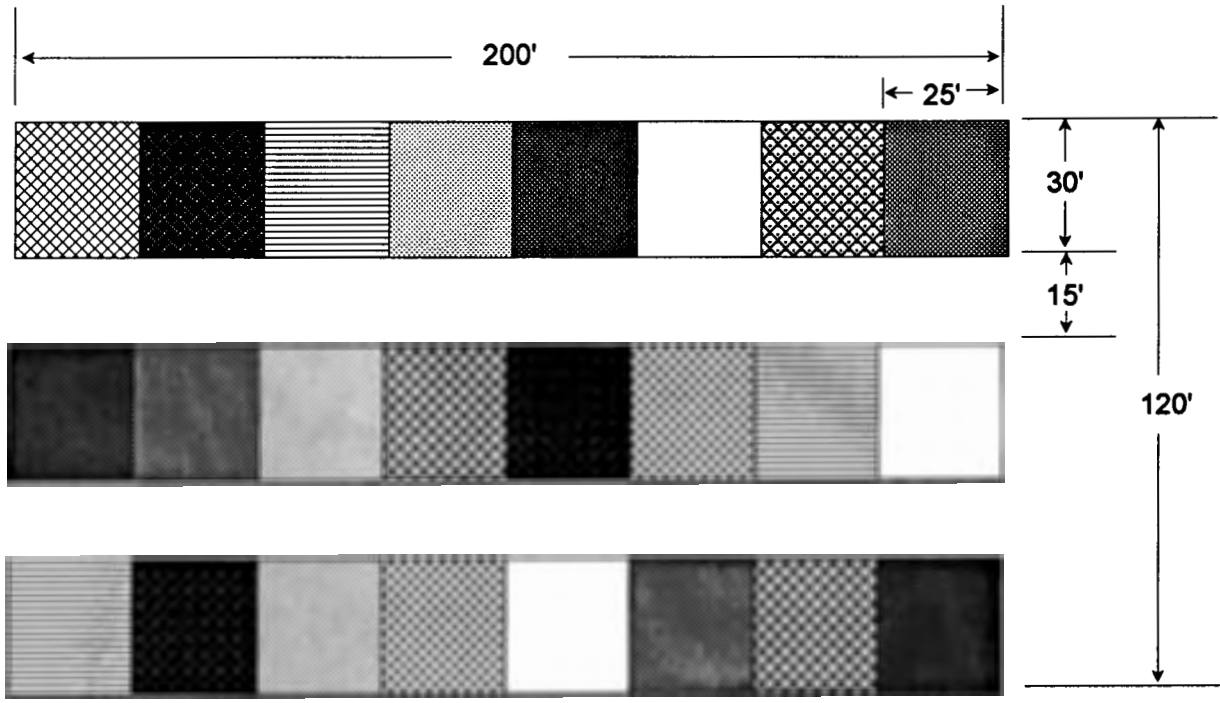
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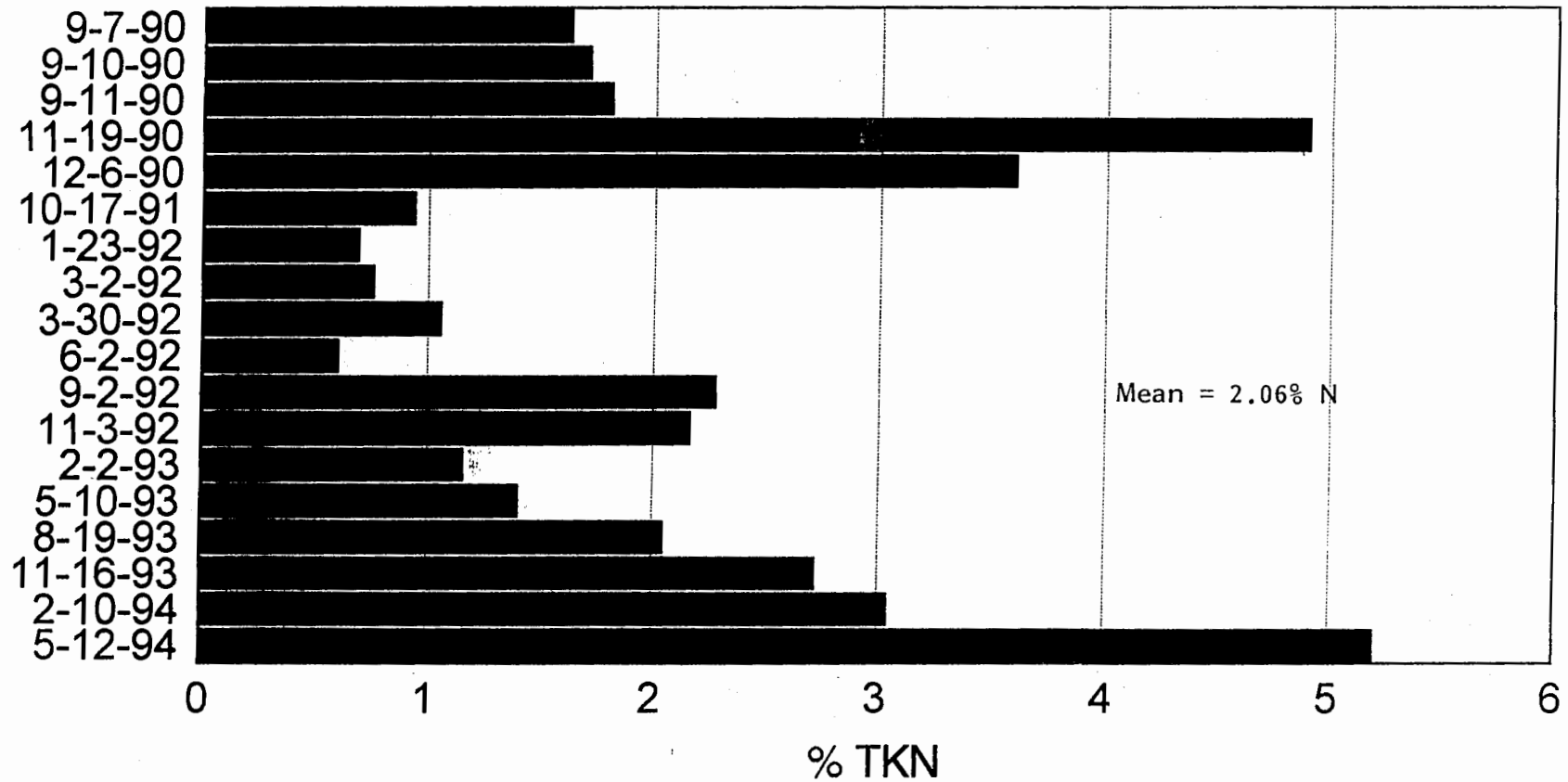


Key: Rates in T/A (DW Basis)

- | | | | |
|------------------|----------------|----------------|----------------|
| Control | Biosolids (25) | Biosolids (50) | Biosolids (75) |
| Current Practice | Manure (25) | Manure (50) | Manure (75) |

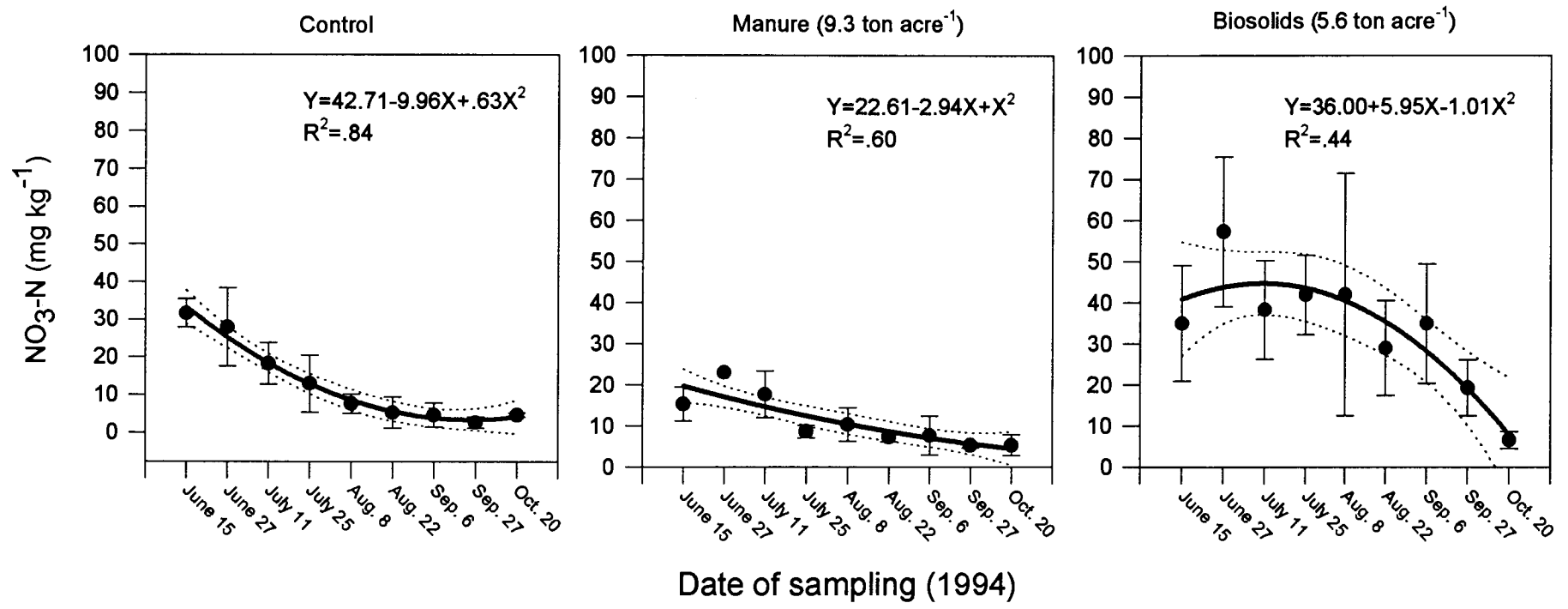
Hall Street WWTF, Concord, NH

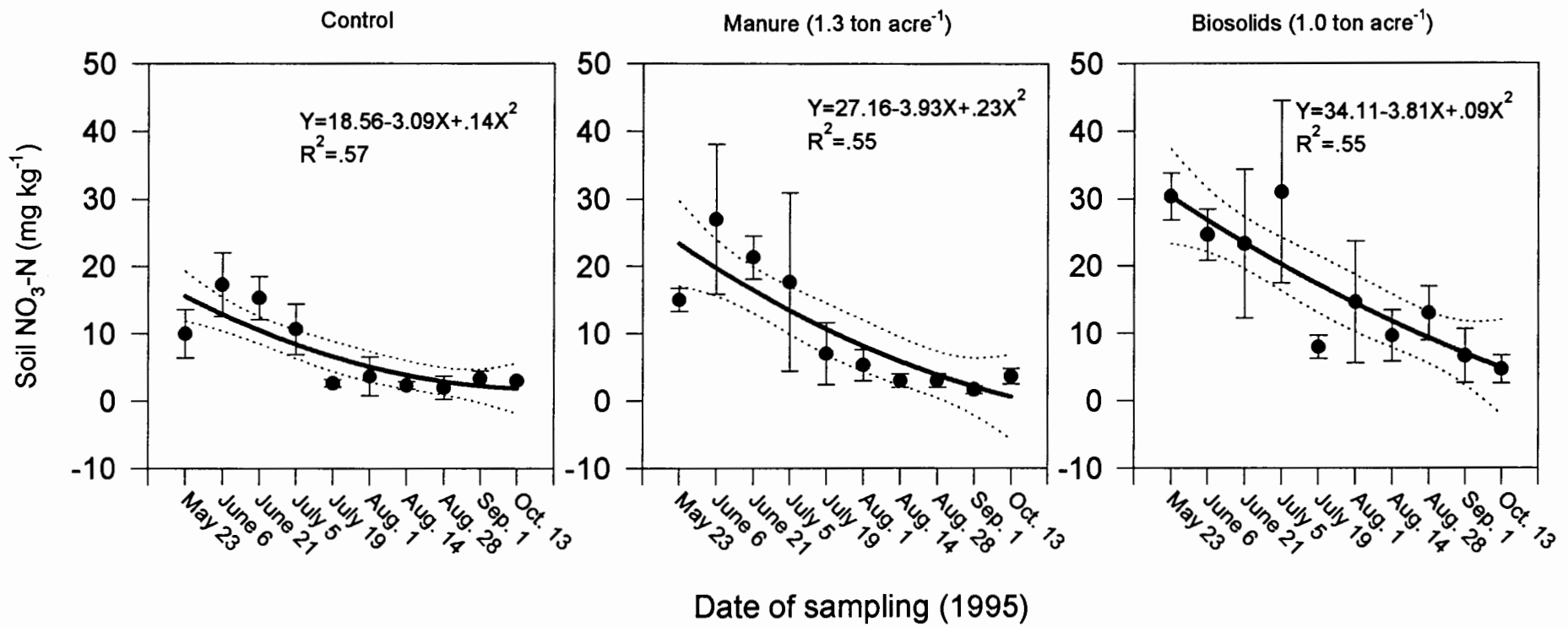
Sludge Cake Nutrient Data

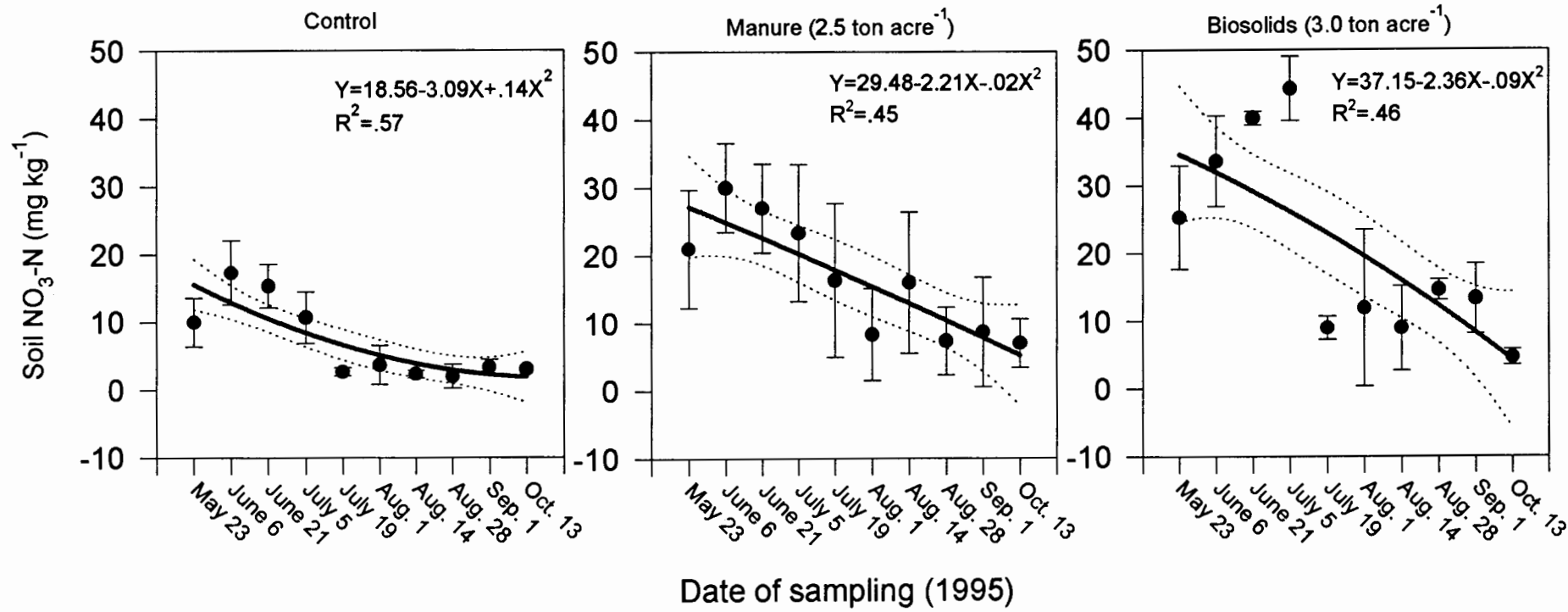


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Figure 3







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	Dry soil mean (range) (mg/kg)	Mean levels in municipal sludge ^a (mg/kg)	Range in phosphate fertilizers (mg/kg)	Mean levels in dairy manure (mg/kg)	Sludge pollutant concentration		Cumulative pollutant loading rate	
					Ceiling ^b (mg/kg)	Average ^c (mg/kg)	(kg/ha)	(ppm) ^d
As	6 (0.1-40)	10.1	2-1200	0.26	75	41	41	20.5
Cd	0.06 (0.01-0.7)	16.5	0.1-170	0.32	85	39	39	19.5
Cr	100 (5-3000)	268.0	66-245	5.2	3000	1200	3000	1500
Cu	20 (2-100)	1028.0	1-300	41.0	4300	1500	1500	750
Pb	10 (2-200)	259.0	7-225	6.6	840	300	300	150
Hg	0.03 (0.01-0.3)	19.8	.01-1.2	0.09	57	17	17	8.5
Mo	2 (0.2-5)	22.5	----	2.5	75	18	18	9
Ni	40 (10-1000)	148.0	7-38	7.8	420	420	420	210
Se	0.2 (0.01-2)	6.2	----	0.5	100	36	100	50
Zn	300 (60-2000)	1618.0	50-1450	215	7500	2800	2800	1000

^a The annual application rate for domestic septage applied to agricultural land, forest, or a reclamation shall not exceed $N/0.0026$, where N is the amount of nitrogen in pounds per acre per 365 day period needed by the crop or vegetation.

^b All pollutants must be below the ceiling concentration.

^c Monthly average concentrations cannot exceed the listed value.

^d Concentration in top 15 cm of soil, assuming soil mass of 2×10^6 kg soil/ha.

pH _(H2O)	7.2	<u>Base Saturation (Summation)</u>	
Organic Matter [†] , %	3.5	Ca, %	84.5
Organic-C, %	1.9	Mg, %	11.2
Soluble Salts, mmhos/cm	0.11	K, %	4.4
<u>Available Nutrients</u> ^{††}	mg kg ⁻¹	<u>Trace Metals</u> ^{†††}	mg kg ⁻¹
P	171	Zn	40.0
K	142	Pb	10.0
Ca	1412	Cu	8.0
Mg	112	N	5.0
		Cr	5.0
		Cd	<.01

[†] Loss-on ignition @ 550° F

^{††} Mehlich III Extraction

^{†††} Acid Extractable

Parameter	Concord Biosolids			Dairy Manure		
	1993 ¹	1994 ²	1995 ¹	1993 ¹	1994 ²	1995 ¹
	%					
Total Solids	35.69	36	41.65	20.51	31	12.12
TOC	NA	20.00	34.89	NA	19.00	44.88
TKN	.52	3.20	2.60	.84	1.50	3.40
P	1.57	1.89	2.96	.39	.04	.12
K	.08	.002	.13	.75	.20	.71
Ca	5.90	3.62	4.90	.99	.54	.46
Mg	.30	.56	.26	.47	1.32	.83
	mg kg ⁻¹					
As	3.0	3.0	4.0	0.50	0.26	0.50
Cd	3.5	5.1	9.1	0.5	2.0	11.0
Cr	127.9	22	42.0	38.6	<4.0	44.0
Cu	283.0	290	230.0	28.7	<3.0	23.0
Pb	43.9	78	55.0	2.5	2.0	2.5
Hg	2.42	1.2	3.65	0.10	0.14	0.10
Mo	9.47	120	7.50	6.38	90	8.90
Ni	27.7	34	21.0	4.7	3.0	0.5
Se	33.3	<5.0	<5.0	<5.0	<5.0	<5.0
Zn	651.6	595	470.0	164.8	NA	110.0
<i>pH</i>	<i>10.42</i>	<i>10.5</i>	<i>8.15</i>	<i>7.81</i>	<i>8.3</i>	<i>7.45</i>

¹ Assay by: Chem Serve Environmental Analysts, Milford, NH

² Assay by: The Scott Lawson Group, Ltd., Concord, NH

	Concord Biosolids				Dairy Manure				
	Tons Acre ⁻¹								
<u>1993</u>									
Wet weight	0	25.0	50.0	75.0	0	25.0	50.0	75.0	
Dry weight	0	8.9	17.9	26.8	0	5.1	10.3	15.4	
<u>1994</u>									
Wet weight	0	15.5	31.0	46.5	0	30.0	60.0	90.0	
Dry weight	0	5.6	11.2	16.7	0	9.3	18.6	27.9	
<u>1995</u>									
Wet weight	0	2.5	7.3	14.5	0	10.5	21.0	42.0	
Dry weight	0	1.0	3.0	6.0	0	1.3	2.5	5.1	

	Concord Biosolids				Dairy Manure			
	lb Acre ⁻¹							
<u>1993</u>								
N	0	92	185	277	0	86.6	173.2	259.6
P	0	279	561	841	0	40.4	80.8	121.2
K	0	13.9	27.9	41.8	0	77	154.1	230.9
Ca	0	1051	2114	3165	0	101.6	203.3	304.8
Mg	0	52.7	106.1	158.8	0	48.6	97.3	145.8
<u>1994</u>								
N	0	357.12	714.24	1071.36	0	279.00	558.00	837.00
P	0	21.05	42.10	63.14	0	8.35	16.70	25.05
K	0	<0.22	<0.45	<0.67	0	38.30	76.59	114.89
Ca	0	403.59	807.18	1210.77	0	100.38	200.77	301.15
Mg	0	62.35	124.70	187.05	0	245.39	490.78	736.17
<u>1995</u>								
N	0	94.10	157	314	0	86.5	173	346
P	0	61.63	178.75	357.51	0	31.55	63.12	126.24
K	0	2.70	7.85	15.70	0	18.07	36.14	72.28
Ca	0	102.02	259.91	591.82	0	117.07	234.14	468.28
Mg	0	5.41	15.70	31.40	0	21.12	42.24	84.48

	Concord Biosolids				Dairy Manure			
	lb Acre ⁻¹							
<u>1993</u>								
As	0	0.50	1.01	1.52	0	<0.05	<0.10	<0.15
Cd	0	0.06	0.13	0.19	0	<0.005	<0.010	<0.015
Cr	0	2.28	4.58	6.85	0	0.39	0.78	1.17
Cu	0	5.03	10.13	15.17	0	0.29	0.58	0.87
Pb	0	0.78	1.57	2.35	0	0.26	0.52	0.78
Hg	0	0.04	0.09	0.13	0	0.001	0.002	0.003
Mo	0	0.17	0.34	0.51	0	0.066	0.131	0.198
Ni	0	0.49	0.99	1.48	0	0.049	0.098	0.147
Se	0	0.59	1.19	1.78	0	0.051	0.103	0.153
Zn	0	11.6	23.3	34.9	0	1.693	3.386	5.079
<u>1994</u>								
As	0	0.03	0.07	0.10	0	0.00	0.00	0.00
Cd	0	0.06	0.11	0.17	0	<0.04	<0.07	<0.11
Cr	0	0.25	0.50	0.74	0	<0.07	<0.15	<0.22
Cu	0	3.24	6.47	9.71	0	<0.06	<0.11	<0.17
Pb	0	0.87	1.74	2.61	0	<0.37	<0.74	<1.12
Hg	0	0.01	0.03	0.04	0	0.00	0.00	0.01
Mo	0	1.34	2.68	4.02	0	1.67	3.35	5.02
Ni	0	0.38	0.76	1.14	0	<0.06	<0.11	<0.17
Se	0	<0.06	<0.11	<0.17	0	<0.09	<0.19	<0.28
Zn	0	6.64	13.28	19.92	0	<0.04	<0.07	<0.11
<u>1995</u>								
As	0	0.01	0.02	0.05	0	0.13	0.25	0.51
Cd	0	0.02	0.05	0.11	0	0.03	0.06	0.11
Cr	0	0.09	0.25	0.51	0	0.11	0.22	0.45
Cu	0	0.05	0.14	0.28	0	0.06	0.12	0.23
Pb	0	0.11	0.33	0.66	0	0.01	0.01	0.03
Hg	0	0.01	0.02	0.04	0	0.00	0.00	0.00
Mo	0	0.02	0.05	0.09	0	0.02	0.05	0.09
Ni	0	0.04	0.13	0.25	0	0.00	0.00	0.01
Se	0	0.01	0.03	0.06	0	0.01	0.03	0.05
Zn	0	<0.98	<2.84	<5.68	0	<0.28	<0.58	<1.12

	Concord Biosolids			Hanover Biosolids			
	Tons Acre ⁻¹						
<u>1993</u>							
Wet weight	0	23.7	47.4	0	9.5	21.0	30.5
Dry weight	0	8.5	16.9	0	1.7	7.4	10.7
<u>1994</u>							
Wet weight	0	22.0	44.0	0	13.3	26.5	39.8
Dry weight	0	7.9	15.8	0	2.3	4.5	6.7
<u>1995</u>							
Wet weight	0	12.0	24.0	0	12.5	25.0	37.5
Dry weight	0	4.7	9.3	0	3.0	6.0	9.0

Parameter	Concord Biosolids			Hanover Biosolids		
	1993 ¹	1994 ²	1995 ¹	1993 ¹	1994 ²	1995 ¹
	%					
Total Solids	35.7	36.0	38.8	17.9	17.0	24.0
TOC	NA	20.00	34.89	NA	NA	NA
TKN	.52	3.20	2.60	5.00	5.40	5.20
Total Org. N	NA	NA	NA	3.50	4.87	NA
P	1.57	.19	2.96	1.62	1.70	1.96
K	.08	.002	.13	.23	.12	.20
Ca	5.90	3.62	4.90	2.17	2.00	1.70
Mg	.30	.56	.26	NA	NA	.48
	mg kg ⁻¹					
As	3.0	3.0	4.0	0.75	NA	NA
Cd	3.5	5.1	9.1	5.00	NA	2.70
Cr	127.9	22	42.0	147.0	NA	16.9
Cu	283.0	290	230.0	18.11	NA	228.00
Pb	43.9	78	55.0	90.0	NA	24.00
Hg	2.42	1.2	3.65	6.64	NA	NA
Mo	9.47	120	7.50	61.0	NA	NA
Ni	27.7	34	21.0	33.0	NA	11.60
Se	33.3	<5.0	<5.0	1.0	NA	NA
Zn	651.6	595	470.0	1787.0	NA	790.00
<i>pH</i>	<i>10.4</i>	<i>10.5</i>	<i>8.2</i>	<i>7.4</i>	<i>7.4</i>	<i>7.4</i>

¹ Assay by: Chem Serve Environmental Analysts, Milford, NH

² Assay by: The Scott Lawson Group, Ltd., Concord, NH

	Concord Biosolids			Hanover Biosolids			
	lb A ⁻¹						
<u>1993</u>							
N	0	84.7	174.9	0	167	370	537
P	0	265.3	530.6	0	54.1	119.9	174.0
K	0	10.2	26.4	0	7.7	17.0	24.7
Ca	0	1007	2014	0	72.5	160.6	233.1
Mg	0	50.1	100.3	0	NA	NA	NA
<u>1994</u>							
N	0	507	1014	0	244	487	731
P	0	29.9	59.8	0	76.8	153.2	230.0
K	0	<0.3	<0.6	0	5.34	10.8	16.2
Ca	0	573	1145	0	90.4	180.2	270.6
Mg	0	NA	NA	0	NA	NA	NA
<u>1995</u>							
N	0	389	778	0	312	624	936
P	0	300	600	0	118	235	353
K	0	24	48	0	12	24	36
Ca	0	1656	3312	0	102	204	306
Mg	0	79.2	158.4	0	28.8	57.6	86.4

	Concord Biosolids			Hanover Biosolids			
	lb A ⁻¹						
<u>1993</u>							
As	0	0.470	0.958	0	0.002	0.006	0.008
Cd	0	0.051	0.102	0	0.017	0.037	0.054
Cr	0	2.149	4.298	0	0.491	1.088	1.579
Cu	0	4.788	9.576	0	6.05	11.34	19.45
Pb	0	0.744	1.488	0	0.301	0.666	0.967
Hg	0	0.034	0.068	0	0.022	0.049	0.071
Mo	0	0.152	0.304	0	0.204	0.451	0.655
Ni	0	0.469	0.938	0	0.102	0.244	0.354
Se	0	0.558	1.116	0	0.003	0.007	0.011
Zn	0	11.03	22.06	0	5.97	13.22	19.19
<u>1995</u>							
Cd	0	0.02	0.04	0	0.02	0.03	0.05
Cr	0	2.41	4.82	0	0.10	0.20	0.30
Cu	0	3.36	6.72	0	1.37	2.74	4.10
Pb	0	1.20	2.40	0	0.14	0.29	0.43
Ni	0	0.55	1.10	0	0.07	0.14	0.21
Zn	0	9.76	19.52	0	4.74	9.48	14.22

Treatment	Date of Sampling																			
	Initial: 4/28/93					7/13/93					7/25/94					5/11/95				
	pH	K	P	Ca	Mg	pH [†]	K [†]	P [†]	Ca [†]	Mg [†]	pH [†]	K [†]	P [†]	Ca [†]	Mg [†]	pH [†]	K [†]	P [†]	Ca [†]	Mg [†]
-----mg/kg-----					-----mg/kg-----					-----mg/kg-----					-----mg/kg-----					
Control	7.2	142	171	1412	112	7.3a	132b	333a	2193c	122a	7.3a	139c	402a	2524a	116d	7.53bc	137cd	344a	2009b	82d
Current Practice	7.2	142	171	1412	112	7.2ab	143b	333a	1793f	135a	7.1a	173bc	433a	1941a	152cd	7.47cd	155abcd	421a	2039b	154bc
Biosolids, 25 tons/Acre	7.2	142	171	1412	112	7.0b	129b	295ab	1916d	128a	7.1a	113c	404a	2926a	125cd	7.63ab	142cd	406a	2855ab	105cd
Manure, 25 tons/Acre	7.2	142	171	1412	112	7.2ab	147b	323a	1779ef	141a	7.2a	187bc	443a	1985a	165c	7.37d	173abc	437a	1954b	152bc
Biosolids, 50 tons/Acre	7.2	142	171	1412	112	7.0b	119b	305ab	2391b	130a	7.1a	109c	441a	2867a	119d	7.70a	107d	450a	3502a	117cd
Manure, 50 tons/Acre	7.2	142	171	1412	112	7.2a	172ab	254b	1814e	135a	7.2a	245ab	466a	2643a	204b	7.40cd	207ab	476a	2528ab	182b
Biosolids, 75 tons/Acre	7.2	142	171	1412	112	7.0b	210a	310ab	2678a	190a	7.1a	150c	465a	2962a	137cd	7.70a	146bcd	408a	3565a	123cd
Manure, 75 tons/Acre	7.2	142	171	1412	112	7.1ab	205a	259b	1793e	165a	7.2a	311a	489a	2537a	253a	7.37d	215a	429a	2193b	242a

† Values followed by the same letter(s) within a column do not differ significantly at (P<0.05) according to Duncan's multiple range test.

Treatment	Cr	Pb	Ni	Cu	Zn	Cd
	mg kg ⁻¹					
Control	6.6	5.5	6.3	6.5	42.3	<0.1
Biosolids	8.0	7.2	7.8	8.2	47.4	<0.1
Manure	8.0	6.7	7.6	7.0	42.7	<0.1

Depth	Cr	Pb	Ni	Cu	Zn	Cd
cm	mg kg ⁻¹					
0-30	7.1	8.6 a	7.1	8.2 a	49.6 a	<0.1
30-60	7.9	6.1 b	7.6	7.3 ab	43.3 b	<0.1
60-90	7.7	5.6 b	7.4	6.8 b	42.9 b	<0.1
90-120	7.4	5.9 b	7.0	6.7 b	40.8 b	<0.1

Treatment	June 21	July 7	July 19	Aug. 1	Aug. 14	Aug. 28
	----- mg/l -----					
Control	12.9	11.2	8.8	11.9	6.9	2.2
Biosolids (75 T/A)	11.4	11.1	16.0	20.2	21.5	20.4
Manure (75 T/A)	27.1	28.2	29.6	36.0	29.2	29.2

Depth (cm)	Control	Biosolids (75T/A)	Manure (75 T/A)
		----- ppm -----	
0-30	9.0	31.3	28.3
30-60	12.0	48.7	13.7
60-90	4.3	36.0	5.7
90-120	4.0	2.5	2.5

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<u>Treatment</u>	<u>1993[†]</u>	<u>1994[†]</u>	<u>1995[†]</u>
	-----Dry Matter Yield, tons/Acre-----		
Control	7.5a	10.1a	7.7a
Current Practice	8.0a	9.6a	9.7a
Biosolids, 25 tons/Acre	8.0a	9.3a	8.9a
Manure, 25 tons/Acre	8.0a	8.9a	10.0a
Biosolids, 50 tons/Acre	7.8a	8.5a	9.7a
Manure, 50 tons/Acre	7.6a	8.6a	10.8a
Biosolids, 75 tons/Acre	7.6a	8.5a	8.7a
Manure, 75 tons/Acre	8.0a	9.1a	9.1a

[†]Values followed by the same letter(s) within a column do not differ significantly at (P<0.05) according to Duncan's Multiple Range Test.

Treatment	Date of Sampling																			
	Initial: 5/18/93					9/30/93					10/13/94					10/10/95				
	pH	K	P	Ca	Mg	pH	K	P	Ca	Mg	pH [†]	K [†]	P [†]	Ca [†]	Mg [†]	pH [†]	K [†]	P [†]	Ca [†]	Mg [†]
-----mg/kg-----					-----mg/kg-----					-----mg/kg-----					-----mg/kg-----					
Control	6.9	126	47	2056	164	7.1	145	51	2154	145	6.9a	144a	58b	2148bc	155a	7.2a	111a	52c	2555ab	150a
Hanover Biosolids, 25 tons/Acre	6.9	126	47	2056	164	6.9	148	54	1897	148	6.7b	100b	52b	2021cd	155a	6.8b	71a	58c	2212bc	143a
Hanover Biosolids, 50 tons/Acre	6.9	126	47	2056	164	6.7	136	43	1704	136	6.3c	101b	60b	1684e	130a	6.4c	82a	65bc	1769cd	124a
Hanover Biosolids, 75 tons/Acre	6.9	126	47	2056	164	6.6	154	74	1783	154	6.1c	113b	91a	1777de	135a	6.3c	86a	78ab	1707d	114a
Concord Biosolids, 25 tons/Acre	6.9	126	47	2056	164	6.9	153	49	2190	153	7.0a	114b	67b	2371b	153a	7.3a	88a	66bc	2930a	143a
Concord Biosolids, 50 tons/Acre	6.9	126	47	2056	164	6.7	133	51	2044	133	7.0a	153a	96a	2890a	153a	7.2a	101a	87a	3000a	128a

[†]Values followed by the same letter(s) within a column do not differ significantly at (P<0.05) according to Duncan's multiple range test.

<u>Treatment</u>	<u>Date of Sampling</u>		
	<u>June 29</u>	<u>August 10</u>	<u>October 13</u>
	-----mg kg ⁻¹ -----		
Control	26	3	7
<u>Hanover</u>			
25 Tons Acre ⁻¹	56	19	14
50 Tons Acre ⁻¹	73	27	19
75 Tons Acre ⁻¹	119	54	61
<u>Concord</u>			
25 Tons Acre ⁻¹	74	53	39
50 Tons Acre ⁻¹	103	123	66

Treatment	Date of Sampling			
	June 2	July 31	Aug. 15	Oct. 10
	mg kg ⁻¹			
Control	23.3	29.5	17.3	4.3
Hanover Biosolids, 25 tons/Acre	43.0	40.6	13.3	9.0
Hanover Biosolids, 50 tons/Acre	60.0	37.6	37.6	23.3
Hanover Biosolids, 75 tons/Acre	59.0	47.7	47.6	18.6
Concord Biosolids, 25 tons/Acre	25.3	57.6	34.0	11.7
Concord Biosolids, 50 tons/Acre	57.3	42.6	53.0	39.0

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Treatment	Date of Sampling					
	July 12	July 24	Aug.15	Sep. 25	Oct. 10	Nov.1
	mg kg^{-1}					
Control	90.5	NA	88.1	98.1	58.3	79.3
Hanover Biosolids, 25 tons/Acre	NA	NA	NA	18.1	17.7	22.1
Hanover Biosolids, 50 tons/Acre	NA	NA	NA	96.4	63.9	93.1
Concord Biosolids, 25 tons/Acre	82.0	92.4	96.4	127.0	156.6	206.9
Concord Biosolids, 50 tons/Acre	69.0	73.8	67.5	193.8	290.2	401.6

<u>Treatment</u>	<u>1993</u>	<u>1994</u>	<u>1995</u>
	-----Dry matter yield, tons/Acre-----		
Control	5.47a [†]	6.40c [†]	2.46a [†]
Hanover Biosolids, 25 tons/Acre	5.98a	6.93bc	2.66a
Hanover Biosolids, 50 tons/Acre	6.39a	8.82a	2.71a
Hanover Biosolids, 75 tons/Acre	5.85a	7.56ab	2.68a
Concord Biosolids, 25 tons/Acre	5.80a	6.78bc	2.62a
Concord Biosolids, 50 tons/Acre	6.01a	7.43ab	2.59a

†Values followed by the same letter(s) within a column do not differ significantly at (P<0.05) according to Duncan's Multiple Range Test.

<u>Treatment</u>	Copper ^{††}	Zinc ^{††}
	-----mg/kg-----	
Control	1.8d	7.4c
Hanover Biosolids, 25 tons/Acre	4.0c	8.1bc
Hanover Biosolids, 50 tons/Acre	6.2b	11.6ab
Hanover Biosolids, 75 tons/Acre	7.7a	14.2a
Concord Biosolids, 25 tons/Acre	2.9cd	10.8abc
Concord Biosolids, 50 tons/Acre	4.2c	13.8a

[†] Acid Extraction via 8 N HNO₃.

^{††} Values followed by the same letter(s) within a column do not differ significantly at (P<0.05) according to Duncan's Multiple Range Test.