ISTC Reports
Illinois Sustainable Technology Center

Dredged Sediment: Application as an Agricultural Amendment on Sandy Soils

Robert G. Darmody
Dorivar Ruiz Diaz
University of Illinois

TR-066
August 2017
www.istc.illinois.edu

ILLINOIS SUSTAINABLE
TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

TR-066

Dredged Sediment: Application as an Agricultural Amendment on Sandy Soils

Robert G. Darmody
Dorivar Ruiz Diaz
University of Illinois

August 2017

Submitted to the
Illinois Sustainable Technology Center
Prairie Research Institute
University of Illinois at Urbana-Champaign
www.istc.illinois.edu

Printed by the Authority of the State of Illinois
Bruce Rauner, Governor

Acknowledgments

People who helped with the fieldwork and in other ways on this project include John C. Marlin, Alexandra Sie, Robert Stahl, and James Lang. Funding was provided by the Illinois Sustainable Technology Center through the Illinois Hazardous Waste Research Fund (Grant Number: HWR02-176).

Table of Contents

List of Tables

List of Figures

List of Photos

Abstract

Periodic dredging of lakes and waterways generates large amounts of material, often stored indefinitely in extensive sediment basins. A proposed dredging project in the Peoria Lake portion of the Illinois River will generate an abundant amount of sediments. This study proposed using sediments dredged from the Illinois River to enhance sandy soils as sediments often have high nutrient levels and physical properties that are desirable for agricultural production. Dredged sediments may greatly improve extensive areas along the Illinois River that have sandy soils with poor physical properties. We built research plots using Peoria Lake sediment at 0, 7, 15, and 30 cm thicknesses applied to the surface of Plainfield sand. Corn and soybean plants were grown on the plots for four years. An analysis of chemical and physical properties of soil treatments revealed a significant improvement in water holding capacity, cation exchange capacity, and the nutrient content of the soil. Animal damage to plants in the experiment, including the excavation and consumption of seeds after planting and grain before harvest, complicated the interpretation of treatment effects. However, a significant plant response was observed when the sediments were applied. In corn, higher vegetative growth and grain yields were observed in plots treated with surface-applied sediment. With soybeans, vegetative growth was greater on sediment plots than on corn plots; however, treatment effects were not as dramatic as with corn, and the highest soybean yields were observed in the 15 cm sediment plots. Concentrations of metals in soils and plant tissues were within levels considered to be normal. However, molybdenum (Mo) levels in soybean grain were found above levels considered to be safe for livestock fodder if the copper (Cu) content was low in ruminants' diets. High Mo levels are a common problem in certain US soils, easily solved by providing feed supplements to ruminants. Polychlorinated biphenyl (PCB) levels in soybeans were below the detection level (17 $\mu g\ kg^{-1}$) for four of six samples from the sediment plots. The other two had levels of 21 and 22 $\mu g\ kg^{-1}$. We concluded that Peoria Lake sediments hold promise as a topsoil additive when applied to sandy soils.

Introduction

The dredging history in Illinois dates back to the 1800s when the Federal Rivers and Harbors Act authorized navigational improvements on the Ohio and Mississippi Rivers. Waterways of the Mississippi, Ohio, and Illinois Rivers were dredged to maintain a minimum depth for navigation in the river channels (Fitzpatrick and Stout, 1988). Likewise, throughout the US and the world, river and harbor dredging over the years has generated vast quantities of materials, and disposal options continue to become increasingly limited and expensive.

Currently, proposed dredging activity in the Illinois River is more oriented to restoring wildlife habitats and aquatic environments. In the past, the river was a productive ecosystem, and now it is severely affected by sedimentation and the consequent loss of water depth. This high rate of sedimentation is especially severe in wide segments of the river such as the Peoria Lakes. Sedimentation also affects many other state water bodies, including rivers and reservoirs used for municipal water, by reducing their storage capacities. For example, Lake Decatur in central Illinois lost an average of 0.53% of its capacity annually between 1922 and 1983. During that time, its average depth decreased from 3 to 2 meters (Darmody and Marlin, 2002). Bottomland lakes in the Illinois River valley lost an estimated average of 72% of their water storage capacity to sedimentation by 1990 (Demissie, 1997).

A proposed dredging project in the Peoria Lakes portion of the Illinois River, designed to restore the ecology and enhance recreation, could produce as much as 119×10^6 m^3 of sediments (Darmody et al., 2004). Placement of this large volume of dredged sediment is problematic and highlights the need for alternative beneficial uses.

The difficulty of depositing large amounts of material dredged each year has led to a national search for a beneficial use of sediments (Landin, 1997). Sediments can be used for many applications, including fill, beach nourishment, wetland creation, and as a landscaping soil (Darmody and Marlin, 2002). For example, material removed from Lake Springfield and Lake Paradise in central Illinois was shown to have the potential to increase crop yields on eroded soils (Olson and Jones, 1987; Lembke et al., 1983). Potomac River sediments were used as topsoil to rehabilitate sand and gravel borrow pits in Virginia (Daniels et al., 2007). Marine sediments are salty, may be pyrite-rich, and can form acid sulfate soils upon weathering. Some harbor sediments may also be heavily contaminated with pollutants (USEPA, 2005). In contrast, many river sediments are relatively uncontaminated and contain no salts or pyrite that would complicate sediment use and management. Indeed, the federal interagency National Dredging Team has prioritized moving suitable materials to upland beneficial-use environments rather than disposing them in impoundments (USEPA, 2003). Given their high soil fertility, organic matter, and water holding capacity, adding dredged sediments to poor soils could greatly benefit agricultural production (Darmody and Marlin, 2002; Darmody et al., 2004; Lee, 2001; Ruiz Diaz et al., 2010). The placement of dredged sediments and their beneficial uses are issues of worldwide concern: Brazil, England, China, Belgium, Ireland, and the Netherlands all have active research projects involving the beneficial use of sediments (Singh et al., 1998; Almeida et al., 2001; Cook and Parker, 2003; Vermeulen et al., 2003, 2005; Sheehan et al., 2010).

Agricultural Use of Dredged Sediment

Some greenhouse experiments have been conducted to evaluate dredged sediment as a potential amendment for poor soils, but field-based research is rare. Olson and Jones (1987) found that dredged sediments had a similar total porosity and higher water retention compared to local topsoil, as well as other characteristics significantly favorable for plant growth. Silty sediments from the Potomac River, when applied in a layer 1–2 m thick, supported exceptional growth of corn in Virginia (Daniels et al., 2007). Lembke et al. (1983) found that dredged sediments from central Illinois had a much darker color than the topsoil when placed in agricultural plots, indicating a higher organic matter content. In addition, plant growth was significantly higher in sediment treatments compared to reference soils, and plots with sediment showed less moisture stress, perhaps due to the greater water holding capacity from the additional organic matter content (Lembke et al., 1983). Typically, the texture of sediments from the Peoria Lake portion of the Illinois River is silt loam to silty clay, similar to the texture of productive Mollisols in Illinois (Darmody and Marlin, 2002).

Considering their texture, water holding capacity, cation exchange capacity (CEC), and fertility, sandy soils are generally less favorable for agricultural production. Adding dredged sediment to soils with poor agricultural characteristics could increase productivity enormously. Canet et al. (2003) conducted greenhouse experiments to evaluate the improvement of local sandy soils using dredged sediment from Albufera Lake in eastern Spain, obtaining significant improvements in characteristics such as soil water retention, CEC, and nutrient content. In addition, lettuce yield and nutrient content increased with sediment application (Canet et al., 2003).

Dredged sediment has also been used as a substrate for willow trees (Vervaecke et al., 2001). In this case, the sediment was shown to provide sufficient available nutrients (nitrogen [N], potassium [K], and calcium [Ca]) for optimal plant development. In addition, foliar N, phosphorus (P), K, Ca, and magnesium (Mg) concentrations were comparable to the nutrient concentrations of willows growing on fertile arable soils. Dredged lake-bottom sediment has been applied to an agricultural soil without impairing plant growth, and, in fact, led to increases in N, P, and K uptake in corn, soybeans, and sunflowers proportional to the amount of sediment mixed with sandy soils (Howard, 1999).

Metals in Sediments

Rivers often receive industrial and municipal wastes, thus the presence of heavy metal pollutants in dredged freshwater sediments used on agricultural land is a concern. However, it is important to consider that significant variability in the types and concentrations of metals found in sediments depends on the type of pollutants entering the water. In addition, plant availability of metals varies with other chemical and physical sediment properties. Ecotoxicity, the overriding issue for most sediment quality research, involves the placement of highly contaminated sediments. However, despite considerable discussion on acceptable contaminant levels, no universal standards exist (Choueri et al., 2009).

The potential phytotoxicity of metal pollutants was measured using land-applied dredged sediment from the Hangzhou section of the Grand Canal in China (Chen et al., 2002). This section of the canal was highly polluted by industrial wastewater and sewage discharge.

However, sediment did not adversely affect plant growth. The final recommendation was to apply up to a 15 cm thick layer of sediment for agricultural purposes. In addition, trees planted on contaminated sediments in England did result in phytoremediation (King et al., 2006), and, in a greenhouse study, *Salix* growth decreased the mobility of zinc (Zn) and cadmium (Cd) in sediments (Bedell et al., 2009). In another study of more than 20 years of field-based sediment experiments (Vandecasteele et al., 2009), Zn and Cd increased in the surface soil because of *Salix* leaf drop. Other studies involving biomagnification of metals from land-placed contaminated sediments did not indicate consistent patterns; for example, mice living on sediments did not have elevated Pb levels (Beyer et al., 1990). In general, a long-term prediction of metal migration in contaminated sediments is uncertain (Tack et al., 1999).

Many chemical and physical changes occur in dredged sediments during dewatering and aeration, a process known in Holland as “ripening” (Vermeulen et al., 2003). This process needs to be studied in more detail because simple quantitative arguments are often not sufficient to explain the release of metallic pollutants. Therefore, more knowledge about speciation could be the key to a better understanding of metallic compounds-release in dredged sediment. However, studies have shown that during the early stages of ripening, the solubility of metals increases rapidly. This rapid increase is likely associated with the pH decrease related to iron-sulfide oxidation in sulfide-rich sediments (Caille et al., 2003; Cappuyns et al., 2006). Caution must be used when interpreting sediment studies because of the highly variable nature of the material. Indeed, a two-year field study in France indicated that seasonal variation in Zn and Cd mobility exceeded long-term trends (Piou et al., 2009).

Metal analysis of dredged sediment from the Peoria Lake portion of the Illinois River demonstrated that all elements were within ranges commonly found in Illinois soils, except for Cd and lead (Pb), which were slightly higher than the Illinois Environmental Protection Agency (IL EPA) statewide soil mean. However, metal levels were below the US Environmental Protection Agency (USEPA) 503 regulations regarding concentrations for biosolids applied to land (Darmody and Marlin, 2002).

Compared to Illinois topsoil, the Peoria Lake sediment had higher concentrations of most common soil elements, especially Ca and Mg, which are biologically magnified by mollusks. Industry-related metals (Cd, Zn, and Pb) were also present in relatively greater concentrations; however, the only elements that exceeded a national survey of uncontaminated agricultural soils were Cd and Zn. None of the sediment levels exceeded concentration ranges of industry contaminants nor common soil elements observed in a statewide survey of Illinois soils (Darmody et al., 2004).

Metal uptake measured in tomatoes grown on Peoria Lake sediments was not significantly different from that in plants grown on natural topsoil in greenhouses or local gardens. Levels of metals in barley, snapbeans, lettuce, and radishes were relatively higher in sediment than topsoil, but were not considered excessive (Darmody et al., 2004). Likewise, vegetables grown on sediment from the Lower Peoria Lake reach of the Illinois River did not contain excessive levels of metals (Ebbs et al., 2006). Inherent properties of dredged sediment from the Illinois River such as high pH, fine texture, and high CEC could contribute to the low mobility and plant availability of metals, reducing the possibility of plant uptake or leaching of pollutants once applied to land (Darmody and Marlin, 2002). A potential way to reduce plant uptake of metals is by mixing biosolids with sediment, which has been shown to improve soil physical properties and lessen Mo uptake in the greenhouse (Ruiz Diaz, 2010).

A long-term field-based evaluation of the effects of dredged sediment on soil properties and agricultural production can provide more knowledge about this material as a soil amendment. Crop yields are usually poor on sandy soils, so any improvement of the soil quality or crop production attributed to the addition of sediment will support the hypothesis that Illinois River sediment can benefit these soils. This hypothesis may also indicate the potential of sediments to address problem soils in other situations including landfill covers, severely eroded soils, strip-mined areas, and brownfields.

Objectives

The hypothesis tested in this project is that sediments will improve the productivity, moisture holding capacity, and fertility of sandy soils. The specific objectives of this research were to determine:

- the impact of sediment application on sandy soils;
- the yield of corn and soybeans grown on sediment-treated sandy soils;
- the effect of the thickness of sediments applied to sandy soils; and
- metal uptake by crops grown on sediment-treated soils.

Materials and Methods

Sediment and Research Plots

Dredged sediment was obtained from the Lower Peoria Lake on the Illinois River at East Peoria, Illinois (river mile 165) (Figure 1). The experiment was performed on a Bloomfield sand soil series (sandy, mixed, mesic Lamellic Hapludalf). Poor water holding capacity and fertility are some of the main limitations of this soil for agricultural production, but widely used irrigation and fertilization (often as fertigation) allow the use of this soil type for row crops (Calsyn, 1995). Crop production levels in sandy soils are relatively low compared with typical Illinois Mollisols (Table 1). The project research plots were located at the University of Illinois Sand Farm (hereafter, the Sand Farm), in Kilbourne of Mason County in Illinois (Figure 1). This is an area of wind-blown sand from the Holocene, producing the still noticeable sand dunes in the area. The farm is surrounded by forest land, home to many corn- and soybean-consuming animals such as deer, raccoons, and squirrels. Animal damage to plants in the experiment, including the excavation and consumption of seeds after planting and consumption of grain before harvest, was recorded.

Figure 1. Location of the source of sediments and the experiment site in Illinois. Star locates the University of Illinois.

Table 1. Agricultural characteristics of the Bloomfield Sand and Drummer Silty Clay Loam in optimum conditions. †

Properties	Bloomfield Fine Sand	Drummer Silty Clay Loam
Subsoil Rooting:	Favorable	Favorable
Corn Yield (kg ha^{-1}):	6,522	10,974
Soybeans Yield (kg ha^{-1}):	2,069	3,574
Wheat Yield (kg ha^{-1}):	2,759	4,139
Oats Yield (kg ha^{-1}):	3,324	5,644
Grass - Legumes Yield (hay ton/ac):	3.50	5.09
Nitrogen Loss Potential:	High	High
P Subsoil:	Low	Low
Cation Exchange Capacity:	Low	High
Lime Group:	D	A
Organic Matter, Ap (%):	1.25	6.00
Minimum Slope (%):	1	0
Maximum Slope (%):	60	2

†Adapted from the Illinois Agronomy Handbook (University of Illinois Extension, 2002).

Bloomfield Sand was the soil at the experimental sediment addition plots; Drummer is a near ideal agricultural soil used for comparison.

The sediment was removed by a clamshell dredging bucket in May 2000, placed on deck barges, and loaded on dump trucks. The wet sediment was transported for storage in a gravel pit near Peoria, where dewatering and some weathering occurred. In May 2001, 89 tons of sediment was trucked to the sand farm to build the plots (Photo 1). No pretreatments were applied to the sediment prior to use. Plots were not constructed all at the same time (span of three years) because of logistical issues and other problems. Not enough sediment was available to construct the 30 cm plot in the west block during the first year, so the west block served as an additional check plot that year. In addition, note that while extracting the sediment from the gravel pit and temporary storage and loading the trucks, the sediment was mixed with small amounts of other materials including coal, tar, and asphalt. This process was exacerbated by storing the sediment on a gravel/asphalt parking lot before use. During the experiment, some of the foreign matter was removed from the plots by hand as time permitted. For this reason, some amount of foreign materials can be observed in the plots, especially the ones constructed in 2001 (east block and plots 3 and 4 from the west block). This is not the case with the plots that were constructed in 2002 (plot 2 from the west block and plots 3 and 4 from the mixed block) and 2003 (plot 1 of the mixed block), which were constructed with clean sediment.

Photo 1. Soil materials used at the Sand Farm research site; A, sediment as delivered to site; B, Bloomfield Sand core showing thin, weak A horizon on right; C, Bloomfield sand core with 30 cm applied sediment; D, 30 cm sediment core showing some mixing at the interface.

The sediment dewatered in storage, so it could be manipulated as a solid. Sediments were spread out at appropriate depths in research plots with a front-end loader. The existing soil was removed to the necessary depth, and the sediments were backfilled into the resulting pits (Figure 2). The original plot design was a randomized complete block consisting of two blocks each with four treatments of sediment thicknesses, 0, 7.6, 15, and 30 cm. Plots within blocks were 6.1 m x 12.2 m and were split in half to accommodate corn and soybeans in alternate years in each plot (Figure 3). With available resources, the plots were expanded to include a third block with control (0 sediment) plots and plots where 7.6 and 15 cm of sediment were mixed via aggressive tillage into the sand. After the 2002 growing season, an irrigation system was installed to supplement natural rainfall. All plots were equally irrigated as necessary to ensure plant growth (Appendix I). The irrigation rate was less than the conventional application rate. The plots were dismantled in October, 2004.

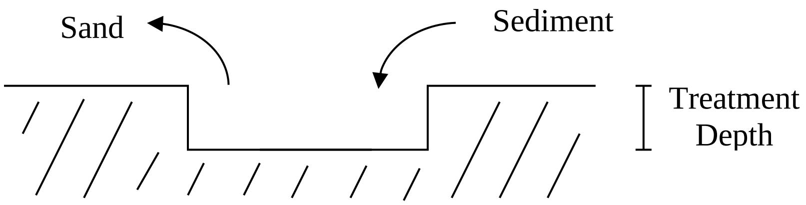


Figure 2. Plot construction schematic of non-mixed plots.

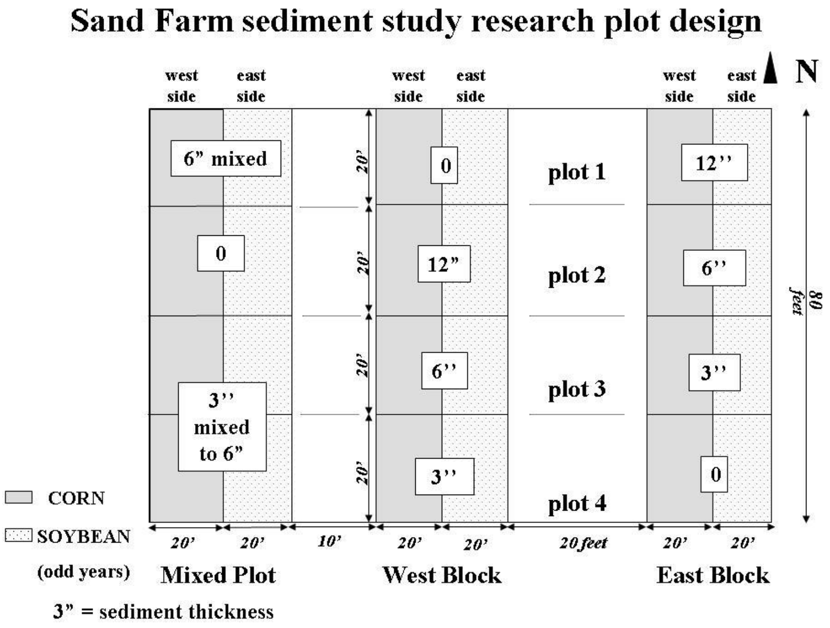


Figure 3. Final experimental plot design at the sediment research site at the University of Illinois Sand Farm.

Experimental Design

The experiment was analyzed as a complete randomized design (CRD) composed of three treatments (sediment thickness) and one control (local soil with no treatment). The design included at least two replications of each treatment, and each plot was divided into two sub-plots, one for soybeans, and the other for corn in alternate years (Figure 3). The designed thicknesses of sediments were 0, 7, 15, and 30 cm (0, 3, 6, and 12 in.). A standard production system of soybean-corn rotation was applied.

The experiment was repeated for four years, allowing time for soil physical and chemical changes associated with soil formation. The design was not established completely the first year, and certain changes in the design occurred from year 1 to year 3, specifically, the addition of more plots to expand and complete the original design (Figure 3). The west and east blocks were constructed in spring 2001, with the exception of the 30 cm plot in the west block, which was built in spring 2002. The mixed block was laid out and the 7 cm mixed block was built in spring 2002. In the spring of 2003, the 15 cm plot in the mixed block was built. Before this experiment, the plot area was dominated by weeds and had not been managed for at least 10 years.

Crops

Roundup Ready® corn (*Zea mays*) and soybeans (*Glycine max*) were planted in 76 cm rows in half of the plots in an alternating rotation each year. Standard agricultural practices were followed, including fertilization (12-12-12 N-P-K) before planting and weed control as needed (Photo 2; Table 2).

Table 2. Soybean and corn varieties and fertilizer used.

Year	Date	Fertilizer† (at planting)	Crop	Variety
2001	4/26/2001	12-12-12	Corn Soybeans	Pioneer 3394 Pioneer 94B01
2002	5/3/2002	36-12-30	Corn Soybeans	DeKalb C60-09 (RR) Asgrow 3302 (RR)
2003	4/22/2003	36-12-30	Corn Soybeans	DeKalb DKC60-09 (RR) Asgrow SW90702 (RR)

† = N - P_2O_5 - K_2O RR= Roundup Ready®

Photo 2. Planting crops at the Sand Farm; A, disking; B, fertilizing; C, planting.

No irrigation was applied in 2001 and 2002, but after poor results in crop development due to deer grazing and dry conditions (especially in corn), irrigation was applied as needed to all plots in 2003. Damage by deer was a significant problem initially, so a deer-proof fence was installed before the next season. Rabbits, raccoons, and/or squirrels were able to dig under or climb over the fence to occasionally dig up the seeds or eat the grain (Photo 3). Animal problems decreased as our fencing improved during the experiment. In addition, as the experimental plots aged, burrowing insects colonized the area and mixed the underlying sand with applied sediments, a natural process that led to better soil formation and physical characteristics (Photo 3).

Looking at the historic climatic conditions in Kilbourne, IL (Figure 4), a typical period of low precipitation in June can be observed. This coincides with the period of crop growth, and corn is usually the most affected due to its higher water demand. In 2003 and 2004, a solid set sprinkler irrigation system with sprinklers at 2 m above the ground was used (Appendix I; Photo 4). Moreover, rain distribution in the experiment was significantly irregular during the four years (Figure 5).

Photo 3. Animal activity on the Sand Farm research plots; A, building deer excluding fence; B, corn seedling exhumed by squirrels; C, soybean plants damaged by deer grazing; D, biopedoturbation by insects, sand from below the applied sediments on the surface due to insect burrowing; E, corn ears grazed by raccoons before we had a chance to harvest.

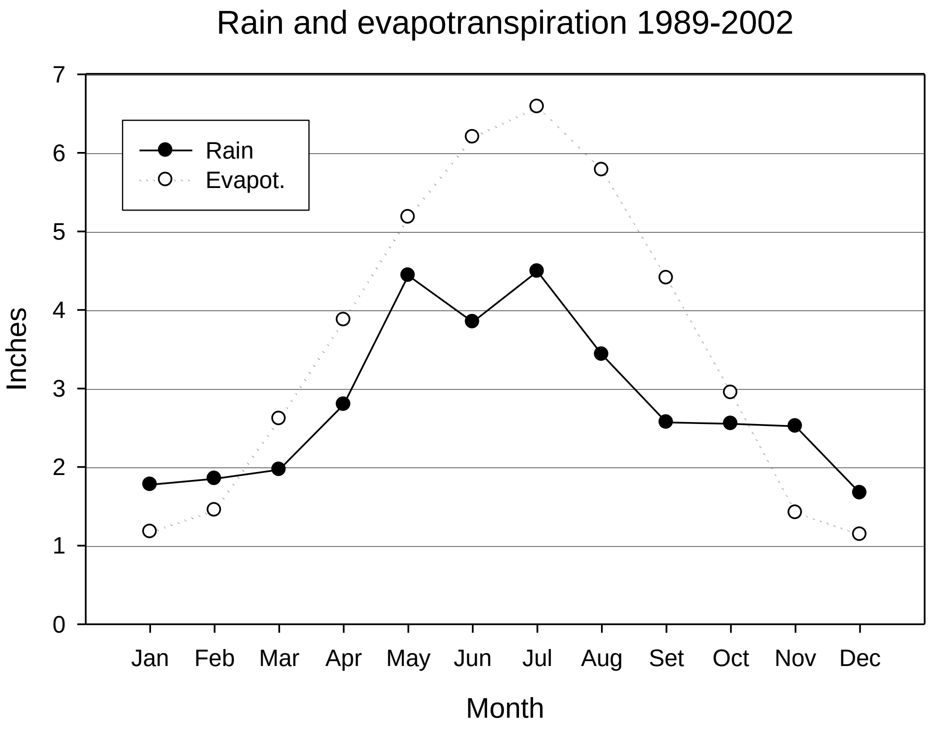


Figure 4. Normal rainfall and evapotranspiration at the Sand Farm (1989–2002).

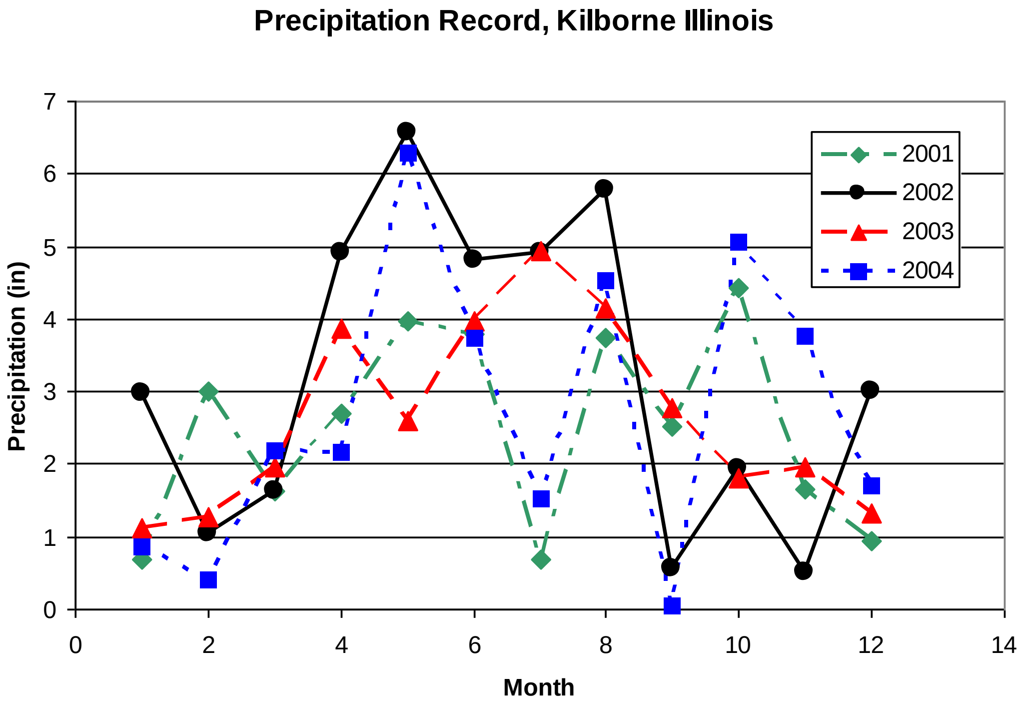


Figure 5. Precipitation at the Sand Farm during the experiment (2001–2004).

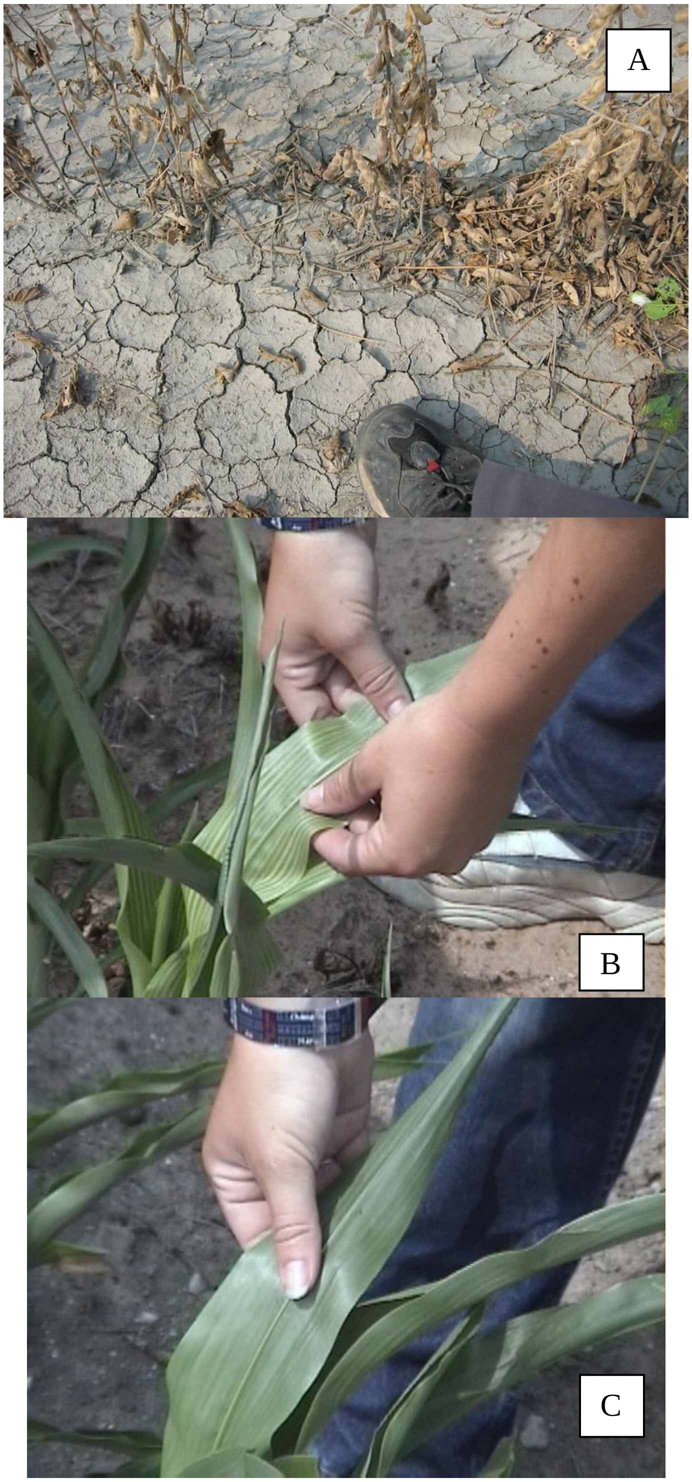


Photo 4. A, poor soil structure in the sediment; B, corn leaf from check plots exhibiting Mg deficiency; C, healthy corn leaf from 30 cm sediment plot.

Soil and Crop Sampling and Analysis

Soil samples were obtained at five different depths (0–7, 7–15, 15–30, 30–45, and 45–60 cm) with a 3 cm diameter push probe. Five subsamples per plot were mixed to compose the sample for the plot. Analyses of nutrient status were performed, including pH, organic matter, soluble sulfur (S), extractable P, K, Ca, Mg, K, Na, B, Fe, Mn, Cu, Zn, and Al by Brookside Labs of New Knoxville, Ohio (Appendix A). Soil pH was determined in a 1:1 soil to water suspension, and organic matter was determined by a loss on ignition at 360° C. Mehlich III-extractable S, P, K, Ca, Mg, Na, B, Fe, Mn, Cu, Zn, and Al were determined by inductively coupled plasma (ICP) (Mehlich, 1984). The cation exchange capacity (CEC) was estimated by the summation of exchangeable bases.

Metals analysis of soil samples and plant tissues was performed by the Illinois Department of Natural Resources' Waste Management Research Center. Results were obtained by inductively coupled plasma mass spectrometry (ICP-MS) using lithium, scandium, niobium, cesium, and bismuth as internal standards. Mercury results were obtained by atomic fluorescence. A nitric acid microwave digestion procedure, equivalent to USEPA Method 3051 (USEPA, 1994a), was used to solubilize metals for analysis.

The water holding capacity was determined by a pressure cell apparatus (pressure plate extractor) at 0.1, 0.33, 1, 5, and 15 atm of pressure (Klute, 1986). Changes in texture at the different depths were monitored to determine mixture of the materials. Soil texture was determined by the hydrometer method (Gee and Bauder, 1986). Soil compaction, another important factor in plant development, was determined using a Rimik CP-20 cone penetrometer (Agridry Rimik PTY Ltd., Toowoomba, QLD, Australia) to a depth of 40 cm. Water aggregate stability was measured by weakening and disintegration using a sieving machine base method described by Kember and Rosenau (1986); this property is considered one of the main factors controlling the chemical, physical, and biological processes that contribute to soil productivity (Yang and Wander, 1998). Soil bulk density was measured by the core method using a double-cylinder, hammer-driven 75 x 75 mm core sampler (Blake and Hartge, 1986). Samples were dried at 105°C, and the ratio of the dry mass of soil to field bulk volume was calculated.

The soil moisture content was monitored at 10 and 30 cm depths during the growing period using the ECHO probe model EC-20, with a Decagon Em5 data logger. The ECHO probe measures the dielectric constant of the soil to estimate its volumetric water content. Water content from zero to saturation was measured; typical accuracy of the device is ± 3% with a soil-specific calibration. Soil temperature was monitored using the ECHO temperature sensor and the same data logger as the ECHO probe.

Crop development was monitored during the growing season. Height was measured throughout the season. At the silking stage for corn, the relative nitrogen level in leaves was measured using a Minolta© SPAD-502 Chlorophyll Meter; the reading was done approximately 1.5 cm from the edge of the ear leaf and at a point three-fourths of the leaf length. Yields were measured at the end of the growing period. Harvest was done by hand along two 3 m row lengths; the center of each plot was sampled to minimize border effects (Figure 6).

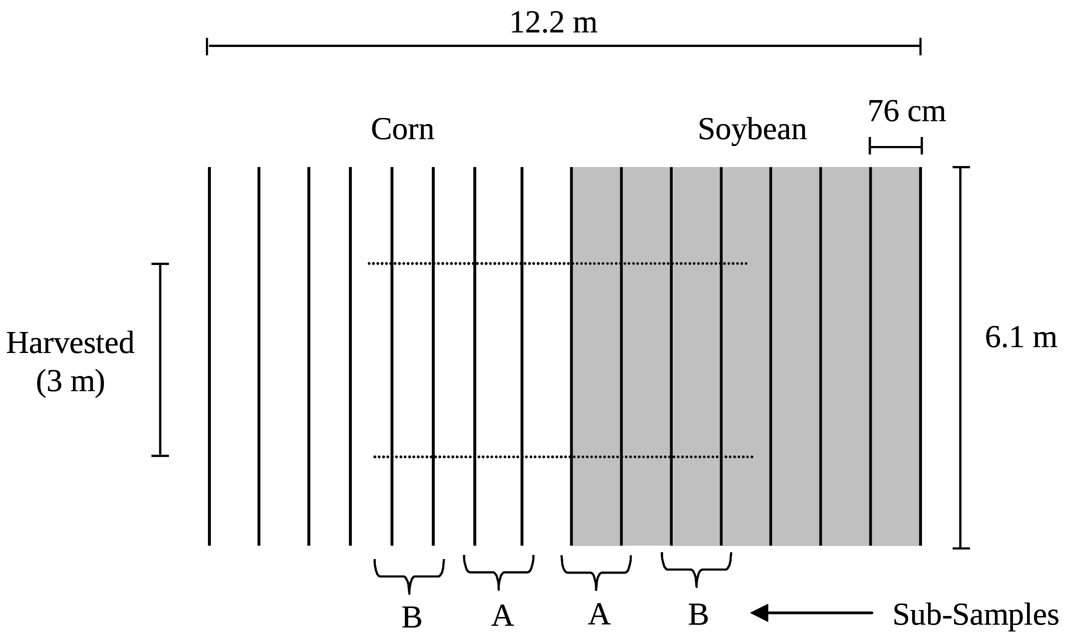


Figure 6. Area harvested of corn and soybeans.

Statistical Analysis

The data were analyzed using the Proc Mixed procedure in the SAS statistical program (SAS Institute, 2000). A time effect was assumed for the development of soil characteristics; therefore, the factor "year" was used as a repeated measure in the model. For soil analysis, samples were obtained at different depths, which were also considered in this analysis as a repeated measure; thus the final model had a double-repeated measure structure. The Akaike information criterion was used to determine the best covariance structure for the final model.

The treatments were randomized when the plots were designed. The original randomization was used in subsequent years, thus location was the same each year. This allowed the evaluation of sediment over time. Note that the randomization was limited by defined blocks, but this issue was not considered for the final statistical analysis.

Data reported as below the limit of detection (LOD) were excluded for statistical analysis; however, when necessary, the LOD values were replaced by LOD/2, following the suggested procedure for analyzing data with nondetects (USEPA, 1998). Unless otherwise noted, significance was reported at $\alpha = 0.05$.

Results and Discussion

Soil Characteristics

Sediment and sandy soil properties differ greatly. Many measured properties are directly related to soil texture and nutrient levels. The sediments were poorly structured and had poor structure initially, but provided better nutrition for crops than sandy soil (Photo 5). The effect of time could be observed in most of the soil properties, as mixing with local soil occurred. These soil characteristics also produced remarkable differences in plant growth.

Photo 5. Sand Farm sediment research plots; A, early season view showing sediment treatments and irrigation system; B, late season view showing crop response to sediment addition.

Soil Texture

Local sand and sediment textures were significantly different, in that the sand had a fine to medium texture (97% sand, 1% silt, and 2% clay), and the sediment consisted of a silty clay loam (11% sand, 60% silt, and 29% clay), which is associated with highly productive soils (Appendix B). The mix of sediment and local sandy soil was expected to produce a texture more desirable for agricultural production than the sandy soil alone, an expectation that was observed in the study period (Figure 7). In the first and second year, the sand content was higher at the surface of the plots, perhaps due to pedoturbation or to wind, tillage and planting activities, or animal activity (Figure 8).

Soil texture differed from the original dredged sediment (silty clay loam) by the second year (Figure 9). In the treatment with 30 cm of sediment, at 15 cm the texture is a silt loam, which can be considered the most similar to the original sediment texture. However, the top 7 cm increases the sand content, changing it to a loam texture, and at 30 cm of depth the texture changed to sandy loam. The lower depths (50–60 cm) had a sandy texture.

Water Holding Capacity

Soil water holding capacity was significantly increased by the addition of dredged sediment. This soil property is one of the most important limiting factors for agricultural production in Illinois and the surrounding area; farming is possible due to the installation of irrigation systems and the application of large amounts of water. Improvement of this soil property would reduce crop production costs by minimizing the amount of irrigation needed.

The water retention curve (Figure 10) demonstrates the substantial difference between the original soil and the sediment-amended soil. The plant-available water in the sand (control) plots ranged from 1.5% to 3.5% moisture, indicating a very low water retention capacity. In contrast, values ranged from 10.5% to 20% moisture in sediment-treated plots, giving a field capacity of 9.5% and providing almost five times more water available for plants than the control plots. Laboratory evaluations of the potential moisture contents of sediment were verified by field moisture contents, in which the volumetric moisture content of the upper 7 cm ranged from about 5% (vol.) for the control plots to 25% for the 30 cm sediment plots (Figure 11).

Bulk Density

Soil bulk density (Db) at the soil surface (0–7.5 cm) was roughly equivalent to the treatments with sediments, but they all differed significantly from sand, which had a higher Db than sediment (Figure 12). Bulk density of a cultivated silt loam with high organic matter typically ranges from 0.9 to 1.5 g cm^{-3}. In contrast, bulk density for cultivated sandy loams and sands with low organic matter ranges from 1.25 to 1.75 g cm^{-3} (Brady and Weil, 2002). The difference in Db is attributed to the amount of total pore space; sandy soil has less total pore space than silty or clayey sediment-derived soil because aggregates of silt and clay contain a large number of fine pores, and sand particles are solid and contain no internal pore space (Brady and Weil, 2002). This factor is also directly related to the water holding capacity of the soil.

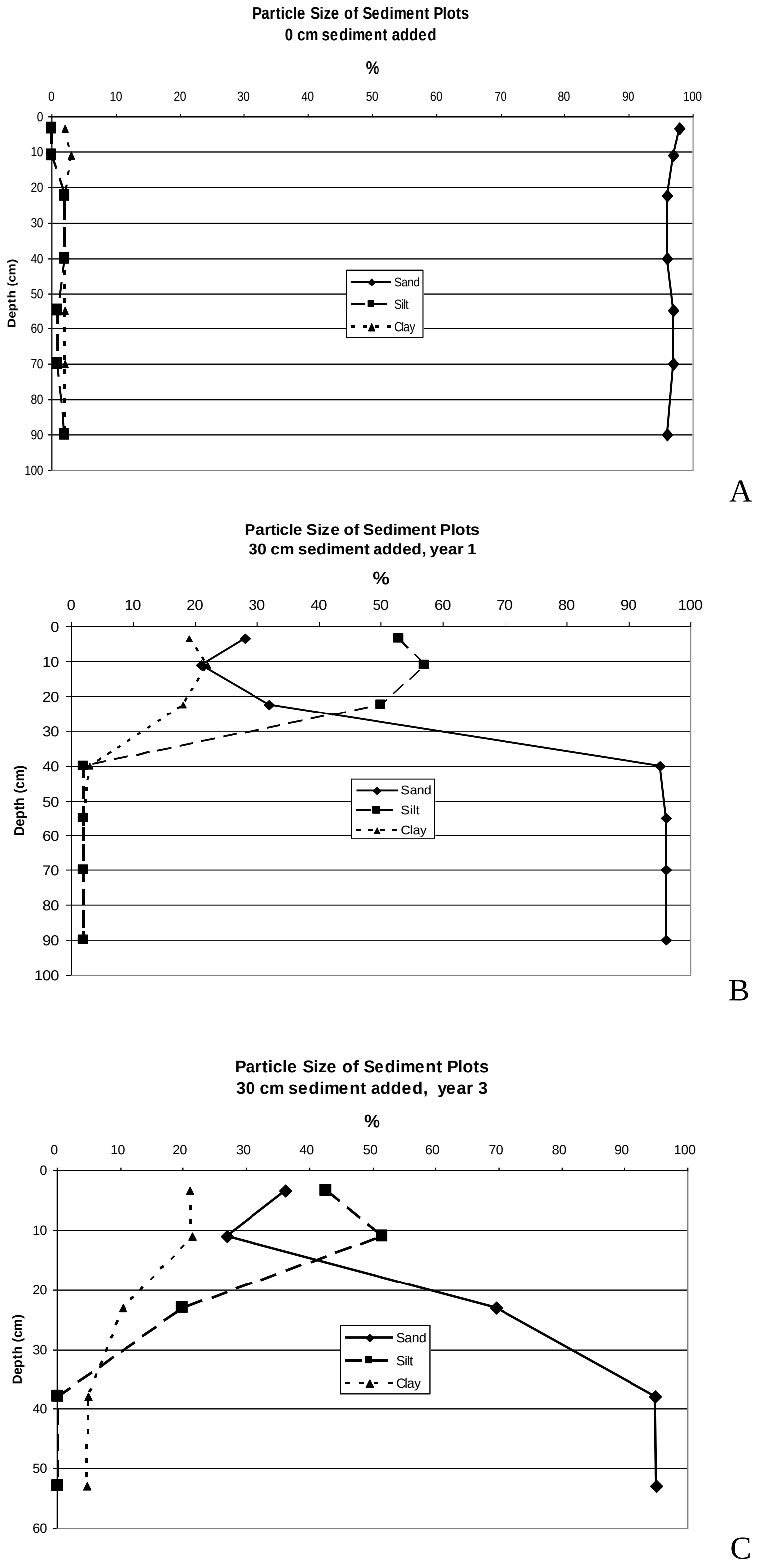


Figure 7. Soil texture at the sediment research plots at the Sand Farm; A, control plots; B, 30 cm plots initial condition, year 1; C, 30 cm plots, year 3.

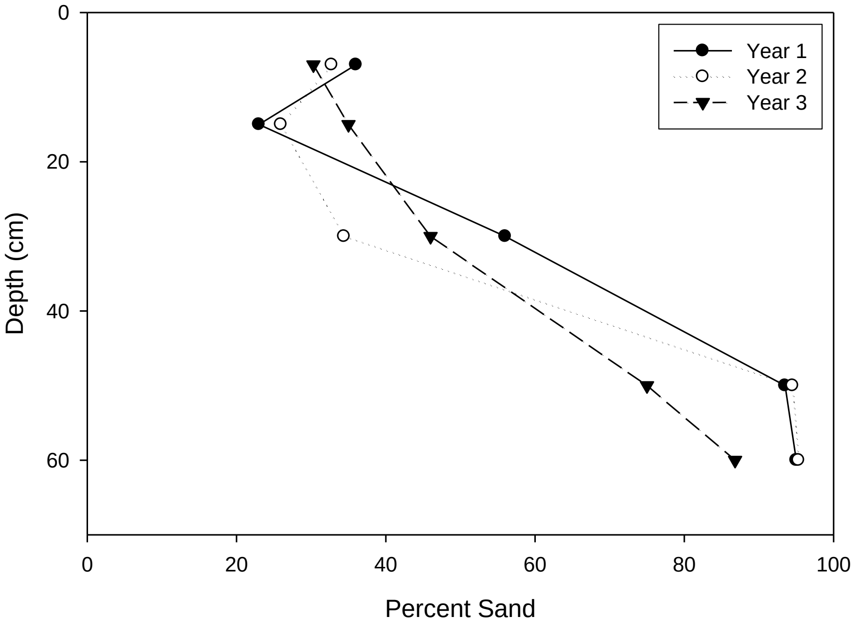


Figure 8. Changes in sand content through the soil profile (30 cm sediment plot).

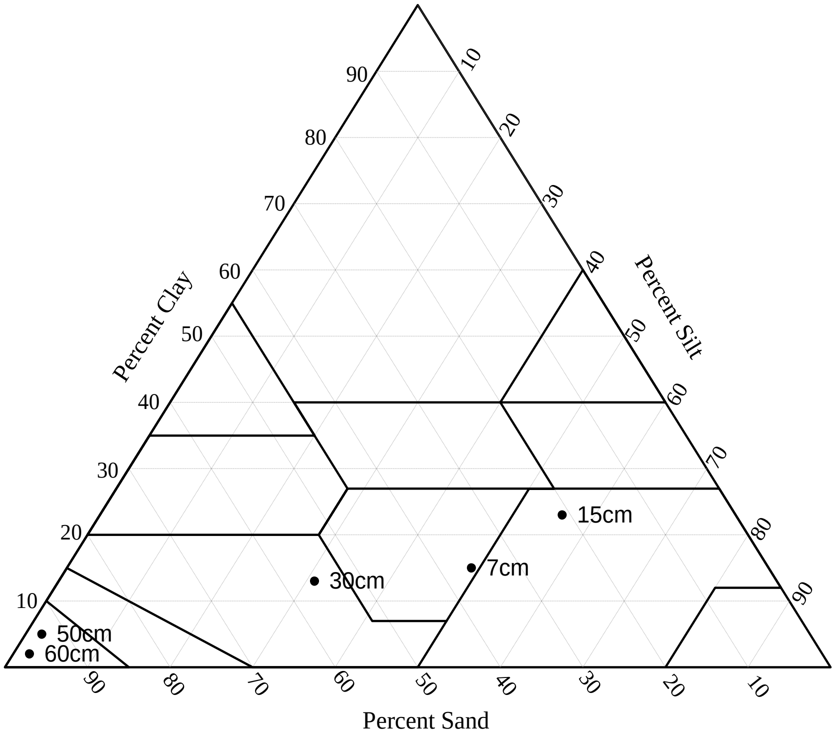


Figure 9. Soil texture at different depths, year 2 (30 cm sediment plot).

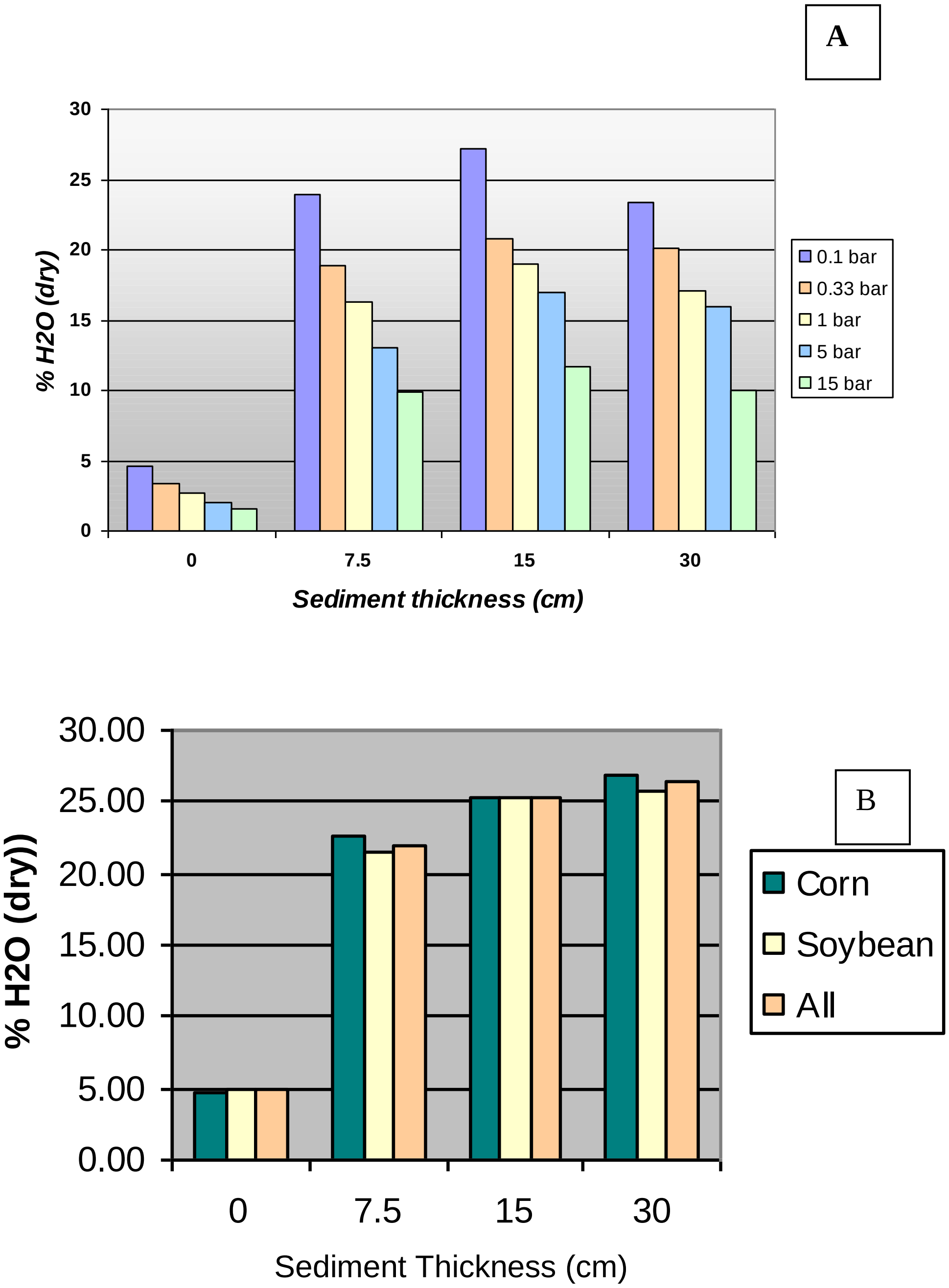


Figure 10. Soil (0–7 cm) moisture holding capacity; A, pressure-moisture content by sediment treatment; B, average moisture content by treatment and crop.

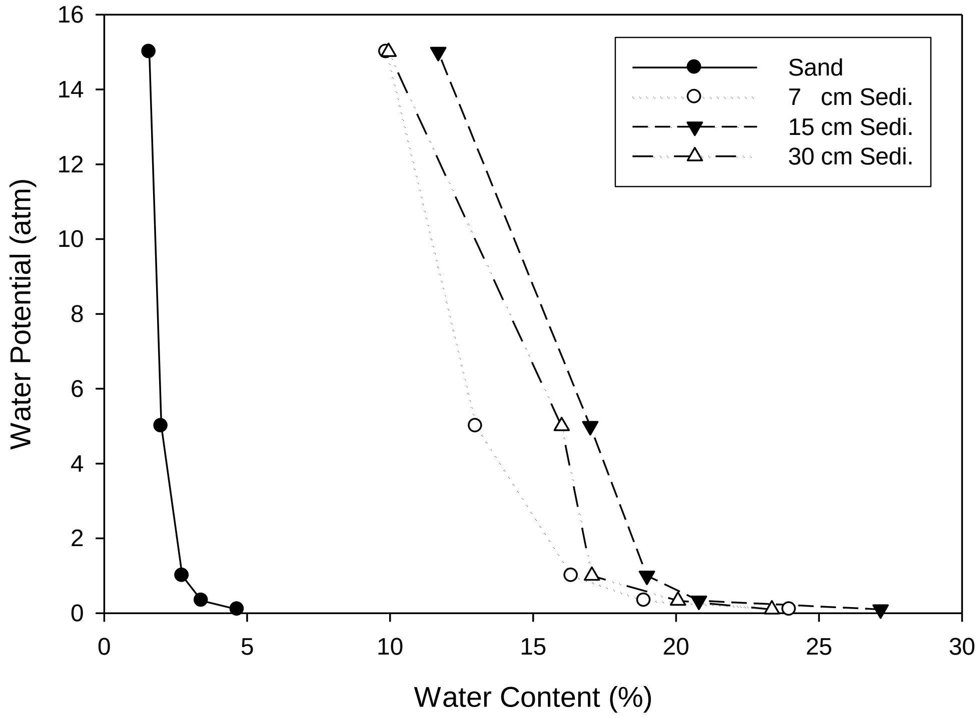
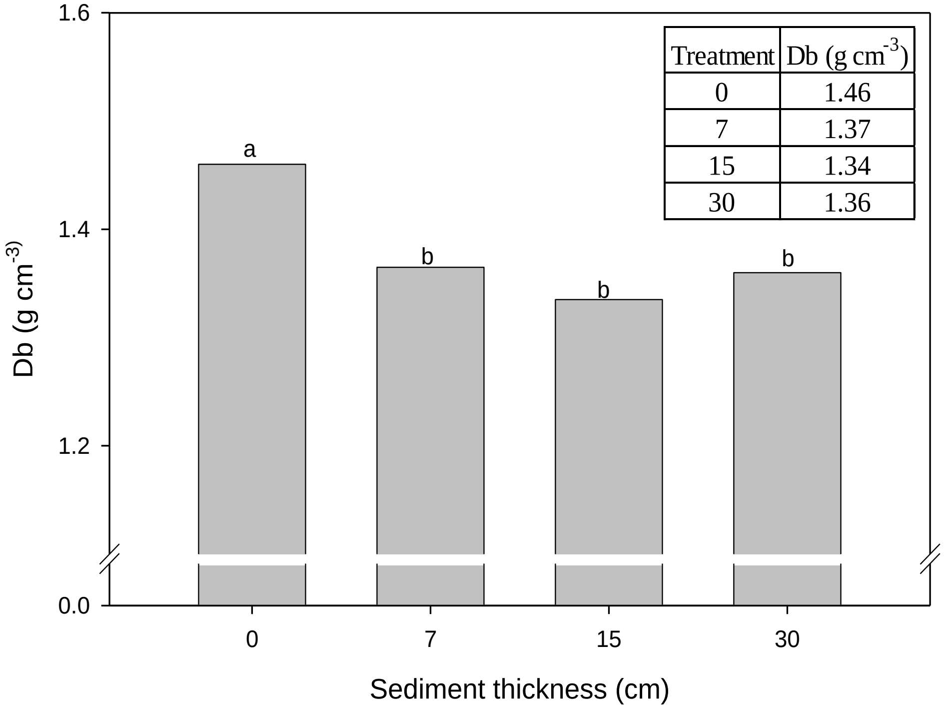


Figure 11. Soil (0–7 cm) moisture content (vol. %) by sediment treatment.



Treatment	Db (g cm^{-3})
0	1.46
7	1.37
15	1.34
30	1.36

Figure 12. Soil (0–7 cm) bulk density by sediment treatment.

Soil Strength

Soil strength, as measured by a penetrometer, was analyzed as a repeated measure (for depth) with an unstructured (un) covariance matrix (SAS, 2000). To take moisture differences in the various treatments into account, moisture was used as a covariant in the model. No significant differences were found, except in the 15 cm treatment, which was different from sand controls and the 30 cm sediment treatment (Table 3). Moreover, the behaviors of the curves of soil strength through the profile were very similar (Figure 13).

When penetrometer values were analyzed by depth, there were significant differences in the upper 7 cm of the profile for all treatments, except for treatments 30 and 15, which had higher values for 30 cm of sediment, followed by 15, 7, and 0 cm sediments (Table 4; Figs. 13, 14, 15). For the rest of the profile, differences between treatments at the same depth were not statistically different. However, no adverse effects of compaction on plant germination or development was observed in any treatment. Statistical analyses were also performed with moisture excluded from the model. These tests yielded slightly different values, yet the final conclusions about treatment effects were unchanged (Figure 16).

Table 3. Differences of least square means of penetrometer resistance between treatments for the entire profile (0–40 cm), year 2.

Trt	Trt	Diff. Estimate	Standard Error	t Value	Pr > |t|
0	7	-396.61	202.69	-1.96	0.065
0	15	-700.69	249.56	-2.81	0.010*
0	30	-18.37	258.28	-0.07	0.944
7	15	-304.08	247.38	-1.23	0.233
7	30	378.24	252.92	1.50	0.150
15	30	682.32	287.81	2.37	0.027*

* Significant at 0.05 probability level.

Table 4. Least square means of moisture corrected penetrometer resistance in the upper 7 cm by treatment.

Treatment (cm Sediment)	LS Means (KPa)
30	1231 a
15	1126 a
7	900 b
0	346 c

Sand Farm Sediment Plots 07/06/01

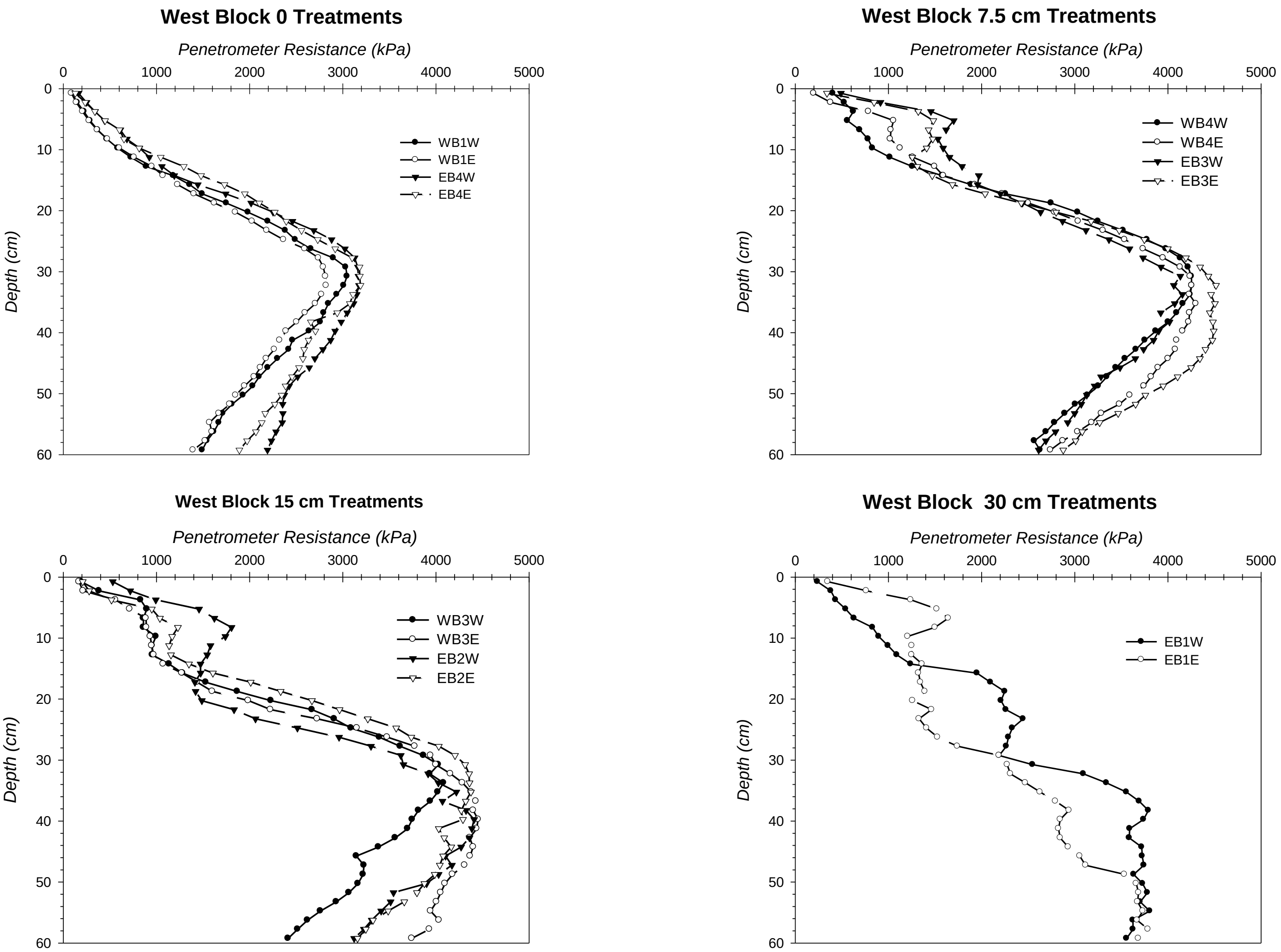


Figure 13. Soil penetrometer resistance, first season, early July.

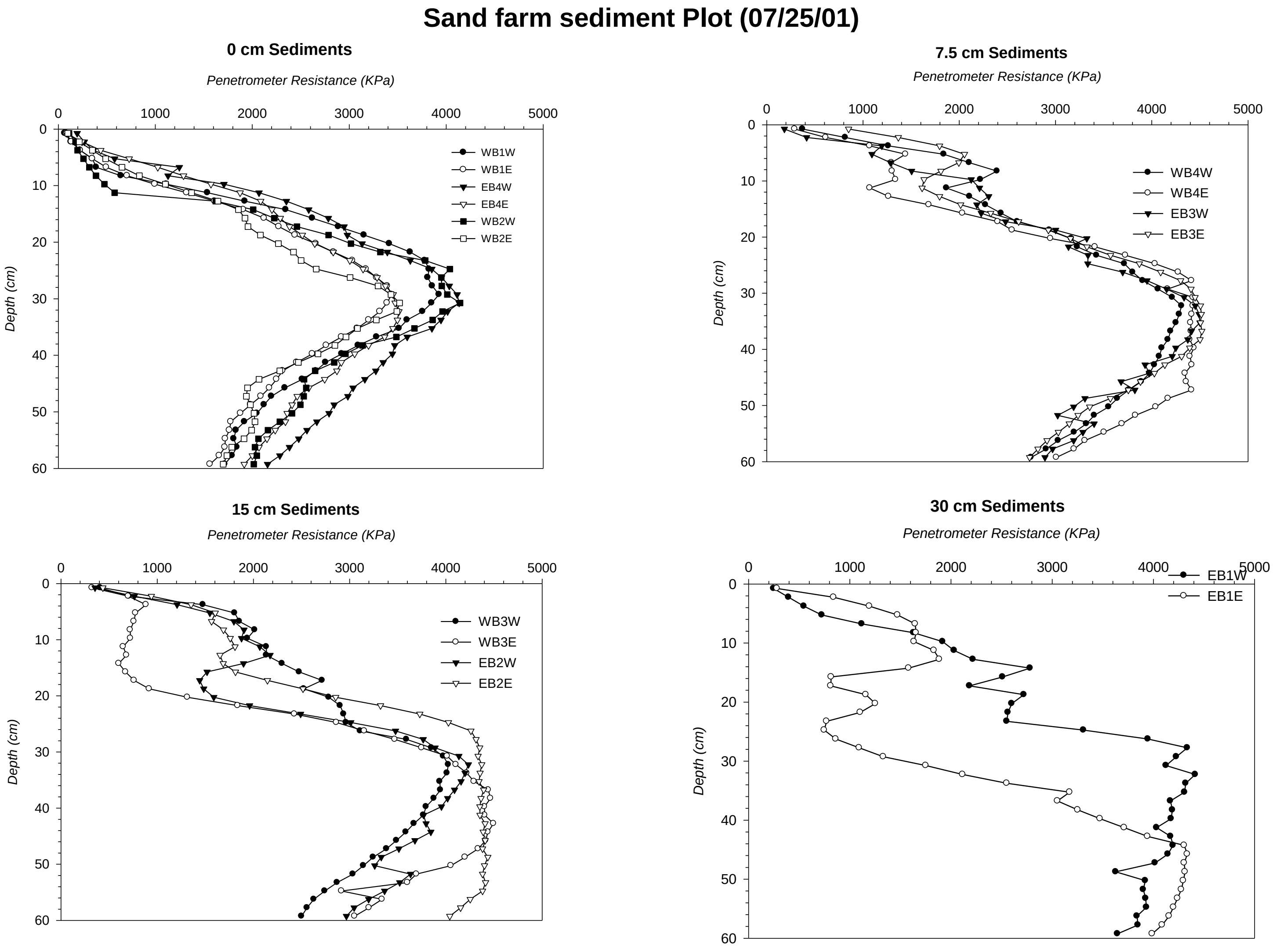


Figure 13 (cont'd). Soil penetrometer resistance, first season, late July.

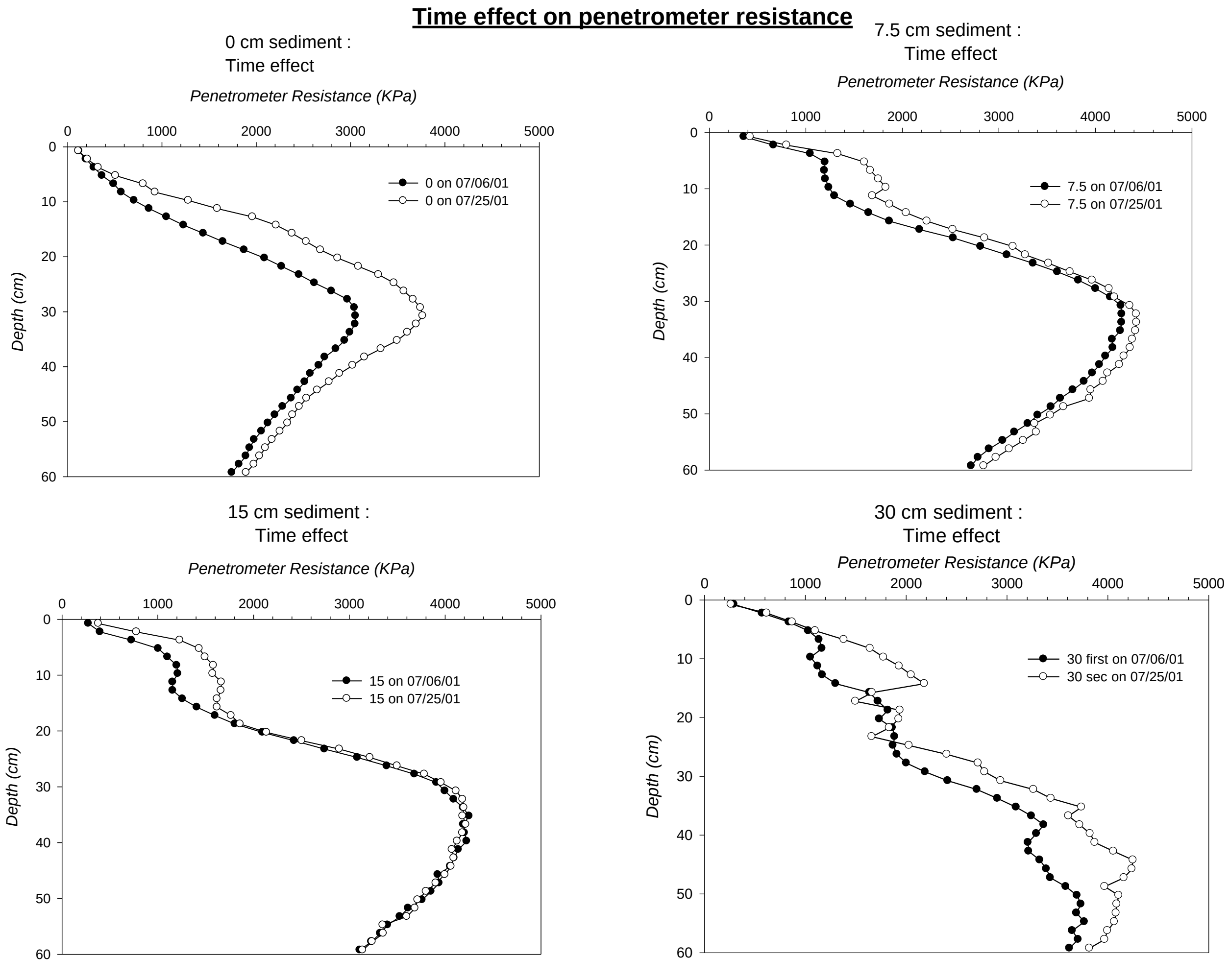


Figure 14. Soil penetrometer resistance, first season, early vs. late July, all plots averaged by treatment.

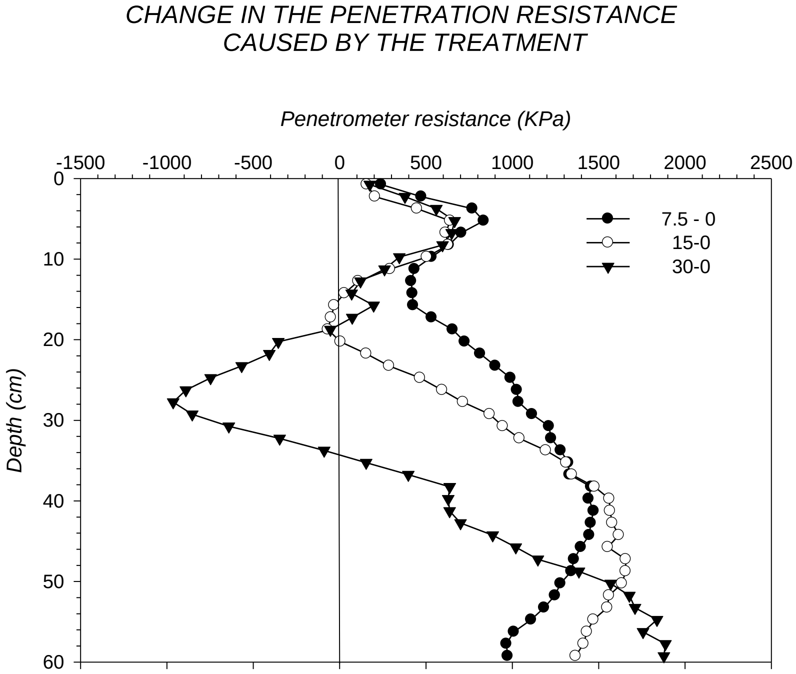


Figure 15. Change in penetration resistance caused by sediment addition.

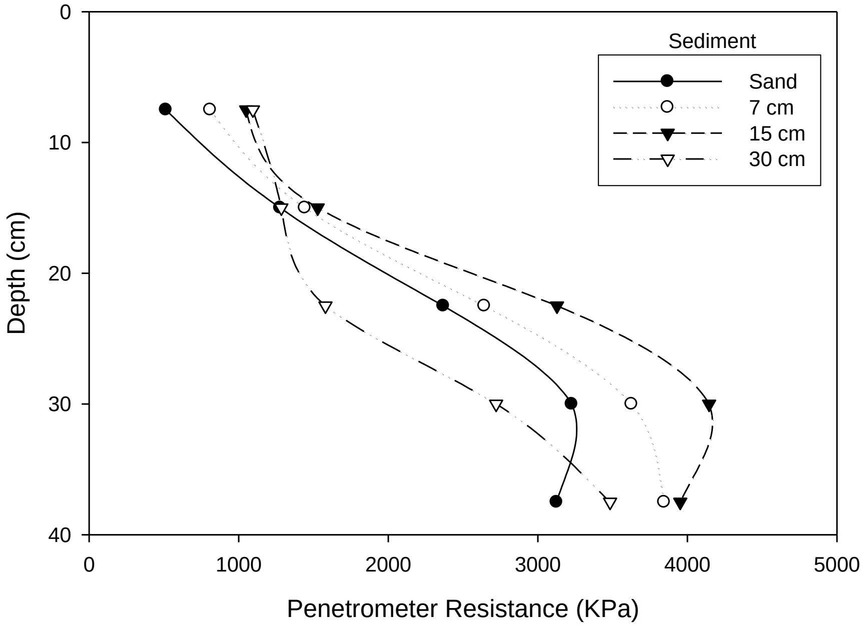


Figure 16. Soil penetration resistance adjusted for moisture content, by sediment treatment.

Wet Aggregate Stability

Soil structure dictates many soil properties, including resistance to erosion. Also, the organization of surface soils into relatively large structural aggregates improves bulk density and provides macropores that are advantageous for agriculture (Brady and Weil, 2002). Additionally, soil aggregation can affect nutrient availability, particularly as related to sorption and release of phosphorus (Linquist et al., 1997).

The size of aggregates sampled from a 0 to 7 cm depth averaged 1 to 2 mm (Figure 17). No aggregates were observed for the control sandy soil, indicating the absence of structure formation that is typical of sandy soils. In plots treated with dredged sediment, a good aggregate formation was observed; however, the source and quality of the sediment provided a significant effect (Table 5). Sediment sources indicated as “A” were exposed to adulteration by other materials in the storage site and during transportation and relocation of the material. “B” sediment was free of unusual extraneous materials, better representing the sediment as extracted from the Illinois River.

Soil Temperature

Plant growth rates are more sensitive to soil temperature than to above ground air temperature (Brady and Weil, 2002). In this experiment, soil temperature was measured at a 10 cm depth during the corn growing period for all treatments (Figure 18). Temperature variation was higher for the control sandy soil (Table 6). Moreover, the highest and lowest temperatures were observed in the control sandy soil. The ideal soil temperature for corn and soybeans is between 25 and 30° C; growth ceases at temperatures above 35° C (Brady and Weil, 2002).

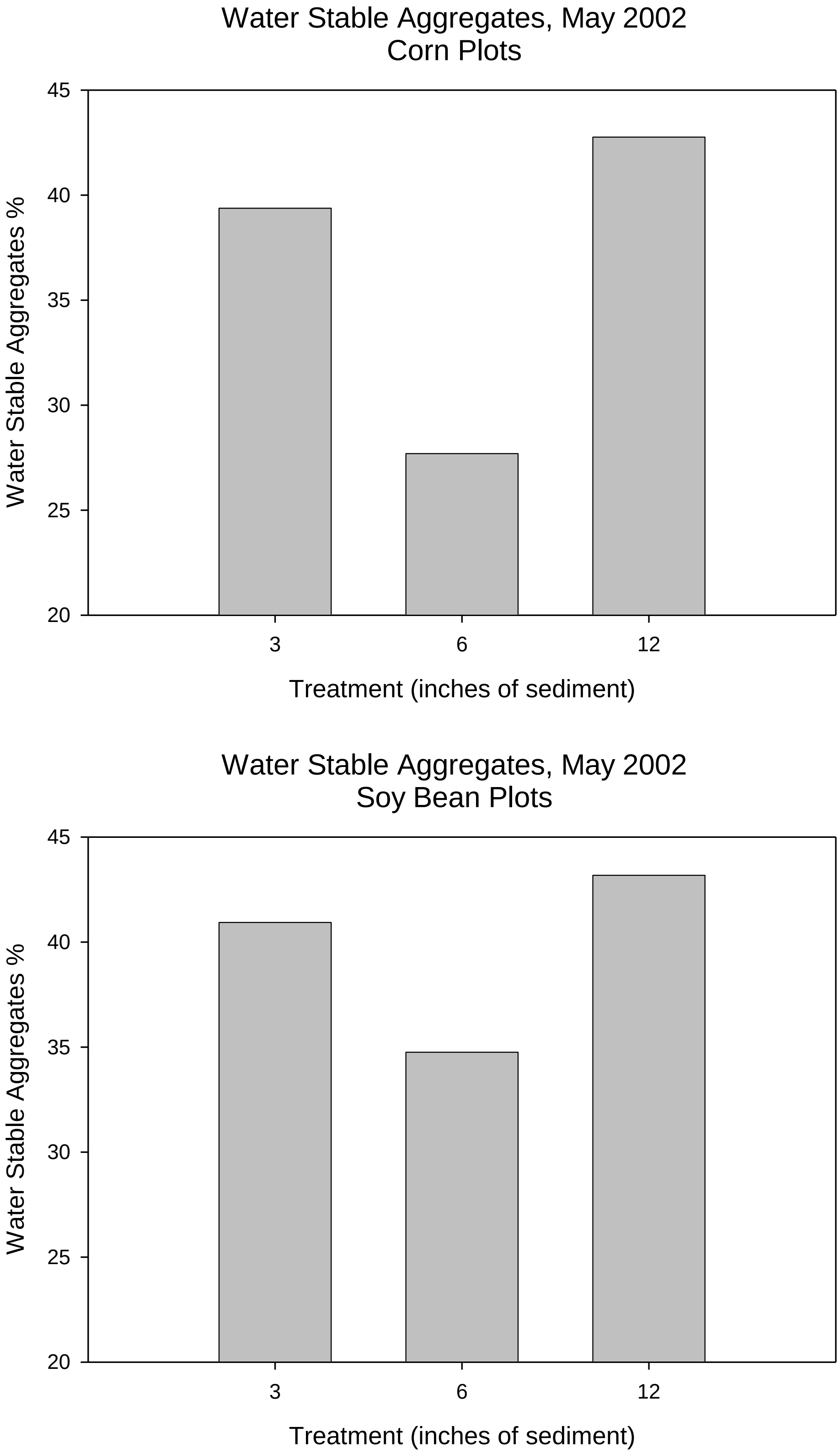


Figure 17. Soil water stable aggregate content, by sediment treatment and by crop.

Table 5. Wet aggregate stability for treatments and sediment source (year 2).

Plot #	Treatment Sediment (cm)	Source of Sediment†	% Water Aggregate Stability
EB1	30	A	29
EB2	15	A	30
EB3	7	A	28
EB4	0	-	0
MP1	0	-	0
MP3	7	B	63
WB1	0	-	0
WB2	30	B	58
WB3	15	A	32
WB4	7	A	29

† Sediment source A was adulterated with debris including concrete, asphalt, and rebar. Source B was relatively unadulterated.

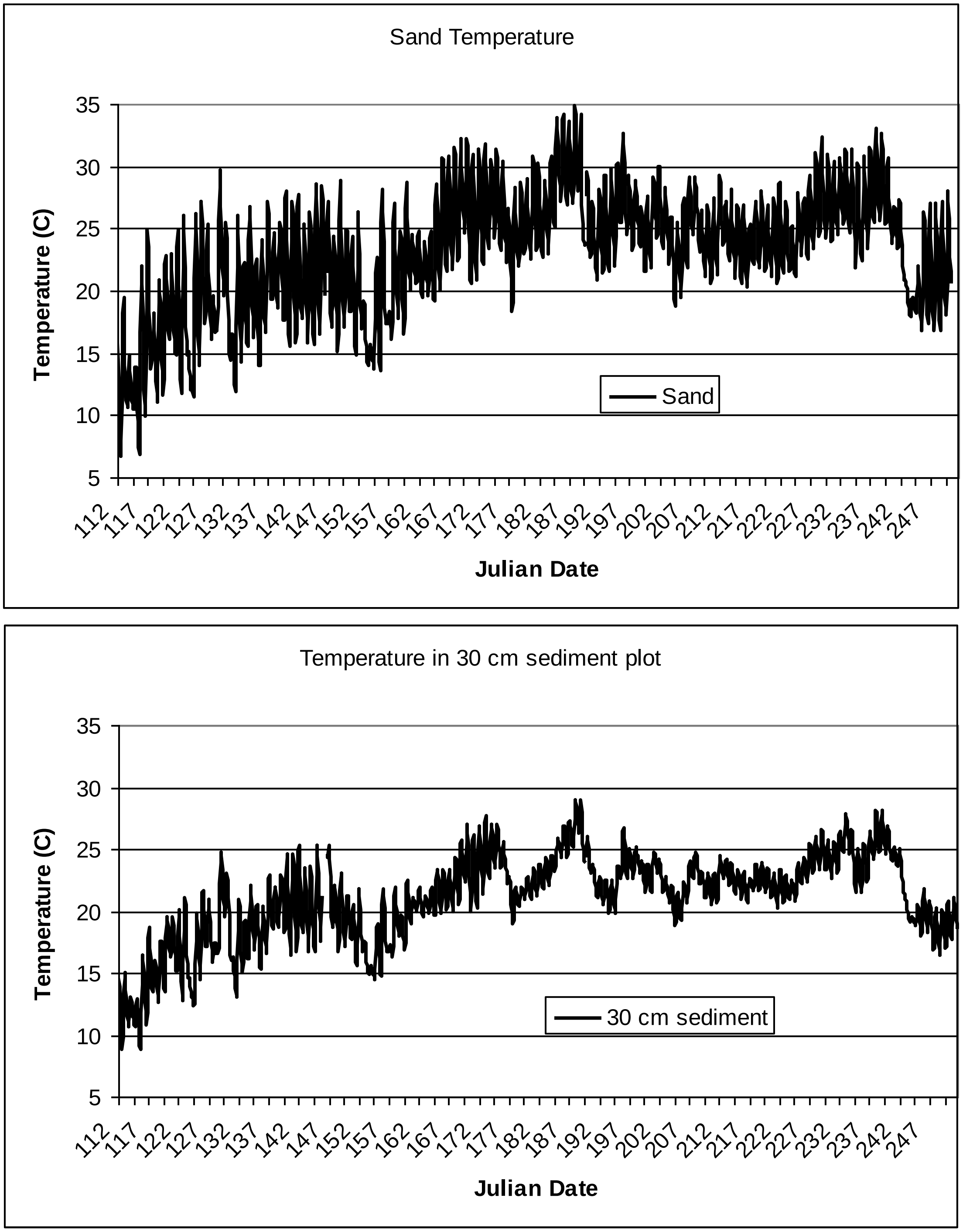


Figure 18. Soil temperature at 10 cm depth, in control (sand) and in 30 cm sediment treatment plots at the sand farm, 2003.

Table 6. Soil temperature during the third corn growth period measured at 10 cm depth.

Treatment	Temperatures			
	Max	Min	Average	Range
30 cm	28.9	3.0	17.1	25.9
15 cm	29.3	2.8	17.0	26.5
7 cm	34.7	1.6	17.8	33.1
0 (Sand)	34.8	1.4	18.5	33.4
Average	31.9	2.2	17.6	29.7

Seasonal Field Soil Moisture

Soil moisture was continuously monitored at two different depths during the corn growing season in the third year of the study. At the 10 cm monitoring depth, a clear difference in moisture content was observed between treatments. Sediment-treated soils contained more plant-available water than the control plots during the growing season (Figure 19). Later in the season, a higher moisture content was observed in the 30 cm sediment treatment plots measured at the 10 cm depth. High moisture variability can be attributed to rain and irrigation events. Furthermore, a general decrease in the moisture content in the first part of the season could be attributed to greater plant water demand. For the control sandy soil at the 0 treatment depth, low water content was observed during the entire season, which is a consequence of a low water holding capacity.

Soil moisture measured at the 30 cm depth (lower plot in Figure 19) was essentially uniform for all treatments. However, somewhat higher moisture contents were observed for the 30 cm sediment treatments compared with the 0, 7, and 15 cm sediment thicknesses, which were very similar. In general, moisture differences measured at a 30 cm depth were not as great as at the 10 cm depth. Lower moisture contents were observed at the 30 cm measurement depth for all treatments, which can be attributed to the presence of the original sandy soil at that depth.

Nutrients and Fertility

Soil fertility was improved by adding sediments (Appendix C, D). Sediments were calcareous and raised the soil pH from ~5.4 to ~7.2 (Table 7; Figure 20). Levels of organic matter (OM) also increased dramatically with the added sediment (Figure 21). The native soil had ~0.1 to 0.5% OM, whereas sediments had ~2.7 to 3.0 % OM. The generalized increase in OM observed over the years can be attributed to enhanced plant growth.

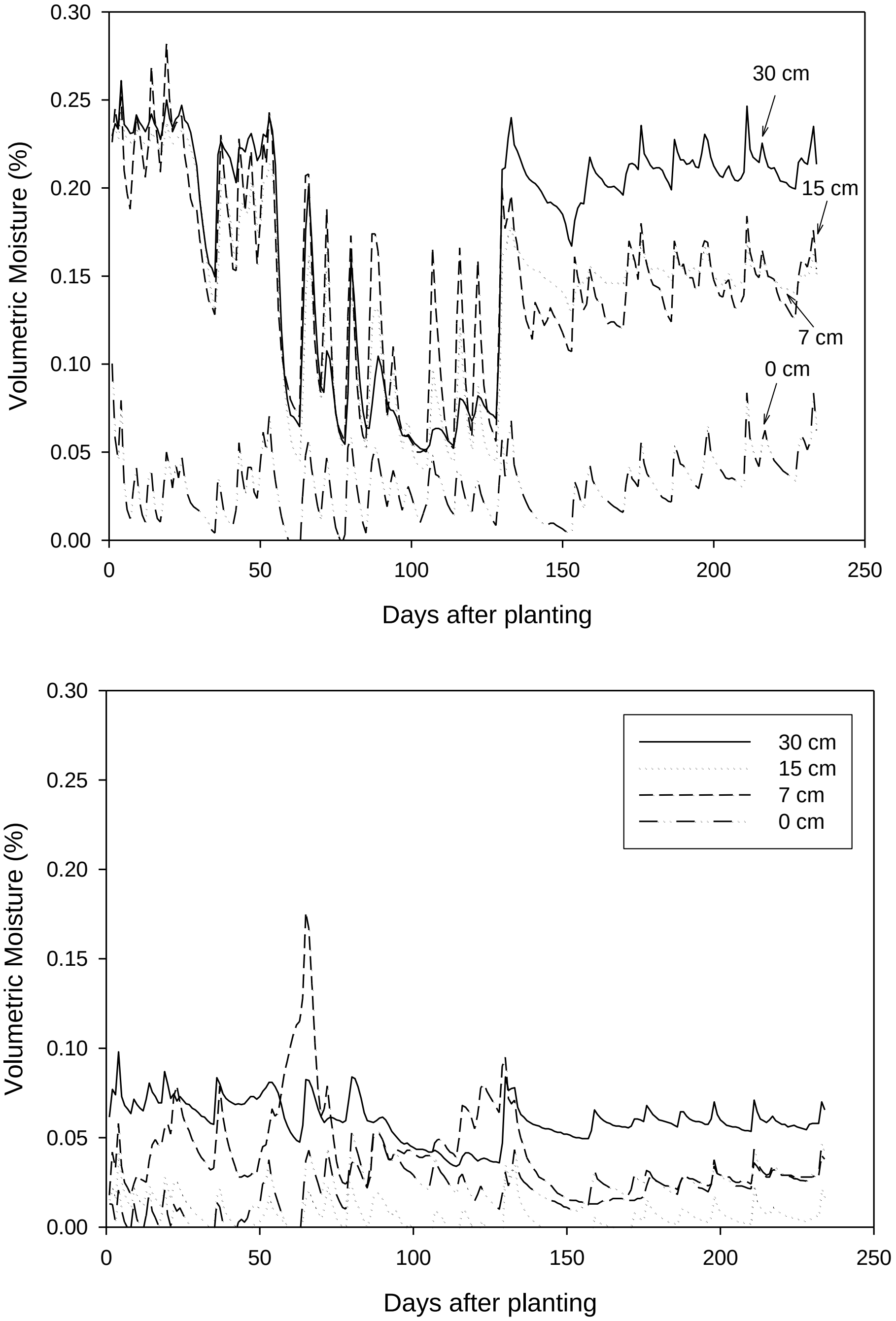


Figure 19. Soil moisture contents measured at two depths, 10 cm (upper) and 30 cm (lower), in the four sediment depth treatment plots at the Sand Farm, 2003.

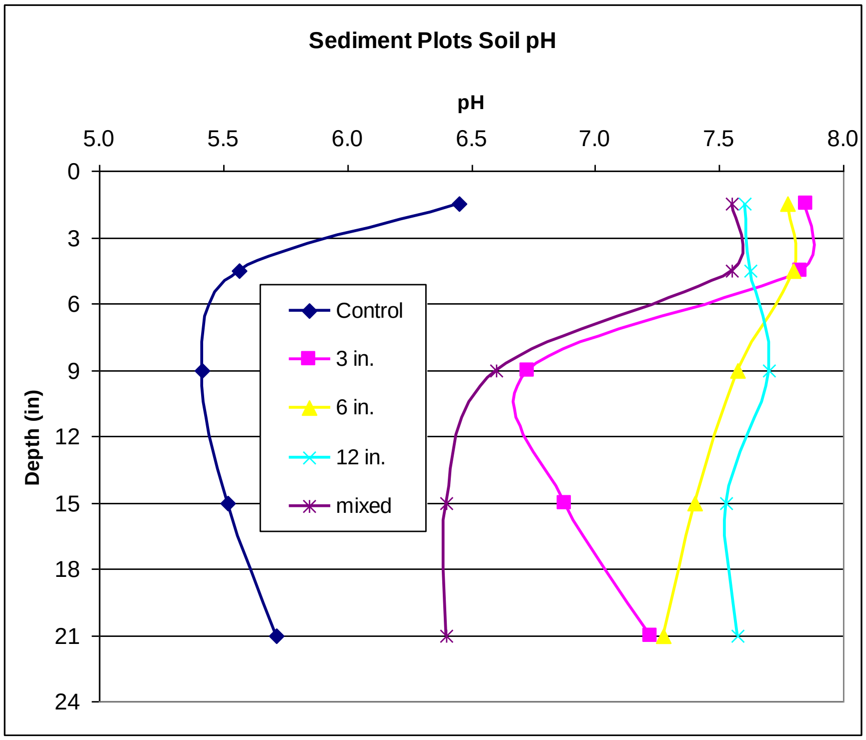


Figure 20. Soil pH by depth in the sediment treated plots at the Sand Farm.

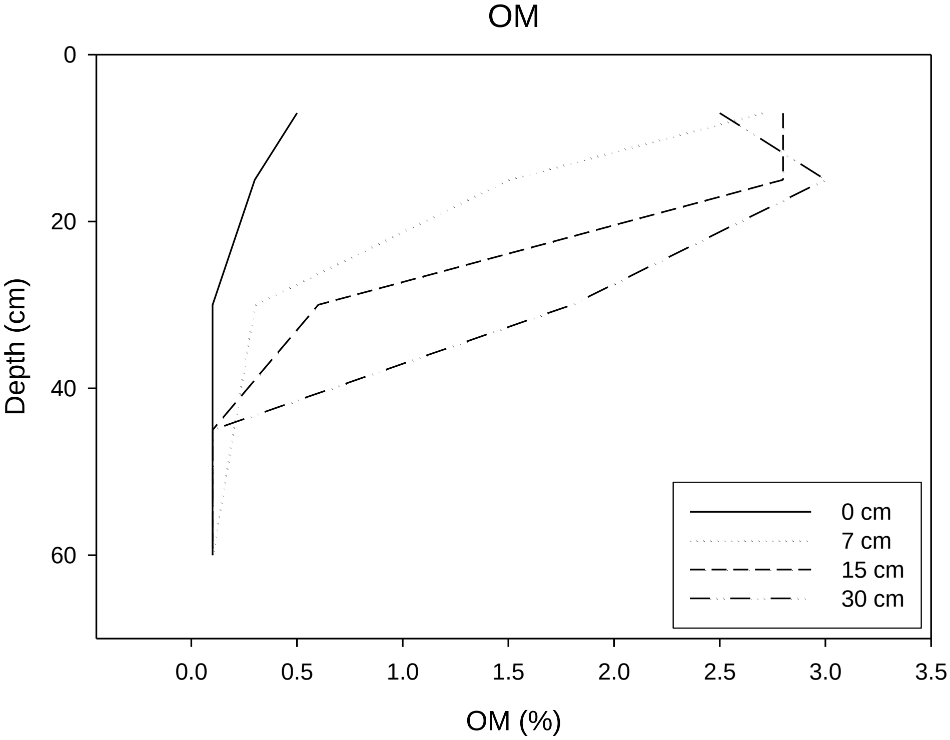


Figure 21. Soil organic matter content after sediment addition.

Table 7. Soil fertility, Sand Farm sediment plots, 2001.

Depth (cm)	TEC	pH	OM%	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al	Ca	Mg	K	Na	H
				Extractable (mg/kg)												%				
0 cm Treatment																				
0-7	2.5	5.6	0.4	22	115	386	55	44	12	0.4	137	42	0.6	2.6	390	75	18	4	2	0
7-15	1.9	5.0	0.2	25	119	281	39	41	12	0.4	151	47	0.6	2.2	427	73	18	6	3	0
15-30	1.6	5.0	0.1	20	97	221	38	38	10	0.4	137	41	0.5	1.1	394	70	21	6	3	0
30-50	1.5	5.1	0.1	17	74	213	36	34	7	0.3	110	30	0.4	0.9	318	72	20	6	2	0
50-60	1.7	5.5	0.1	17	69	244	44	37	11	0.5	118	26	0.5	1.0	345	71	21	5	3	0
60-80	1.4	5.4	0.1	14	56	195	38	35	8	0.3	100	16	0.3	0.5	314	69	22	6	2	0
80-100	1.7	5.8	0.1	14	70	243	41	54	11	0.3	108	15	0.4	0.4	386	70	19	8	3	0
7.6 cm Treatment																				
0-7	32.7	7.3	3.0	257	126	5617	474	146	73	1.2	426	71	4.3	15.6	252	86	12	1	1	0
7-15	24.9	7.2	1.4	163	129	4328	334	98	44	0.9	420	60	3.3	11.1	263	87	11	1	1	0
15-30	8.2	6.5	0.4	55	119	1403	120	46	20	0.5	268	39	1.2	3.5	325	81	15	2	2	0
30-50	2.9	6.3	0.1	37	103	450	61	33	10	0.5	154	33	0.4	1.1	370	78	18	3	2	0
50-60	1.6	5.8	0.1	22	74	224	41	31	8	0.4	122	28	0.3	0.7	345	71	22	5	2	0
60-80	2.6	6.4	0.1	24	68	381	62	36	10	0.4	145	31	0.4	0.9	365	74	21	4	2	0
80-100	1.5	5.9	0.1	17	61	203	34	49	8	0.4	115	17	0.3	0.5	388	69	19	9	2	0
15 cm Treatment																				
0-7	32.6	7.1	3.1	370	134	5482	517	169	101	1.3	443	94	4.2	16.9	51	84	13	1	1	0
7-15	33.4	7.3	3.0	314	98	5549	577	168	90	1.4	446	83	5.0	18.4	81	83	14	1	1	0
15-30	17.2	7.2	0.9	109	106	2987	232	73	30	0.8	406	59	2.5	7.8	205	87	11	1	1	0
30-50	3.9	6.7	0.1	36	82	618	81	34	13	0.5	181	52	0.8	1.3	376	79	17	2	1	0
50-60	2.2	6.1	0.1	27	58	311	58	31	13	0.4	126	44	0.7	0.8	328	72	22	4	3	0
60-80	3.0	6.4	0.1	28	58	464	67	37	13	0.4	130	36	0.7	0.9	307	77	18	3	2	0
80-100	4.4	6.5	0.1	25	56	701	86	52	14	0.5	157	25.5	0.9	1.3	321	77	17	4	2	0
30 cm Treatment																				
0-7	27.9	7.4	2.5	255	119	4798	400	133	61	1.1	420	77	4.2	12.7	138	86	12	1	1	0
7-15	28.7	7.4	3.0	248	81	4719	528	139	75	1.2	422	66	4.5	16.2	58	82	15	1	1	0
15-30	22.5	7.4	1.8	146	86	3790	367	101	49	0.9	406	57	3.6	10.8	62	85	13	1	1	0
30-50	4.8	7.1	0.1	42	60	752	106	36	15	0.5	167	34	1.0	1.7	315	78	19	2	1	0
50-60	2.9	6.8	0.1	36	51	441	67	32	14	0.4	130	33	0.7	0.9	328	75	20	3	2	0
60-80	3.0	6.9	0.1	28	48	466	65	37	11	0.7	132	29	0.8	1.2	303	77	18	3	2	0
80-100	3.2	7.1	0.2	23	46	481	73	43	11	0.6	130	24.5	0.7	0.9	286	75	19	4	1	0

Table 7 (cont'd). Soil fertility, Sand Farm sediment plots, 2002.

Depth (cm)	TEC	pH	OM %	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al	Ca	Mg	K	Na	H
				Extractable (mg/kg)												%				
0 cm Treatment																				
0-7.6	3.9	6.5	0.7	17	118	579	97	60	9	0.7	204	37	1.2	4.0	322	74	21	4	1	0
7.6-15	2.0	5.6	0.5	17	111	282	49	55	8	0.6	153	31	1.0	2.2	356	70	21	7	2	0
15-30	1.8	5.4	0.4	17	88	246	43	52	8	0.7	133	25	0.9	1.2	372	70	20	8	2	0
30-46	1.7	5.5	0.3	14	67	238	47	46	8	0.7	121	25	0.9	0.9	342	68	23	7	2	0
46-60	1.7	5.7	0.3	13	53	229	49	44	8	0.7	110	24	0.8	0.7	317	67	24	7	2	0
7.6 cm Treatment																				
0-7.6	30.0	7.8	3.0	62	109	5089	486	158	18	1.4	493	48	5.5	30.1	246	85	13	1	0	0
7.6-15	16.7	7.7	1.4	60	131	2823	282	75	17	1.1	467	37	3.8	16.5	296	84	14	1	0	0
15-30	3.4	6.7	0.4	29	116	519	82	39	11	0.8	203	26	1.2	3.0	369	75	20	3	2	0
30-46	2.9	6.7	0.4	24	89	431	71	38	10	0.8	156	23	1.0	1.4	376	74	21	3	2	0
46-60	3.1	7.0	0.3	29	70	461	83	42	10	0.8	170	25	1.1	1.7	334	73	22	4	2	0
15 cm Treatment																				
0-7.6	30.9	7.8	3.1	50	98	5261	499	146	18	1.4	481	48	5.4	18.6	196	85	13	1	0	0
7.6-15	32.5	7.8	3.0	59	85	5508	547	118	25	1.5	497	48	5.1	19.7	192	85	14	1	0	0
15-30	7.6	7.6	0.6	26	106	1253	143	45	13	0.9	272	30	1.8	3.9	319	78	19	2	1	0
30-46	3.0	7.4	0.3	19	76	428	84	34	9	0.7	152	28	1.3	1.4	332	72	24	3	1	0
46-60	3.0	7.3	0.2	23	60	430	80	37	11	0.7	135	25	0.9	1.2	331	72	23	3	2	0
30 cm Treatment																				
0-7.6	31.3	7.6	3.3	82	108	5251	537	166	24	1.3	457	48	6.5	38.4	219	84	14	1	0	0
7.6-15	31.7	7.6	3.2	126	94	5307	568	130	32	1.3	465	47	6.5	39.8	246	84	15	1	0	0
15-30	33.8	7.7	3.5	161	92	5626	623	137	40	1.5	467	48	6.3	43.4	236	83	15	1	1	0
30-46	10.9	7.5	1.0	74	98	1776	218	59	18	0.8	299	32	2.8	16.6	310	76	21	2	1	0
46-60	7.1	7.6	0.5	50	87	1152	143	46	13	0.8	275	29	1.9	8.7	317	74	22	3	1	0

All other elements measured were greatly increased by adding dredged sediment, as was the total cation exchange capacity (Figure 22). The maximum initial sediment depth was 30 cm; consequently, no dredged sediment material was expected at 45 or 60 cm. Although an increase in the concentration of some elements was observed at those depths, this trend could be attributed to leaching, enhanced plant growth, or biopedoturbation activity observed in the plots (ants, etc.). Comparing year 1 and 2 (Table 7) at 45 and 60 cm depths, an evident increase in total exchangeable cations (TEC) can be observed, as well as levels of Ca, Mg, Fe, and Zn, which were found in high concentrations in the sediment. P and K were added as fertilizer at the beginning of each season. In contrast, lower concentrations of Na, B, Mn, Cu, and Al were measured in the original dredged sediment and did not demonstrate a noticeable increase at lower depths in the soil profile.

Statistical analyses of nutrient levels, including all sediment depths (7, 15, 30, 45, and 60 cm), corroborate the influence of dredged sediment on sandy soils (Table 8). Throughout the entire profile, organic matter content was higher in treatment 30. TEC was also significantly higher when adding sediment. P and K also increased with the addition of sediment, but the differences were not as large because these nutrients were also added with fertilizer application to the entire experimental plot area (Figure 23).

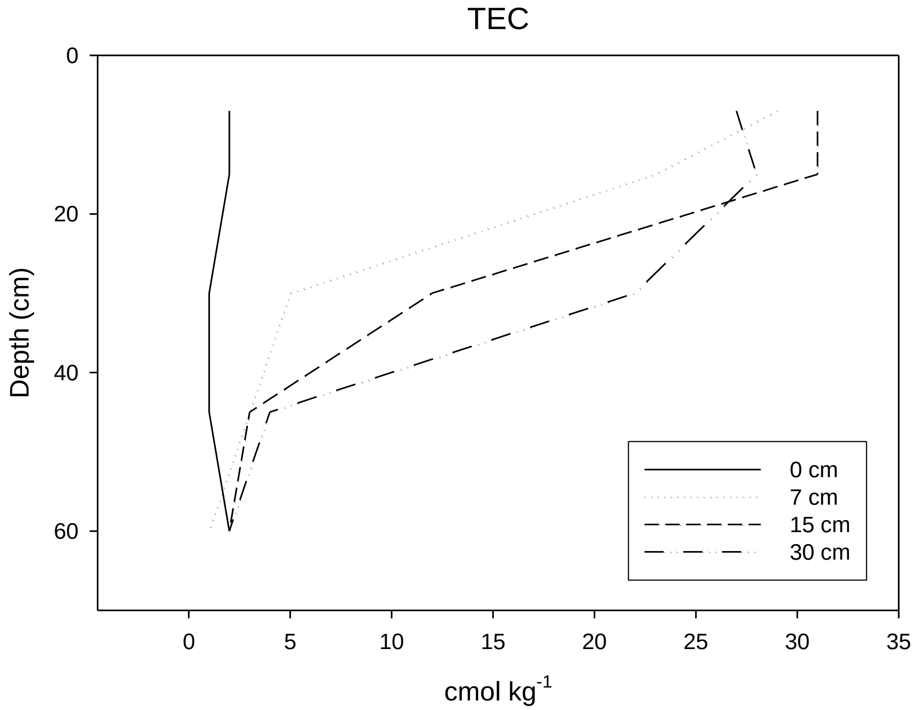


Figure 22. Soil total exchange capacity after sediment addition.

Table 8. Least square means of soil nutrients of 0–60 cm, by treatment (2001, 2002).

Treatment (cm Sediment)	OM (%)	pH	TEC cmol kg^{-1}	P	Ca	Mg	K
				------------------mg kg^{-1}-------------------			
30	1.7 a[†]	7.4 a	20 a	90 a	3720 a	365 a	100 a
15	1.3 b	7.2 a	16 b	89 ab	2606 b	272 b	84 ab
7	1.0 b	6.8 b	12 c	101 a	1936 c	195 c	71 b
0	0.2 c	5.4 c	2 d	87 b	292 d	47 d	44 c
	Na	B	Fe	Mn	Cu	Zn	Al
	-------------------------------------mg kg^{-1}------------------------------------						
30	26 a	1.0 a	343 a	47 a	3.5 a	29.0 a	264 b
15	16 b	0.9 a	318 a	44 ab	2.8 b	9.4 b	272 b
7	13 bc	0.8 a	285 b	39 b	2.2 c	9.3 b	324 a
0	8 c	0.5 b	146 c	34 c	0.9 d	1.5 b	342 a

† Values in a column followed by the same letters are not statistically different (α = 0.05).

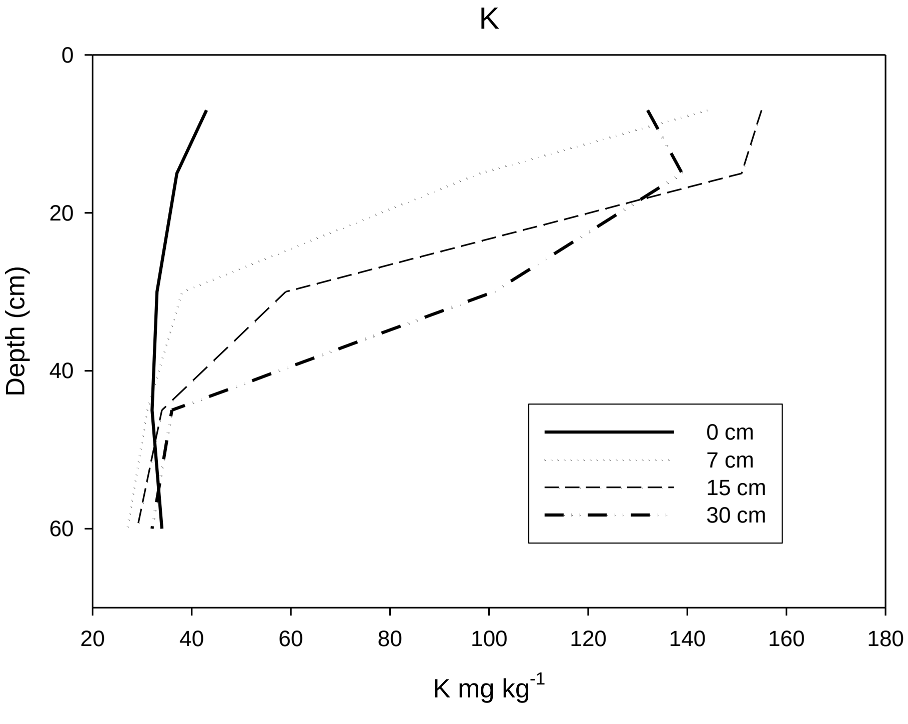


Figure 23. Soil extractable K content after sediment addition.

As the dominant cations, Ca, Mg, and Na follow the trends of the TEC; that is, they increased in sediment-treated plots. A small increase of Mn and Cu in sediment-treated plots could also be observed, as well as an increase in the level of Zn. The one element reduced by applying the sediment was Al, which is considered advantageous because this element is often associated with toxicity in plants. The trend in Al concentrations in the soil is the opposite of Ca and other cations. Compounds governing Al solubility vary from soil to soil; however, a variation of total soluble Al is a function of pH for kaolinite, gibbsite, halloysite, and amorphous $Al(OH)_3$ with a minimum at pH ~7.0 (Marion et al., 1976). In treatments with dredged sediment, pH levels were typically at or above 7.0, suggesting a significant influence on total Al solubility.

In terms of fertility, the dredged sediment had essentially the same characteristics as a highly productive Mollisol from Illinois (Darmody et al., 2004). Plant-available elements in sediments were considered ideal for plant growth, eliminating the possibility of potential plant damage by excess elements (University of Illinois Extension, 2002).

Sediment Metal Content

Acceptable levels of pollutant metals in sediments intended for land application have not been formally established; instead, pollutant limits for land application of sewage sludge from Part 503 (USEPA, 1994b) are used here as a reference (Appendix H).

None of the elements exceeded one-eighth of the ceiling levels established by the USEPA (1994b) for land application of sewage sludge and biosolids (Table 9). Concentrations of metals through the soil profile showed a relatively lower concentration in the upper 7 cm; this trend could be attributed to pedoturbation activities that allow soil from the lower depths to be deposited at the surface, contributing to the dilution of elements in the soil. Leaching or mixing to lower depths should also be considered (Figure 24).

Soil samples were also analyzed for metal pollutants at the end of the third year for the control sandy soil as well as plots with 15 and 30 cm of sediment applied. No replicates were analyzed; therefore, a descriptive analysis is presented in Figure 25. All elements occurred in lower concentrations in the control sandy soil, except for Se, which was below the limit of detection (LOD) for all treatments (Table 10). At comparable depths (7 and 15 cm), the 15 cm sediment treatment showed an overall lower concentration of metals than the 30 cm sediment treatment. Perhaps a thinner sediment layer (15 cm) promoted further mixing and consequential dilution of metals than the 30 cm sediment layer. Distribution of metals through the soil profile in the third year followed the same trend observed at the end of the first year, with lower concentrations at the upper surface. Cd levels in the 30 cm sediment plot were above the suggested normal soil range; in contrast, possible dilution in the 15 cm sediment plot reduced Cd concentrations to a typical range.

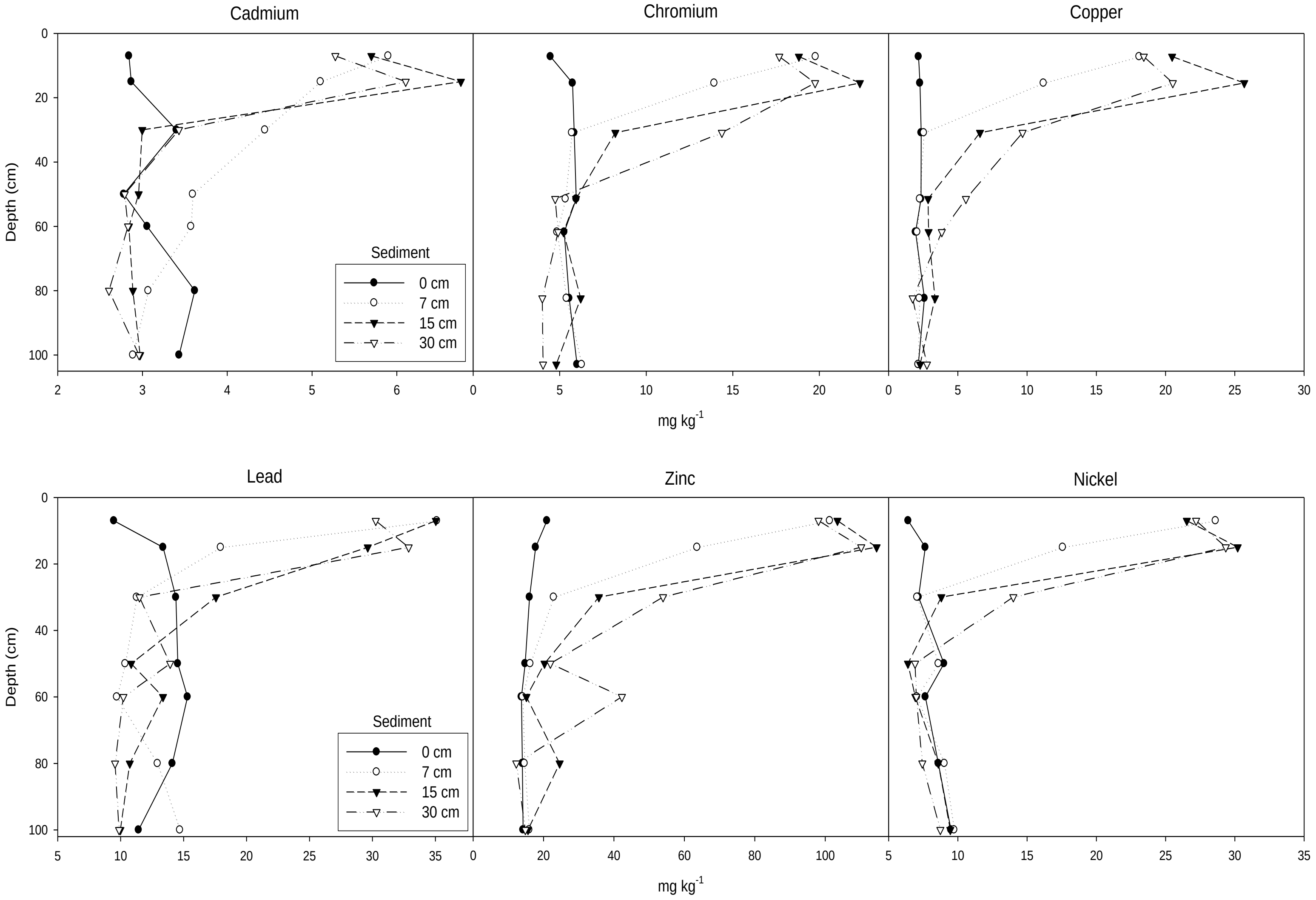


Figure 24. Total extractable metal content (DTPA) in the soil profile (after first cropping season).

Table 9. Total recoverable metals in sediments and soils after one season (mg kg^{-1}).

Treatment	Depth	Cd	Cr	Cu	Pb	Ni	Zn
0	0-7	2.8	4.5	2.2	9.5	6.4	21.0
	7-15	2.9	5.7	2.3	13.4	7.7	17.8
	15-30	3.4	5.8	2.4	14.4	7.2	16.0
	30-50	2.8	6.0	2.3	14.5	9.0	14.8
	50-60	3.1	5.3	1.9	15.3	7.7	13.7
	60-80	3.6	5.6	2.6	14.1	8.6	14.0
	80-100	3.4	6.0	2.1	11.4	9.5	14.2
	Mean	3.1b†	5.5c	2.3c	13.2b	8.0b	15.9c
7.5	0-7	5.9	19.8	18.1	35.1	28.6	101.3
	7-15	5.1	13.9	11.2	17.9	17.6	63.6
	15-30	4.4	5.7	2.5	11.3	7.1	22.9
	30-50	3.6	5.3	2.3	10.4	8.6	16.2
	50-60	3.5	5.5	2.0	9.6	7.7	14.2
	60-80	3.1	5.4	2.2	12.9	9.0	14.6
	80-100	2.9	6.3	2.1	14.7	9.7	15.9
	Mean	4.1a	8.8b	5.8b	16.0ab	12.6a	35.5b
15	0-7	5.7	18.8	20.5	35.0	26.5	103.5
	7-15	6.8	22.3	25.7	29.6	30.2	114.6
	15-30	3.0	8.2	6.6	17.6	8.8	35.7
	30-50	3.0	5.9	2.9	10.8	6.4	20.3
	50-60	2.8	5.2	2.9	13.4	6.9	15.1
	60-80	2.9	6.2	3.4	10.7	8.6	24.6
	80-100	3.0	4.8	2.3	10.0	9.5	15.6
	Mean	3.9a	10.2a	9.2a	18.2a	13.8a	47.1a
30	0-7	5.3	17.7	18.4	30.3	27.2	98.1
	7-15	6.1	19.8	20.5	32.9	29.3	110.2
	15-30	3.4	14.4	9.7	11.5	14.0	53.9
	30-50	2.8	4.7	5.6	13.9	6.9	21.9
	50-60	2.8	4.9	3.8	10.2	7.0	42.3
	60-80	2.6	4.0	1.7	9.6	7.4	12.3
	80-100	3.0	4.0	2.8	9.9	8.7	14.8
	Mean	3.7ab	9.9ab	8.9a	16.9ab	14.4a	50.5a
Mean	0-7	4.9a	15.2a	14.8a	27.5a	22.2a	81.0a
	7-15	5.2a	15.4a	14.9a	23.5a	21.2a	76.6a
	15-30	3.6b	8.5b	5.3b	13.7b	9.3b	32.1b
	30-50	3.0b	5.5c	3.2c	12.4b	7.7b	18.3c
	50-60	3.1b	5.1c	2.7c	12.5b	5.2b	21.3c
	60-80	3.0b	5.3c	2.5c	11.8b	8.4b	16.4c
	80-100	3.1b	5.3c	2.3c	11.5b	9.4b	15.1c
	Mean	3.7	8.6	6.5	16.1	12.2	37.3

† Values within a group followed by different letters are statistically different (α = 0.05).

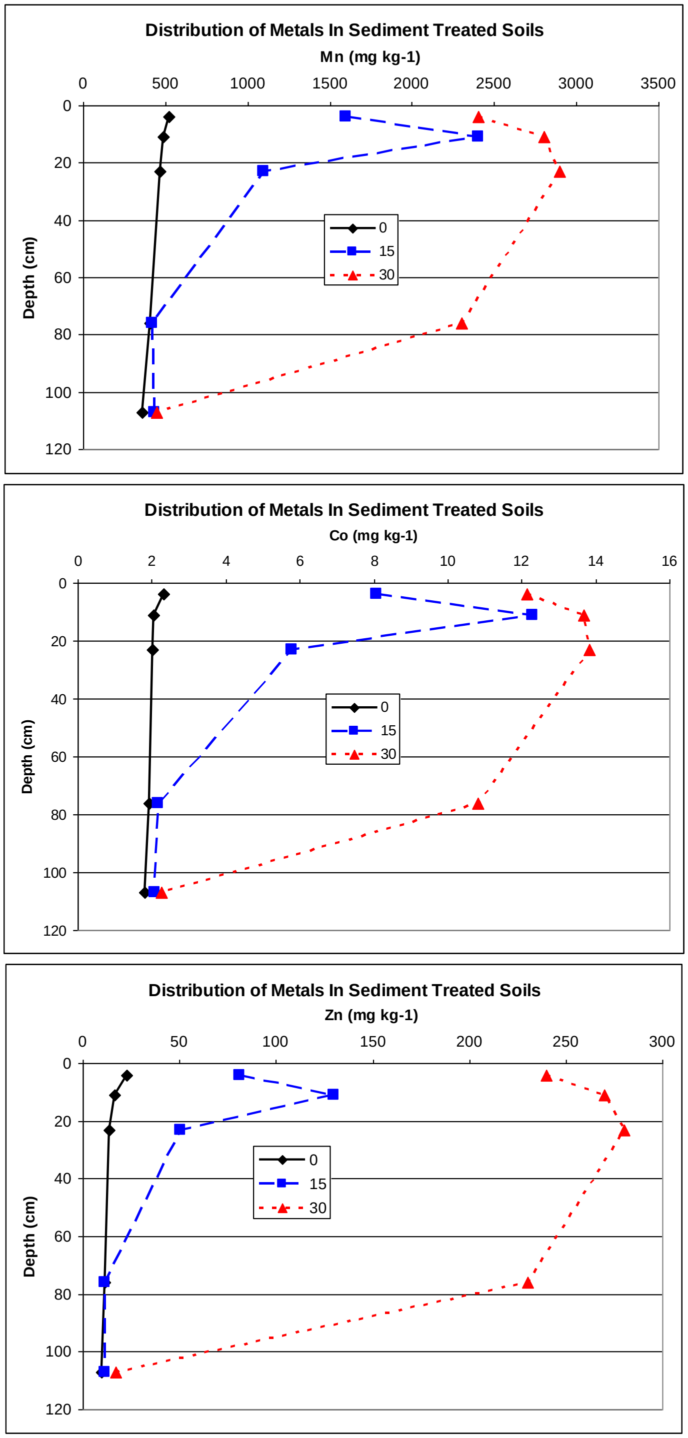


Figure 25. Total recoverable metal content (USEPA 3050) in the soil profile (after third cropping season).

Table 10. Soil metals analysis (total recoverable) of selected treatments by depths, sampled at the end of year 3 at the Sand Farm field research site.

Treatment	Depth (cm)	Be	B	Ti	V	Cr	Mn	Co	Ni	Cu	Pb
			mg kg^{-1}								
0	7	< 0.5	< 10	98	12	8	520	2	5	3	7
0	15	< 0.5	< 10	110	11	8	490	2	4	2	7
0	30	< 0.5	< 10	130	13	7	470	2	4	2	4
0	45	< 0.5	< 10	108	10	6	403	2	4	2	2
0	60	< 0.5	< 10	110	10	6	360	2	4	2	2
15	7	< 0.5	20	180	35	34	1600	8	18	15	22
15	15	0.7	23	150	44	48	2400	12	27	21	35
15	30	< 0.5	11	81	21	20	1100	6	11	9	13
15	45	< 0.5	< 10	94	10	7	420	2	5	2	2
15	60	< 0.5	< 10	100	11	6	430	2	4	2	3
30	7	0.8	24	200	49	75	2400	12	36	32	61
30	15	0.9	31	240	57	88	2800	14	42	37	66
30	30	0.9	27	202	54	87	2900	14	42	38	68
30	45	0.7	21	150	40	65	2300	11	31	29	22
30	60	< 0.5	< 10	120	13	7	450	2	4	3	4

		Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Hg
			mg kg^{-1}							
0	7	23	1	< 3	0.2	< 0.2	< 0.2	24	< 0.2	0.007
0	15	16	1	< 3	0.2	< 0.2	< 0.2	16	< 0.2	0.004
0	30	14	1	< 3	0.2	< 0.2	< 0.2	15	< 0.2	0.003
0	45	11	1	< 3	0.2	< 0.2	< 0.2	14	< 0.2	0.004
0	60	10	1	< 3	0.2	< 0.2	< 0.2	19	< 0.2	0.002
15	7	81	6	< 3	0.5	< 0.2	0.9	120	0.3	0.051
15	15	130	8	< 3	0.6	0.3	1.5	170	0.4	0.075
15	30	50	4	< 3	0.4	< 0.2	0.5	71	< 0.2	0.028
15	45	11	1	< 3	0.2	< 0.2	< 0.2	15	< 0.2	0.003
15	60	12	1	< 3	0.2	< 0.2	< 0.2	17	< 0.2	0.004
30	7	240	10	< 3	0.8	0.9	4.4	150	0.5	0.211
30	15	270	11	< 3	1.1	1.1	5.1	180	0.6	0.221
30	30	280	11	< 3	1.1	1.1	5.5	180	0.6	0.213
30	45	230	9	< 3	1.0	0.7	3.7	140	0.4	0.171
30	60	17	1	< 3	0.2	< 0.2	< 0.2	21	< 0.2	0.012

Crop Characteristics and Development

Differences in plant response were observed for the different treatments. Plant growth showed the most marked differences between treatments, and yields were highly altered by the damage occasioned by animals except in the last two years of data. In the first two years of the experiment, crop growth was severely affected by deer and rabbit grazing. In subsequent years, the animals were largely kept out of the plots by improved fencing. In addition, drought conditions during the first two years hindered crop growth. Installation of the irrigation system in the third year promoted better growth on all plots.

Plant Germination and Survival

The application of dredged sediments had a significant effect on the germination and growth of crop plants. A lower germination rate was observed for the control sandy soil two weeks after germination (Table 11); in contrast, higher germination rates were observed for treatments with 30 cm sediment in corn and soybeans. However, no difference in corn plant numbers were observed between sediment-treated soils. Improved soil properties in sediment-treated plots, such as water holding capacity, promoted germination compared with the control sandy soil.

Plant Growth

Plant height and chlorophyll content were affected by treatment (Figures 26, 27). Treatment effects on plant growth were less marked for soybeans, but there was a direct relationship between the amount of sediment applied and plant height (Figure 28).

Corn development showed stronger differences between sediment treatments and controls (Table 12). Plant growth was also directly related to the amount of sediment applied. This can likely be attributed to the improvement in soil fertility and soil moisture storage in the sediment-treated soil.

Differences in plant height were not statistically significant in the first half of the growing period; however, in the second half, a clear treatment effect was observed, especially in corn (Photo 6). A typical crop growth pattern can be characterized by a growth function referred to as a sigmoid curve. The time frame could vary, but this sigmoid accumulation pattern typifies all organisms (Gardner et al., 1985). This pattern was seen in plants growing on dredged sediment. However, plants on sandy soils, particularly corn, showed a different growing curve than expected for normal plant development (Figure 28).

The treatment effect for plant growth response changed over time. For corn and soybeans in 2002, significant differences were observed between the control sandy soil and the sediment amendment soils. However, the difference was less manifest than in the following year. The last project year showed three different groups for corn. A clear increase in plant growth was directly correlated with the amount of sediment applied, with greater growth in plots with more sediment. Soybean growth was less affected by dredged sediment application than corn; however, a statistically significant difference was observed, with higher growth in treatments with higher sediment application rates. This pattern was not affected by deer grazing as it was in the previous year, so treatment effects were more reliable.

Table 11. Least square means of number of plants per 6 m of row (years 1, 2), two weeks after germination.

Treatment Sediment (cm)	Corn	Soybeans
0	49 b[†]	155 c
7	56 a	202 a
15	55 a	178 b
30	57 a	217 a

† Numbers with the same letter are not statistically different at α = 0.1

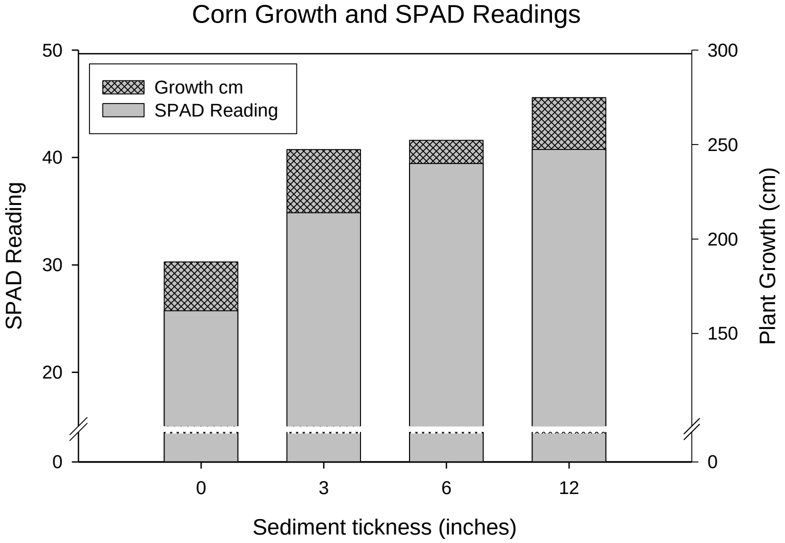


Figure 26. Corn chlorophyll content and growth at the sediment research plots.

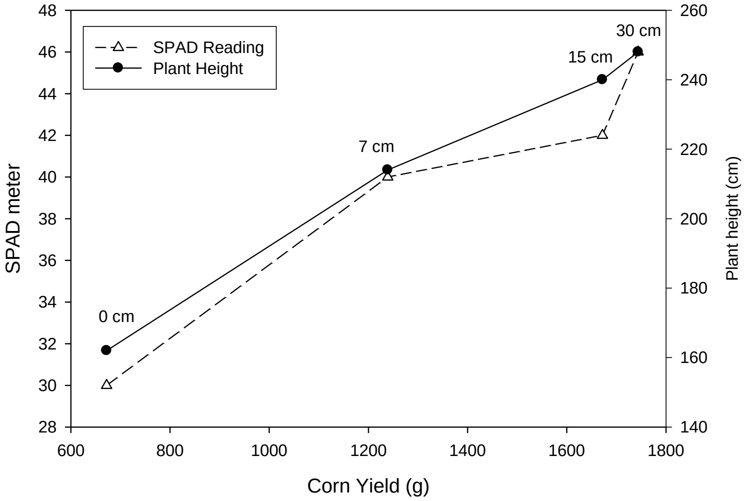


Figure 27. Corn response to sediment application (year 3).

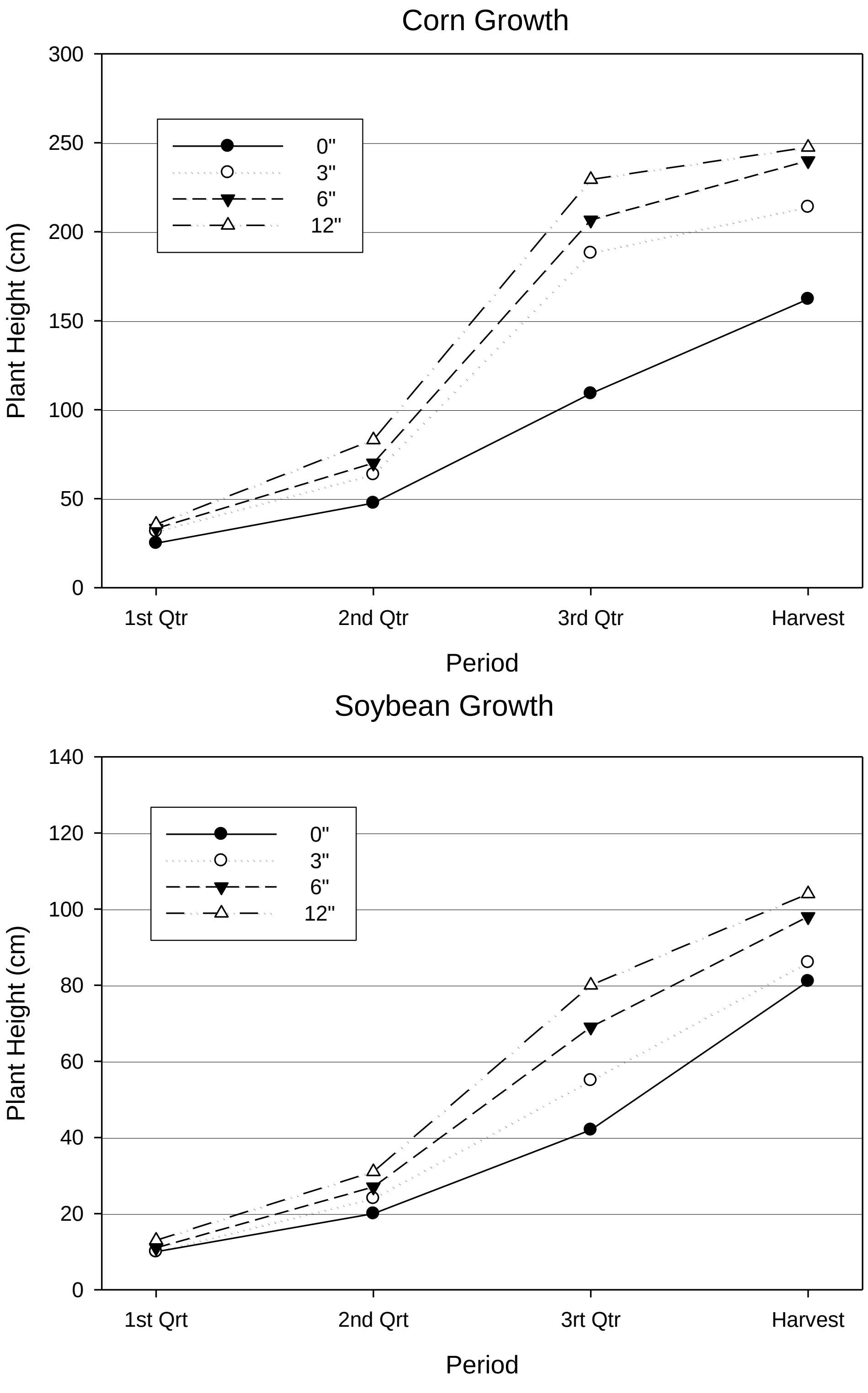


Figure 28. Corn and soybean growth at the Sand Farm, 2003.

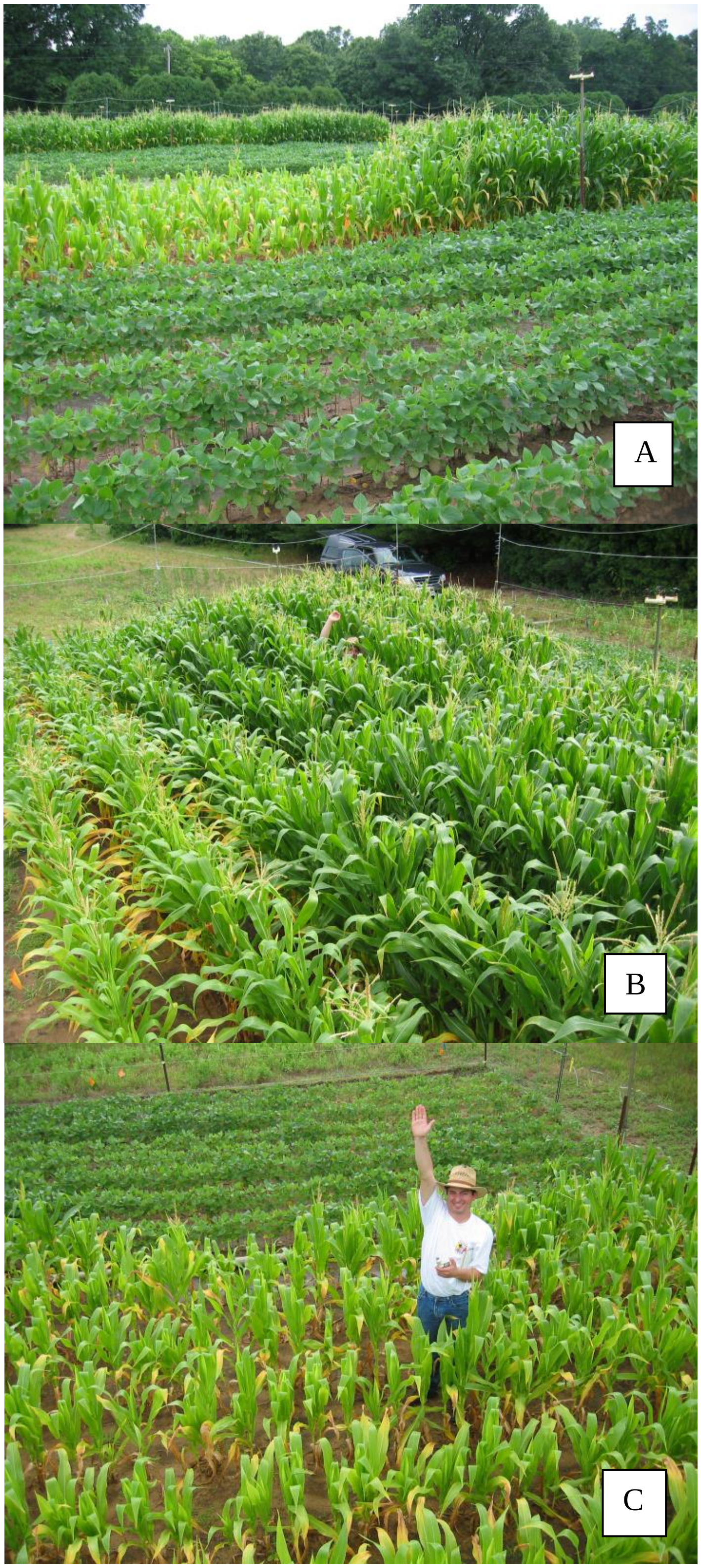


Photo 6. Crop response to sediment addition, 2003; A, view of plots showing strong response of corn and weak response of soybean to sediment addition; B, corn height at mid-season in sediment plot in contrast to C, corn height on check plot.

Table 12. Least square means of plant height at harvest.

Treatments Sediment (cm)	Year 2002		Year 2003	
	Corn	Soybeans	Corn	Soybeans
	cm			
0	86 b	46 b	162 c	81 b
7	90 b	46 b	214 b	86 b
15	95 ab	53 a	240 a	98 a
30	106 a†	51 ab	248 a	104 a

† Values in a column with the same letter are not statistically different.

Relative Chlorophyll Level in Corn

Chlorophyll content in corn leaves, measured with the SPAD meter, showed significant differences between treatments, with a value of 30 for the control sandy soil and 40, 42, and 46, respectively, for the 7, 15, and 30 cm sediment treatments. All treatment values were statistically different from the control (Figure 27). As the level of sediment increased, improved nutrient levels (particularly N) in plant tissues were presumed from this chlorophyll response.

Direct relationships between corn yield and plant growth and yield and chlorophyll content were observed. All these variables responded directly to the level of dredged sediment applied. Furthermore, higher nutrient levels in the plants growing on sediment allowed better overall crop performance.

Crop Yield

Yields of both crops were very low in the first two years, attributed mainly to damage from wild animals and poor rainfall distribution (Table 13). Therefore, no clear treatment effects were observed (Figure 29). However, yields in subsequent years were considered a direct effect of experimental treatments, given that herbivory was minimized through the erection of fences after year 3 (Photo 7). Statistical analyses included only the data from the last two years of harvest, after animal grazing was better controlled, but not eliminated (Appendix D).

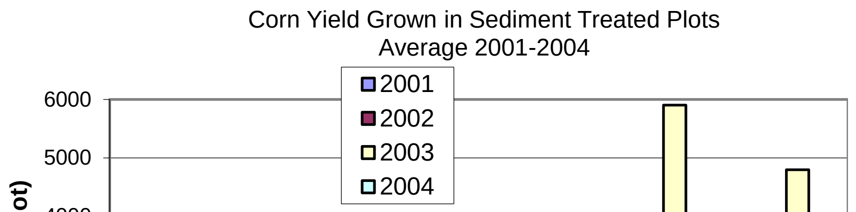
Soybean responses to sediment treatments tended to be irregular; however, significantly higher yields were obtained with the application of 15 cm of sediment. No statistically significant differences were observed in treatments with 0, 7, and 30 cm of applied sediment. This pattern contradicts the one observed for soybean height (Table 12).

Corn yield showed a direct positive response to sediment treatments (Appendix D). Treatments with sediment produced significantly higher yields than the control sandy soil. Across all years, the highest yield occurred in treatments with 30 cm of sediment (Photo 8). Corn height followed the same pattern (Figure 30).

Table 13. Mean annual soybean and corn grain yields from sediment-treated plots.

Year	Treatment (cm)	Yield (g per plot)	
		Corn	Soybeans
2001	0	399a[†]	9
	8	96b	11
	15	87b	17
	30	54b	54
	Average	159	23
2002	0	153	399
	8	55	255
	mixed 8	63	93
	15	79	363
	30	29	320
	Average	76	286
2003	0	1269d	974bc
	8	3802c	961bc
	mixed 8	3164c	848c
	15	3780c	1271ab
	mixed 15	5902a	1549a
	30	4795b	883c
	Average	3785	1081
2004	0	508b	742
	8	1778a	795
	mixed 8	901ab	861
	15	1353ab	844
	mixed 15	1439ab	947
	30	1392ab	981
	Average	1228	862
Average	0	582	531
	8	1433	505
	mixed 8	1376	601
	15	1325	624
	mix 15	3670	1248
	30	1568	559
	Average	1312	563
Total	0	2328	2124
	8	5731	2022
	15	5298	2496
	30	6270	2237

[†] Means within a year followed by a different letter are significantly different ($\alpha = 0.05$).



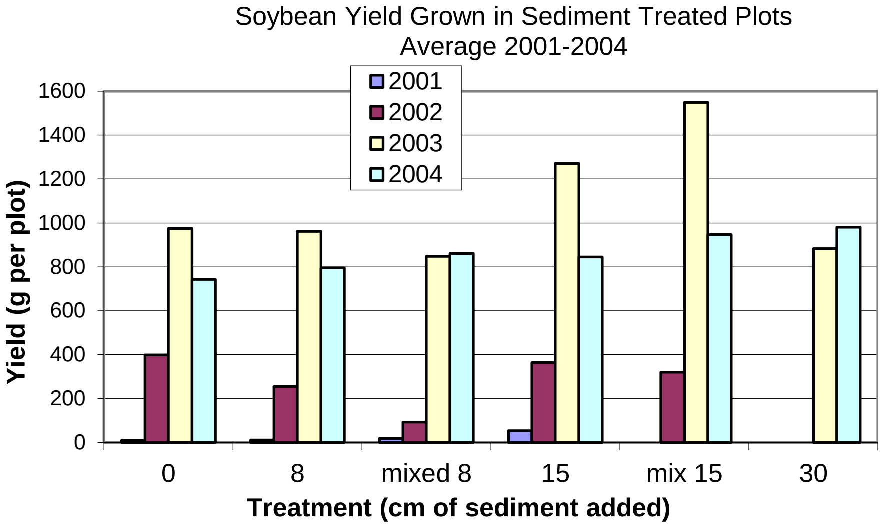


Figure 29. Crop yields at the Sand Farm sediment research plots. The 30 cm plots were added in 2003.

Photo 7. Harvesting crops at the Sand Farm in two 10 ft. (3.05 m) rows; A, cutting all soybean plants; B, hand harvesting all ears of corn; C, yields from individual plots, control left, 15 cm sediments right.

Photo 8. Corn response to sediment addition at end of growing season; A, corn grown on check plot; B, corn on 30 cm sediment plot; C, corn grown on sediment left, and check plot, right.

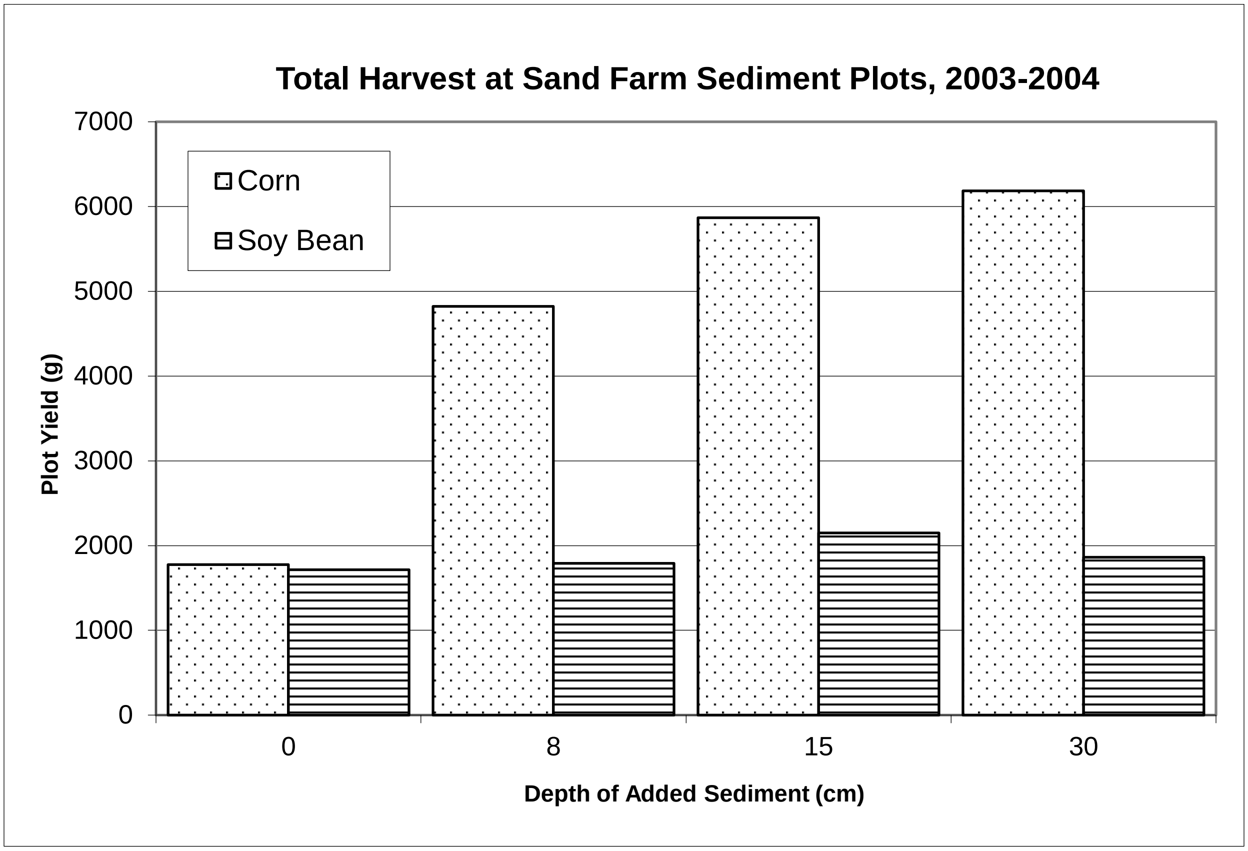


Figure 30. Total crop yield, years 2003–2004, at the Sand Farm sediment research plots.

Metal Uptake by Soybeans

For plant tissues, most metals reported here were essentially equivalent to a total metals analysis. Metal content, in general, was higher in sediment-treated plots (Table 14), but levels were still low enough not to be considered problematic.

Metal concentration analysis was performed only for soybeans. Metal values were for plants from individual plots; therefore, no statistical analysis could be done. Instead, noticeable trends are described in this article. Levels of Be, Se, Ag, and Tl were below the limit of detection (LOD) in soybean tissue for all treatments and plant parts (leaves or grain). Concentrations of B, Cu, Zn, Cd, and Hg were higher in plants grown on sediment-amended soil than in the control sandy soil. This trend is for both leaves and grain (Table 14). The level of Mo followed the same trend; however, a marked difference could be observed between plant leaves and grain, with concentrations of up to 10-fold greater in the grain.

Table 14. Metals in soybean leaves and grain grown at the field sediment research site. †

Material	Sediment (cm)	B	Ti	V	Cr	Mn	Co	Ni	Cu
		mg kg^{-1}							
Leaves	0	19	6	0.1	0.5	190	0.2	0.7	2.0
Leaves	15	40	5	0.1	0.5	86	0.1	0.5	3.2
Leaves	30	34	5	0.1	0.5	46	0.1	1.6	3.4
Grain	0	10	10	0.02	0.05	55	0.2	2.4	3.7
Grain	15	30	11	0.02	0.08	30	0.1	3.0	9.4
Grain	30	34	10	0.02	0.08	28	0.1	2.6	8.2
		Zn	As	Mo	Cd	Ba	Pb	Hg	
		mg kg^{-1}							
Leaves	0	9	0.17	0.1	0.1	114	0.9	0.016	
Leaves	15	42	0.19	2	0.5	11	0.7	0.015	
Leaves	30	38	0.19	4	0.5	10	0.9	0.056	
Grain	0	24	0.02	2	0.1	19	0.02	0.001	
Grain	15	40	0.02	23	0.3	3	0.03	0.001	
Grain	30	40	0.02	21	0.4	2	0.06	0.001	

† Be, Se, Ag, and Tl are below the limit of detection (LOD) for all treatments and materials.

Concentrations of Ti, V, Cr, Ni, As, and Pb were similar for all treatments. In contrast, levels of Mn, Co, and Ba were consistently higher in plants grown on the control sandy soils, despite lower levels of these elements in the control soil versus the sediment-amended soil. Levels of B, Cu, Zn, Mo, and Cd increased with sediment application, as was expected. Levels of Hg were very low and inconsistent (levels were at the lower limit of detection), increasing with sediment application in the leaves, but not varying in the grain.

Properties of the soil, such as pH and the presence of competing ions, influence uptake, general health, and biomass of a plant which in turn influences contaminant concentrations resulting in plant stress conditions that could promote high concentration of certain elements. In general, the element levels analyzed were considered sufficient or normal (Kabata-Pendias and Pendias, 1992). However, excessive Mo was found in the soybean grain grown in sediment-treated plots, rendering it unfit for use exclusively as a feedstock for ruminants. A minimum ratio of Cu to Mo of 2:1 in feed is recommended to avoid Cu deficiencies in ruminants (McBride et al., 2000; Mattioli et al., 1996). In leaves and grain of plants grown on the control sandy soil, the minimum Cu to Mo ratio was met; however, for all samples of plants grown on sediment, the values were below the minimum recommended. The problem with Mo in plants is essentially a theoretical one, considering that the materials would pose a potential problem only if they were the only food available to the target animals. Where natural soils present this problem, feed supplements are routinely used (McBride et al., 2000).

Differences in metal accumulation between plant leaves and grain can be observed for a number of elements (Table 15); for instance, statistically significant differences were found for V, Cr, Mn, Cu, Zn, Mo, Co, Cd, and Hg, suggesting a significant relocation of elements within the soybean plant.

The differential uptake of metals, defined as the ratio of the metal content in the plant as compared to the soil, was striking (Table 16). Because certain elements were quite rare in the soil, the uptake ratio could be very high, as was the case with Hg, approximately four times more concentrated in soybean leaves than in the control soil. This ratio was lower in grain and where sediments were applied (because the Hg content was higher), yet the plant absorbs very little. Because Mo is a necessary element for legumes, the plant had a strong ability to absorb it despite the low concentration in sediments (Table 10).

In addition to the metal content, the potential uptake of organic contaminants in the sediments was also a potential problem. We conducted a limited analyses of PCB content of soybean grain (six samples from the sediment plots), and detected only two congeners of the PCB Aroclor-1254 (Table 17). Differences in the lipid and solid contents between sediment- and sand-grown grain were not evident.

Table 15. Difference in metals in soybean leaves and grain from plants grown at the field sediment research site. †

Element	α	Element	α	Element	α
B	0.9900	Ni	0.6313	Co*	0.0261
Ti	0.3477	Cu*	0.0048	Cd*	0.0050
V*	< 0.0001	Zn*	0.0010	Ba	0.3578
Cr*	< 0.0001	As	0.4007	Pb	0.0962
Mn*	< 0.0001	Mo*	< 0.0001	Hg*	< 0.0001

† Be, Se, Ag, and Tl are below the limit of detection (LOD) for all treatments and materials.

* Significant difference (α = 0.05).

Table 16. Preferential metal uptake by soybean leaves and grain. †

Material	Sediment (cm)	B	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	As	Mo	Cd	Ba	Pb	Hg
Leaves	0	LOD‡	0.05	0.011	0.079	0.42	0.075	0.16	0.91	0.61	0.058	0.4	LOD	6.48	0.222	3.980
Leaves	15	2.2	0.04	0.005	0.021	0.07	0.017	0.04	0.33	0.74	0.047	5.4	0.54	0.14	0.049	0.467
Leaves	30	1.3	0.03	0.003	0.008	0.02	0.007	0.05	0.12	0.18	0.022	5.0	0.11	0.07	0.019	0.338
Grain	0	LOD	0.09	0.002	0.007	0.12	0.110	0.58	1.68	1.62	0.007	7.1	LOD	1.08	0.005	0.128
Grain	15	1.7	0.09	0.001	0.003	0.03	0.015	0.24	0.97	0.70	0.005	58.0	0.29	0.04	0.002	0.019
Grain	30	1.3	0.05	0.001	0.001	0.01	0.006	0.08	0.30	0.19	0.002	24.3	0.08	0.01	0.001	0.005

† Expressed as the ratio of plant concentration to soil concentration (0–60 cm), Be, Se, Ag, and Tl are below the limit of detection (LOD) for all treatments and materials.

‡ Limit of detection.

Table 17. PCB, lipid, and solid contents of soybean grain grown in sediment and sand, 2004.

Plot Sample	Treatment	Aroclor-1254 (µg/kg)	Lipids %	Solids %
EB4A	0†	<17‡	11.0	91.5
EB4B	0	<17	9.9	91.4
WB1A	0	<17	6.8	91.2
WB1B	0	<17	10.3	90.8
MP1A	15	<17	10.5	91.3
MP1B	15	<17	10.7	90.5
EB1A	30	<17	10.4	90.5
EB1B	30	22	10.7	90.5
WB2A	30	21	11.9	91.1
WB2B	30	<17	10.2	90.8

† Treatment is the depth (cm) of sediment added to plots.

‡ Below detection limit, all results non-significant ($\alpha = 0.05$).

Conclusions

The overall conclusions were based on soil analyses and plant performance from four years, but extensive plant damage from animals in the first two years significantly altered the measured plant parameters, especially yield. Data from the third and fourth years were likely more representative of the actual findings because the worst impacts of dry weather and damages from animals were largely controlled in those years.

Analyses of chemical and physical soil properties suggested that the addition of dredged sediment to sandy soils significantly improved the overall quality of the soil for crop production. Outstanding improvements were observed in the water holding capacity of the soil, a property that may be one of the most relevant for this region, given that application of irrigation water represents one of the highest production costs. Soil nutrient levels increased significantly with the added dredged sediment, as well as desirable properties such as cation exchange capacity and organic matter content.

Despite the higher surface compaction observed in the sediment-treated plots, no negative effect was observed in any of the crops grown on the sediment treatments. Levels of metals in the soil increased with the added sediments. For example, the total concentration of Cd in soil in some of the sediment-treated plots were above suggested normal values, but the rest of the element levels were considered normal for US soils.

Corn growth was directly proportional to the amount of sediment applied, with the best plant height and yield found in the 30 cm sediment treatments. This was also supported by higher values of SPAD chlorophyll-meter readings, suggesting greater nutrient levels in the plant, especially N. In soybeans, greater plant growth was observed in treatments with 30 cm sediment; however, plant lodging occurred at harvest in this treatment in 2003, perhaps because of excessive vegetative growth or high winds. Treatments with 15 cm of sediment produced higher soybean yields, but note that soybeans did not show a constant yield response to the application of sediment, as observed for corn. Metal concentrations in soybean tissue were, in general, within normal suggested values for US soil; however, levels of Mo in soybean grain require care if it will be used exclusively for ruminant feeding. The overall conclusion of the research is that sediments improved the physical, chemical, and crop growth properties of Bloomfield soils without significantly adding bioavailable contaminants to the soil.

References

Almedia, M.S.S., L.S. Borma, and M.C. Barbosa. 2001. Land disposal of river and lagoon dredged sediments. Engineering Geology 60:21‒30.

Bedell, J-P., X. Capilla, C. Giry, C. Schwartz, J-L. Morel, and Y. Perrodin. 2009. Distribution, movement and availability of Cd and Zn in a dredged sediment cultivated with *Salix alba*. Environmental and Experimental Botany 67:403‒414.

Beyer, W.N., G. Miller, and J.W. Simmers. 1990. Trace elements in soil and biota in confined disposal facilities for dredged material. Environmental Pollution 65:19‒32.

Blake, G.R., and K.H. Hartge. 1986. Bulk density, 363‒375. In Method of soil analysis, part 1. Physical and mineralogical methods-agronomy monograph no. 9 (2nd Ed.). A. Klute (Ed.) American Society of Agronomy and Soil Science Society of America. Madison, WI.

Brady, N.C., and R.R. Weil. 2002. The nature and properties of soils. 13th ed. Upper Saddle River, NJ: Prentice Hall Press.

Caille, N., C. Tiffreau, C. Leyval, and J.L. Morel. 2003. Solubility of metals in an anoxic sediment during prolonged aeration. The Science of the Total Environment 301:239‒250.

Calsyn, D.E. 1995. Soil Survey of Mason County, Illinois. USDA Natural Resources Conservation Service.

Canet, R., C. Chavez, F. Pomares, and R. Albiach. 2003. Agricultural use of sediments from the Albufera Lake (eastern Spain). Agriculture Ecosystem and Environment 95:29‒36.

Cappuyns, V., R. Swennen, and A. Devivier. 2006. Dredged river sediments: Potential chemical time bombs? A case study. Water, Air, and Soil Pollution 171:49‒66.

Chen, Y.X., G.W. Zhu, G.M. Tian, G.D. Zhou, Y.M. Lou, and S.C. Wu. 2002. Phytotoxicity of dredged sediment from urban canal as land application. Environmental Pollution 117:233‒241.

Choueri, R.B., A. Cesarb, D.M.S. Abessac, R.J. Torres, R.D. Morais, I. Riba, C.D.S. Pereirab, M.R.L. Nascimentog, A.A. Mozetod, and T.A. DelVallsa. 2009. Development of site-specific sediment quality guidelines for North and South Atlantic littoral zones: Comparison against national and international sediment quality benchmark. Journal of Hazardous Materials 170:320‒331.

Cook, S.R., and A. Parker. 2003. Geochemical changes to dredged canal sediments following land spreading: A review. Land Contamination & Reclamation 11:405‒410.

Daniels, W.L., G.R. Whittecar, and C.H. Carter III. 2007. Conversion of Potomac River dredge sediments to productive agricultural soils. 2007 National Meeting of the American Society of Mining and Reclamation, Gillette, WY, June 2‒7, 2007. pp. 183‒199.

Darmody, R.G., and J.C Marlin. 2002. Sediments and sediment-derived soils in Illinois: Pedological and agronomic assessment. Environmental Monitoring and Assessment 77:209‒227.

Darmody, R.G., J.C. Marlin, J. Talbott, R.A. Green, E.F. Brewer, and C. Stohr. 2004. Dredged Illinois River sediments: Plant growth and metal uptake. Journal of Environmental Quality 33:458‒464.

Demissie, M. 1997. Patterns of Erosion and Sedimentation in Illinois River Basin, Proceedings of the 1997 Governor's Conference on the Management of the Illinois River System.

Special Report 23. Oct. 7–9, 1997. Water Resources Center, University of Illinois. Urbana, IL.

Ebbs, S., J. Talbott, and R. Sankaran. 2006. Cultivation of garden vegetables in Peoria Pool sediments from the Illinois River: A case study in trace element accumulation and dietary exposures. Environment International 32:766–774.

Fitzpatrick, W.P., and G.E. Stout. 1988. Beneficial uses from dredged lake sediments in Illinois. Technical Report D-88-8. Inland Waterways: Proceedings of a National Workshop on the Beneficial Uses of Dredged Material, October 27–30, 1987, St. Paul, Minnesota. M.C. Landin (ed.), U.S. Army Engineer Waterways Experiment Station. pp. 184–191.

Gardner, F.P., R.B. Pearce, and R.L. Mitchell. 1985. Physiology of crop plants. 1st ed. Iowa State University Press, Ames, Iowa.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. pp. 383–411. In: Method of Soil Analysis, Part 1. Physical and Mineralogical Methods-Agronomy Monograph no. 9 (2nd Ed.). A. Klute (Ed.) American Society of Agronomy and Soil Science Society of America. Madison, WI.

Howard, W.J. 1999. Plant growth on soils mixed with dredged sediment. Journal of Environmental Science and Health. Part A, Toxic/Hazardous Substances and Environmental Engineering 34(6):1229–1252.

Kabata-Pendias, A., and H. Pendias. 1992. Trace elements in soils and plants. 2nd ed. CRC Press, Boca Raton, FL.

Kember, W.D., and R.C. Rosenau. 1986. Aggregate Stability and Size Distribution. pp. 425–442. In Method of Soil Analysis, Part 1. Physical and Mineralogical Methods. Agronomy Monograph no. 9 (2nd Ed.). A. Klute (Ed.) American Society of Agronomy and Soil Science Society of America. Madison, WI.

King, R.F., A. Royle, P.D. Putwain, and N.M. Dickinson. 2006. Changing contaminant mobility in a dredged canal sediment during a three-year phytoremediation trial. Environmental Pollution 143:318–326.

Klute, A. 1986. Water Retention: Laboratory Methods. pp. 635–662. In Method of Soil Analysis, Part 1. Physical and Mineralogical Methods-Agronomy Monograph no. 9 (2nd Ed.). A. Klute, ed. American Society of Agronomy and Soil Science Society of America. Madison, WI.

Landin, M.C. 1997. Proceeding: International Workshop on Dredged Material Beneficial Uses. Baltimore, MD. US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Lee, C.R. 2001. Manufactured soil field demonstrations on brownfields and abandoned minelands. DOER Technical Notes Collection (ERDC TN-DOER-C25), U.S. Army Engineer Research and Development Center, Vicksburg, MS. www.wes.army.mil/el/dots/doer

Lembke, W.D., J.K. Mitchell, J.B. Fehrenbacher, and M.J. Barcelona. 1983. Dewatering dredged sediment for agriculture. Transactions of the American Society of Agricultural and Biological Engineers 26:805–813.

Linquist, B.A., P.W. Singleton, R.S. Yost, and K.G. Cassman. 1997. Aggregate size effects on the sorption and release of phosphorus in an Ultisol. Soil Science Society of America Journal 61:160–166.

Marion, G.M., D.M. Hendricks, G.R. Dutt, and W.H. Fuller. 1976. Aluminum and silica solubility in soils. Soil Science 121:76–84.

Mattioli, G.A., C.E. Ramirez, M.J. Giuliodori, C.M. Tittarelli, H. Yano, and T. Matsui. 1996. Characterization of cattle copper deficiency in the Magdalene district. Livestock Production Science 47:7‒10.

McBride, M.B., B.K. Richards, T. Steenhuis, and G. Spiers. 2000. Molybdenum uptake by forage crops grown on sewage sludge-amended soils in the field and greenhouse. Journal Environmental Quality 29:848‒854.

Mehlich, A.1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Communications in Soil Sciences and Plant Analysis 15(12):1409‒1416.

Olson, K.R., and R.L Jones. 1987. Agronomic use of scrubber sludge and soil as amendments to Lake Springfield sediment dredgings. Journal of Soil Water Conservation 42:57‒60.

Piou, S., P. Bataillard, A. Laboudigue, J-F. Ferard, and J-F. Masfaraud. 2009. Changes in the geochemistry and ecotoxicity of a Zn and Cd contaminated dredged sediment over time after land disposal. Environmental Research 109:712‒720.

Ruiz Diaz, D.A., R.G. Darmody, J.C. Marlin, G.A. Bollero, and F.W. Simmons. 2010. Trace metal bioaccumulation and plant growth on dredged river sediment and biosolids mixtures. Water Air Soil Pollution 206:321‒333.

SAS Institute. 2000. The SAS system for Windows. Release 8.02. SAS Institute, Cary, NC.

Sheehan, C., J. Harrington, and J.D. Murphy. 2010. A technical assessment of topsoil production from dredged material. Resources Conservation and Recycling 54:1377‒1385 doi:10.1016/j.resconrec.2010.05.012

Singh, S.P., F.M.G. Tack, and M.G. Verloo. 1998. Land disposal of heavy metal contaminated dredged sediments: A review of environmental aspects. Land Conservation & Reclamation 6:149‒158.

Tack, F.M.G., S.P. Singh, and M.G. Verloo. 1999. Leaching behavior of Cd, Cu, Pb, and Zn in surface soils derived from dredged sediments. Environmental Pollution 106:107‒114.

University of Illinois Extension. 2002. Illinois Agronomy Handbook, 23rd ed. University of Illinois Extension Service, University of Illinois at Urbana-Champaign.

USEPA. 1994a. Microwave assisted acid digestion of sediments, sludge, soils, and oils. In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, Office of Solid Waste and Emergency Response, Washington, DC.

USEPA. 1994b. A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503. Office of Wastewaters Management, Washington, DC.

USEPA. 1998. Guidance for data quality assessment. EPA QA/G-9. USEPA Quality Assurance Division, Washington, DC.

USEPA. 2003. Dredged Material Management Action Agenda for the Next Decade, United States Environmental Protection Agency EPA 842-B-04-002.

USEPA. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites, EPA-540-R-05-012, Office of Solid Waste and Emergency Response OSWER 9355.0-85 Dec. 2005. http://www.epa.gov/superfund/resources/sediment/guidance.htm.

Vandecasteele, B., P. Quataert, G. Genouw, S. Lettens, and F.M.G. Tack. 2009. Effects of willow stands on heavy metal concentrations and top soil properties of infrastructure spoil landfills and dredged sediment-derived sites. Science of the Total Environment 407:5289‒5297.

Vermeulen, J., T. Grotenhuis, J. Joziasse, and W. Rulkens. 2003. Ripening of clayey dredged sediments during temporary upland disposal. Journal of Soils and Sediments 3:49–59.

Vermeulen, J., S.G. van Dijk, J.T.C. Grotenhuis, and W.H. Rulkens. 2005. Quantification of physical properties of dredged sediments during physical ripening. Geoderma 129:147–166.

Vervaeke, P., S. Luyssaert, J. Mertens, B. De Vos, L. Speleers, and N. Lust. 2001. Dredged sediment as a substrate for biomass production of willow trees established using the SALIMAT technique. Biomass and Bioenergy 21:81–90.

Yang, X.M., and M.M. Wander. 1998. Temporal changes in dry aggregate size and stability: Tillage and crop effects on a silt loam Mollisol in Illinois. Soil and Tillage Research 49:173–183.

Appendix A: Soil Test Parameters from Brookside Labs

Table A-1. Soil tests from Brookside Labs.

Test	**Definitions**
TEC	Total Exchange Capacity- The ability of the colloids in sample to retain cations, units are meq/kg
pH	Hydrogen ion activity, conventional units
SMP Buffer	Used to estimate lime requirement to raise pH for most agricultural crops *
Organic Matter	Soil Organic Matter Content, %
ENR	Estimate of Nitrogen release for soil organic matter
Soluble Sulfur	Water Extractable S
P	Mehlich 3 Extractable P expressed as P_2O_5 lbs/ac
P_ppm	Mehlich 3 Extractable P expressed as ppm P
Ca	Mehlich 3 Extractable Ca expressed as lbs/ac
Ca_ppm	Mehlich 3 Extractable P expressed as ppm
Mg	Mehlich 3 Extractable Mg expressed as lbs/ac
Mg_ppm	Mehlich 3 Extractable Mg expressed as ppm
K	Mehlich 3 Extractable K expressed as K_2O lbs/ac
K_ppm	Mehlich 3 Extractable K expressed as ppm
Na	Mehlich 3 Extractable Na expressed as lbs/ac
Na_ppm	Mehlich 3 Extractable Na expressed as ppm
Ca_pct	Exchangeable Ca expressed as % of TEC
Mg_pct	Exchangeable Mg expressed as % of TEC
K_pct	Exchangeable K expressed as % of TEC
Na_pct	Exchangeable Na expressed as % of TEC
H_pct	Exchangeable H expressed as % of TEC
B_ppm	Mehlich 3 Extractable B expressed as ppm
Fe_ppm	Mehlich 3 Extractable Fe expressed as ppm
Mn_ppm	Mehlich 3 Extractable Mn expressed as ppm
Cu_ppm	Mehlich 3 Extractable Cu expressed as ppm
Zn_ppm	Mehlich 3 Extractable Zn expressed as ppm
Al_ppm	Mehlich 3 Extractable Al expressed as ppm

***** The SMP buffer was developed for soils having a relatively high lime requirement and significant reserves of exchangeable Al. The SMP buffer is suited for Alfisols having large amounts of 2:1 clays and high organic matter content. The majority of laboratories in the Midwest use the SMP buffer.

Mehlich-3 Extractant:

0.2N CH_3COOH + 0.25N NH_4NO_3 + 0.013N HNO_3 + 0.015N NH_4F + 0.001M EDTA

Function of components:

Acetic acid (CH_3COOH) buffers the extracting solution to pH 2.5 when all reagents are added and mixed, thus preventing calcium from being precipitated as calcium fluoride.

Ammonium nitrate (NH_4NO_3) facilitates extraction of basic cations such as calcium, magnesium, sodium, and potassium and reacts with acetic acid to form ammonium acetate.

Nitric acid (HNO_3) extracts a portion of calcium phosphates, and its acid component [H^+] aids in the extraction of basic and micronutrient cations.

Ammonium fluoride (NH_4F) extracts iron and aluminum phosphates, and the NH_4^+ ion complements ammonium nitrate in extracting basic cations.

Ethylenediaminetetraacetic acid (EDTA) chelates micronutrients (particularly copper) and prevents precipitation of calcium fluoride.

Appendix B: Soil Fertility Analysis at the End of the Year 1

Table B-1. Soil fertility analysis at the end of year 1.

Plot #	Trt. (cm)	Depth cm	TEC	pH	OM	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
						mg kg^{-1}											
EB1E	30	7	28	7.3	2.3	163	136	4957	320	120	40	1.1	417	82	3.9	11.2	229
EB1E	30	15	27	7.4	2.9	195	77	4436	486	132	66	1.2	407	62	4.2	15.7	55
EB1E	30	30	19	7.3	0.9	100	90	3230	259	80	31	0.8	375	54	2.9	7.6	95
EB1E	30	50	6	7.1	0.1	51	70	894	117	40	16	0.5	189	36	1.1	2.1	322
EB1E	30	60	4	6.9	0.1	55	59	620	89	35	20	0.5	164	37	0.9	1.3	347
EB1E	30	80	4	7.1	0.1	38	54	600	79	35	11	0.5	168	37	0.8	1.4	293
EB1E	30	100	4	7.3	0.3	28	53	615	90	37	13	0.4	156	31	0.8	1.2	286
EB1W	30	7	28	7.4	2.8	347	102	4638	480	145	81	1.2	423	72	4.5	14.2	47
EB1W	30	15	30	7.4	3.0	300	85	5002	569	145	84	1.2	437	70	4.8	16.6	60
EB1W	30	30	26	7.5	2.8	192	81	4350	475	121	67	1.1	436	60	4.4	14.0	28
EB1W	30	50	4	7.1	0.1	33	50	610	94	31	13	0.5	144	31	0.9	1.4	307
EB1W	30	60	2	6.6	0.1	16	42	262	44	28	7	0.2	95	28	0.6	0.4	308
EB1W	30	80	2	6.6	0.1	18	42	331	50	38	11	0.9	95	21	0.7	1.1	313
EB1W	30	100	2	6.9	0.1	17	39	347	56	48	8	0.7	103	18	0.6	0.5	286
EB2E	15	7	31	7.0	2.9	317	106	5332	487	138	90	1.2	453	96	4.2	15.4	48
EB2E	15	15	37	7.0	3.0	371	99	6190	614	161	104	1.5	455	99	4.8	17.4	100
EB2E	15	30	17	6.9	0.7	121	109	2915	208	63	27	0.6	386	65	2.1	6.3	289
EB2E	15	50	5	6.9	0.2	33	86	748	93	34	12	0.4	209	51	0.8	1.6	375
EB2E	15	60	2	6.0	0.1	19	59	303	55	31	12	0.4	142	55	0.6	0.9	345
EB2E	15	80	3	6.4	0.1	21	55	506	65	36	11	0.4	146	41	0.7	1.1	314
EB2E	15	100	6	7.2	0.1	27	58	1027	110	53	14	0.6	189	29	1.1	1.9	287
EB2W	15	7	34	7.1	3.3	422	162	5632	547	199	111	1.3	432	92	4.2	18.5	54
EB2W	15	15	30	7.5	2.9	257	97	4907	540	174	75	1.3	437	66	5.2	19.3	61
EB2W	15	30	18	7.4	1.1	97	103	3058	256	83	33	0.9	425	52	3.0	9.2	120
EB2W	15	50	3	6.5	0.1	39	77	488	68	33	13	0.5	152	53	0.9	1.1	377
EB2W	15	60	2	6.1	0.1	34	56	319	60	30	13	0.4	109	33	0.7	0.7	310
EB2W	15	80	3	6.3	0.1	34	60	422	68	37	15	0.4	114	30	0.7	0.8	299
EB2W	15	100	3	5.7	0.1	22	54	374	61	51	13	0.5	124	22	0.8	0.7	355
EB3E	7.6	7	32	7.2	2.8	248	128	5502	457	144	67	1.2	432	70	4.0	14.9	257
EB3E	7.6	15	20	7.0	1.0	107	134	3468	235	80	29	0.7	419	55	2.3	8.6	267
EB3E	7.6	30	2	6.0	0.2	31	98	338	53	32	14	0.5	139	30	0.5	1.5	325
EB3E	7.6	50	3	6.3	0.1	33	91	457	63	35	11	0.5	154	31	0.4	1.0	363
EB3E	7.6	60	2	6.3	0.1	21	70	241	41	35	8	0.4	133	25	0.4	0.6	341
EB3E	7.6	80	3	6.3	0.1	25	72	492	67	46	11	0.4	171	26	0.5	1.0	355
EB3E	7.6	100	1	6.0	0.1	17	63	166	31	51	9	0.4	123	20	0.3	0.4	404

Table B-1 (cont'd.). Soil fertility analysis at the end of year 1.

Plot #	Trt. (cm)	Depth (cm)	TEC	pH	OM	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
						---------------------------------------mg kg^{-1}---------------------------------------											
EB3W	7.6	7	33	7.3	3.3	265	124	5732	491	147	78	1.2	419	71	4.5	16.2	246
EB3W	7.6	15	30	7.3	1.8	218	124	5188	432	116	59	1.1	420	65	4.2	13.6	259
EB3W	7.6	30	14	7.0	0.6	79	140	2467	186	60	25	0.6	396	47	1.8	5.6	324
EB3W	7.6	50	3	6.3	0.2	41	114	443	59	30	9	0.5	154	35	0.5	1.3	377
EB3W	7.6	60	1	5.3	0.1	23	78	206	41	26	8	0.4	110	31	0.2	0.8	349
EB3W	7.6	80	2	6.4	0.1	23	63	270	56	26	9	0.4	118	36	0.3	0.8	374
EB3W	7.6	100	2	5.8	0.1	16	59	239	36	46	7	0.4	106	14	0.4	0.5	371
EB4E	0	7	3	5.1	0.3	22	106	447	52	44	12	0.3	139	43	0.7	2.5	444
EB4E	0	15	2	4.9	0.1	22	107	373	39	47	10	0.4	145	47	0.7	2.3	459
EB4E	0	30	2	5.3	0.1	17	88	290	46	42	10	0.4	125	33	0.6	1.0	390
EB4E	0	50	2	5.3	0.1	16	72	221	40	36	7	0.3	110	27	0.5	1.1	313
EB4E	0	60	2	5.5	0.2	17	68	248	47	37	8	0.5	118	28	0.5	1.1	346
EB4E	0	80	1	5.5	0.1	12	50	193	36	34	8	0.2	97	17	0.4	0.5	294
EB4E	0	100	2	5.7	0.1	14	50	241	40	50	10	0.3	106	14	0.5	0.4	356
EB4W	0	7	2	6.1	0.4	22	124	325	57	44	11	0.5	134	40	0.4	2.7	335
EB4W	0	15	1	5.1	0.4	27	130	189	38	34	13	0.5	156	47	0.5	2.0	395
EB4W	0	30	1	4.7	0.1	22	106	151	30	33	10	0.4	148	48	0.4	1.3	397
EB4W	0	50	1	4.9	0.1	18	76	204	31	31	6	0.3	110	32	0.4	0.6	322
EB4W	0	60	2	5.5	0.1	17	69	240	40	36	13	0.5	117	24	0.5	0.8	344
EB4W	0	80	1	5.3	0.1	15	61	197	39	35	8	0.4	102	14	0.3	0.4	333
EB4W	0	100	2	5.8	0.1	14	90	245	41	57	11	0.4	110	16	0.4	0.4	416
WB1E	0	7	1	5.1	0.6	25	73	203	36	34	6	0.3	106	37	0.7	2.4	239
WB1E	0	15	1	4.4	0.4	26	90	142	27	30	6	0.4	127	36	0.6	1.7	282
WB1E	0	30	1	4.4	0.2	25	111	130	23	32	5	0.5	161	43	0.7	1.0	399
WB1E	0	50	1	4.7	0.1	25	67	99	23	28	7	0.4	125	36	0.6	0.7	349
WB1E	0	60	1	4.5	0.1	20	39	132	18	26	7	0.5	112	32	0.5	0.5	339
WB1E	0	80	2	4.4	0.2	25	41	315	25	33	9	0.5	103	31	0.7	0.6	354
WB1E	0	100	3	4.8	0.5	23	43	544	39	60	10	0.5	106	33	0.7	0.6	459
WB1W	0	7	2	5.1	0.5	24	88	352	43	49	9	0.5	122	40	0.7	3.1	303
WB1W	0	15	2	4.7	0.2	29	106	248	38	36	10	0.6	149	51	0.9	3.1	355
WB1W	0	30	1	4.4	0.1	22	86	203	20	24	6	0.5	148	50	0.7	1.5	413
WB1W	0	50	1	4.7	0.1	23	63	168	33	32	7	0.4	125	33	0.6	0.9	347
WB1W	0	60	1	4.8	0.1	19	54	205	38	38	9	0.5	118	29	0.6	0.7	328
WB1W	0	80	1	5.3	0.1	17	47	203	33	42	6	0.4	92	21	0.6	0.4	306
WB1W	0	100	2	5.7	0.1	16	50	243	33	52	6	0.4	98	23	0.6	0.4	372
WB3E	15	7	30	7.1	2.6	219	121	5167	414	145	58	1.1	453	94	4.1	13.6	44
WB3E	15	15	31	7.2	2.5	236	100	5211	478	139	62	1.2	464	81	4.3	15.6	55
WB3E	15	30	10	7.0	0.1	68	120	1624	167	58	23	0.7	278	50	1.7	5.0	318
WB3E	15	50	4	7.0	0.1	47	89	589	101	37	15	0.5	166	36	1.0	1.9	349
WB3E	15	60	2	6.0	0.1	32	50	268	60	28	11	0.5	116	28	0.6	0.8	327
WB3E	15	80	4	7.0	0.1	30	60	630	111	40	13	0.6	138	23	0.8	1.3	284
WB3E	15	100	2	5.5	0.1	34	48	295	67	48	12	0.5	106	23	0.7	0.6	422

Table B-1 (cont'd.). Soil fertility analysis at the end of year 1.

Plot #	Trt. (cm)	Depth (cm)	TEC	pH	OM	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
						mg kg^{-1}											
WB3W	15	7	27	7.4	2.5	169	97	4649	419	136	55	1.2	440	82	4.5	13.1	50
WB3W	15	15	28	7.4	2.7	232	89	4703	517	128	68	1.4	453	69	4.8	17.2	45
WB3W	15	30	5	6.8	0.4	56	111	854	97	33	14	0.7	202	48	1.2	2.5	366
WB3W	15	50	2	6.5	0.1	45	93	363	58	32	11	0.6	143	42	0.8	1.3	408
WB3W	15	60	1	5.7	0.1	35	47	175	41	30	9	0.5	104	26	0.6	0.6	319
WB3W	15	80	2	5.8	0.1	43	47	242	53	41	11	0.6	112	23	0.6	0.6	353
WB3W	15	100	2	6.3	0.1	38	46	313	48	48	9	0.6	116	19	0.7	0.7	376
WB4E	7.6	7	26	7.2	2.5	155	119	4510	330	116	39	1.2	435	74	3.7	11.3	53
WB4E	7.6	15	18	7.0	1.2	108	103	3037	240	82	31	0.8	379	57	2.8	8.5	102
WB4E	7.6	30	4	6.3	0.3	43	99	561	79	36	10	0.6	164	36	0.9	1.9	348
WB4E	7.6	50	3	6.6	0.3	47	78	428	63	32	9	0.6	141	32	0.8	1.1	377
WB4E	7.6	60	2	4.9	0.1	39	53	240	41	25	9	0.4	123	32	0.6	0.9	345
WB4E	7.6	80	1	5.1	0.1	36	46	197	35	31	10	0.5	107	23	0.6	0.6	370
WB4E	7.6	100	1	5.2	0.1	39	42	173	44	36	11	0.6	125	25	0.7	0.6	452
WB4W	7.6	7	27	7.3	2.0	124	118	4805	342	169	35	1.1	410	77	4.0	12.8	135
WB4W	7.6	15	25	7.0	1.7	197	102	4370	345	114	37	1.2	455	77	3.5	11.5	48
WB4W	7.6	30	2	6.0	0.2	41	84	365	60	24	13	0.7	156	32	0.8	1.4	357
WB4W	7.6	50	3	6.5	0.1	40	72	511	86	27	12	0.7	144	31	0.7	1.0	335
WB4W	7.6	60	1	5.3	0.1	26	50	156	39	22	9	0.5	108	34	0.6	0.7	309
WB4W	7.6	80	4	7.0	0.1	27	53	567	95	41	12	0.6	152	33	0.8	1.4	319
WB4W	7.6	100	2	5.7	0.1	21	47	286	54	46	13	0.5	126	20	0.7	0.7	405

Table B-2. Soil fertility analysis at the end of the year 2.

Plot#	Trt (cm)	Depth (cm)	TEC	pH	OM %	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
						mg kg^{-1}											
EB1E	30	7	29.7	7.5	3.3	85	85	4988	518	142	25	1.4	477	49	4.6	16.9	188
EB1E	30	15	30.1	7.6	3.3	118	71	5027	548	107	31	1.4	475	47	4.7	16.9	184
EB1E	30	30	28.6	7.8	2.7	125	78	4792	503	100	32	1.4	497	44	4.1	15.6	177
EB1E	30	45	3.3	7.4	0.3	28	72	470	96	33	10	0.6	175	26	0.8	1.1	331
EB1E	30	60	2.7	7.6	0.4	30	61	378	86	35	10	0.8	159	27	0.7	0.8	330
EB1W	30	7	30.6	7.8	3.3	61	99	5192	489	163	22	1.5	485	47	5.4	19.1	178
EB1W	30	15	32.5	7.8	3.0	90	69	5500	552	117	28	1.6	484	46	5.2	17.7	196
EB1W	30	30	33.7	7.8	3.9	109	74	5657	598	117	35	1.7	490	44	5.3	20.4	194
EB1W	30	45	3.5	7.6	0.3	30	86	499	96	40	12	0.9	170	29	1.4	1.2	331
EB1W	30	60	2.8	7.4	0.4	34	69	382	85	39	12	0.8	150	24	1.2	1.0	331
EB2E	15	7	31.7	7.7	3.3	58	106	5347	536	169	22	1.5	460	50	6.7	19.1	219
EB2E	15	15	30.7	7.7	2.3	56	92	5194	518	125	27	1.5	495	50	5.9	20.8	232
EB2E	15	30	3.7	7.6	0.5	19	95	533	104	39	13	0.7	175	28	1.4	1.8	331
EB2E	15	45	2.5	7.5	0.4	17	67	352	77	33	10	0.7	146	31	2.1	1.2	320
EB2E	15	60	2.7	7.3	0.2	19	56	382	82	37	11	0.6	144	26	1.0	1.4	339
EB2W	15	7	32.4	7.9	3.4	55	95	5504	529	146	20	1.6	496	45	5.4	21.0	176
EB2W	15	15	35.5	7.8	3.9	64	84	5993	607	132	31	1.7	503	46	5.3	22.4	192
EB2W	15	30	16.6	7.9	1.0	38	120	2867	239	67	17	1.2	498	32	3.3	9.0	245
EB2W	15	45	3.0	7.3	0.4	24	86	440	83	39	12	0.8	153	29	1.3	1.3	335
EB2W	15	60	2.8	7.3	0.3	27	58	397	77	39	13	0.7	126	23	1.1	1.0	301
EB3E	7.6	7	29.9	7.8	3.2	42	99	5106	478	137	17	1.4	481	49	5.1	17.0	236
EB3E	7.6	15	10.1	7.8	0.8	28	127	1655	193	56	14	1.0	388	35	2.6	5.4	295
EB3E	7.6	30	2.9	6.7	0.5	21	99	441	72	37	10	0.7	162	24	1.2	1.6	351
EB3E	7.6	45	2.7	6.7	0.5	21	72	395	73	38	9	0.8	151	23	1.3	1.1	347
EB3E	7.6	60	3.6	7.6	0.3	28	67	538	94	44	10	0.8	183	30	1.5	1.4	325
EB3W	7.6	7	31.5	7.9	3.2	58	95	5373	500	141	18	1.5	493	48	5.4	17.5	222
EB3W	7.6	15	25.3	7.9	2.0	53	110	4398	365	85	21	1.3	506	38	4.5	13.6	242
EB3W	7.6	30	3.0	7.0	0.5	25	106	440	79	42	12	0.8	161	26	1.3	2.0	348
EB3W	7.6	45	2.9	7.1	0.4	23	80	418	75	43	11	0.9	146	23	1.3	1.3	329
EB3W	7.6	60	2.5	7.0	0.2	24	65	357	68	48	11	0.8	130	27	1.2	0.9	332
EB4E	0	7	5.1	7.0	0.7	17	139	730	149	64	7	0.8	250	41	1.3	3.4	325
EB4E	0	15	2.5	5.7	0.7	17	126	349	67	57	8	0.7	168	36	1.2	2.3	363
EB4E	0	30	2.1	5.7	0.5	27	76	281	56	56	9	0.7	131	27	1.1	1.1	352
EB4E	0	45	2.2	6.0	0.4	16	61	295	62	53	10	0.8	121	24	1.1	1.0	303
EB4E	0	60	1.8	6.1	0.4	14	47	241	51	49	11	0.7	107	18	1.0	0.7	280
EB4W	0	7	3.2	6.4	0.7	17	132	468	82	67	9	0.8	193	39	1.3	3.2	337
EB4W	0	15	2.3	5.8	0.6	27	126	321	57	66	9	0.8	160	38	1.2	2.8	380
EB4W	0	30	2.1	5.8	0.4	15	86	311	45	54	9	0.8	135	27	1.3	1.6	347
EB4W	0	45	2.2	6.2	0.3	15	61	310	55	46	10	0.8	120	21	1.2	0.9	294
EB4W	0	60	2.4	6.5	0.3	17	60	339	65	49	11	0.8	122	19	1.3	0.7	308

Table B-2 (cont’d.). Soil fertility analysis at the end of year 2.

Plot#	Trt. (cm)	Depth (cm)	TEC	pH	OM %	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
						--------------------mg kg^{-1}--------------------											
MP(1-2)E	0	7	3.2	5.9	0.6	17	113	470	82	65	9	0.6	166	35	0.9	3.6	317
MP(1-2)E	0	15	2.0	5.7	0.4	13	111	287	39	63	7	0.6	149	31	0.8	2.0	357
MP(1-2)E	0	30	1.5	5.1	0.2	15	90	213	34	54	8	0.8	138	21	0.7	0.9	380
MP(1-2)E	0	45	1.6	5.3	0.3	15	72	218	44	48	8	0.8	128	25	0.7	0.7	358
MP(1-2)E	0	60	1.6	5.4	0.2	13	57	205	45	48	7	0.8	123	25	0.7	0.7	354
MP(1-2)W	0	7	2.5	5.8	0.7	16	127	347	65	62	7	0.6	179	36	0.9	3.5	338
MP(1-2)W	0	15	1.3	5.1	0.5	16	114	170	33	53	7	0.8	150	30	0.7	1.8	337
MP(1-2)W	0	30	1.5	5.2	0.3	15	105	198	34	57	7	0.8	140	27	0.8	1.4	406
MP(1-2)W	0	45	1.6	5.3	0.3	13	89	225	42	52	8	0.8	130	24	0.7	1.0	389
MP(1-2)W	0	60	1.5	5.7	0.4	13	67	190	47	46	7	0.7	115	26	0.7	0.7	346
MP(3-4)E	7.6	7	31.4	7.4	3.8	126	134	5170	593	194	27	1.5	523	46	7.4	59.2	330
MP(3-4)E	7.6	15	26.7	7.5	2.6	184	150	4422	493	132	31	1.4	551	42	6.5	48.5	294
MP(3-4)E	7.6	30	6.8	7.1	0.7	63	156	1068	150	51	13	1.1	412	32	1.9	9.3	369
MP(3-4)E	7.6	45	2.6	6.2	0.4	41	108	371	71	45	13	0.7	177	21	0.7	2.0	382
MP(3-4)E	7.6	60	4.1	7.0	0.4	58	88	607	109	49	11	1.0	246	22	1.2	3.8	350
MP(3-4)W	7.6	7	31.4	7.7	3.6	68	134	5239	543	231	18	1.5	517	47	6.9	58.3	319
MP(3-4)W	7.6	15	14.2	7.6	1.3	44	184	2372	243	82	14	1.2	581	37	4.0	19.6	341
MP(3-4)W	7.6	30	2.4	6.1	0.4	29	138	342	58	39	14	0.8	187	24	0.9	2.1	394
MP(3-4)W	7.6	45	3.6	6.6	0.4	27	113	593	58	40	12	0.8	183	24	0.9	1.8	505
MP(3-4)W	7.6	60	1.9	5.8	0.3	28	71	265	55	40	13	0.8	152	24	0.8	1.3	381
WB1E	0	7	4.9	6.7	0.7	15	97	753	108	54	12	0.4	219	33	1.2	5.6	314
WB1E	0	15	1.8	5.3	0.5	14	89	245	47	39	8	0.4	137	23	0.7	1.7	366
WB1E	0	30	1.6	5.3	0.4	12	69	215	43	37	8	0.3	109	21	0.6	0.9	365
WB1E	0	45	1.4	5.4	0.3	12	50	180	43	36	6	0.4	102	23	0.5	0.6	336
WB1E	0	60	1.4	5.7	0.3	10	40	181	44	33	5	0.3	92	26	0.5	0.7	301
WB1W	0	7	4.5	6.9	0.6	18	100	703	97	47	9	0.7	219	37	1.3	4.7	303
WB1W	0	15	2.2	5.8	0.4	14	98	319	52	50	8	0.6	154	25	1.1	2.4	334
WB1W	0	30	1.8	5.4	0.3	15	99	255	47	51	9	0.7	143	24	1.0	1.2	383
WB1W	0	45	1.4	4.9	0.2	12	68	197	37	43	6	0.6	126	30	0.9	0.9	373
WB1W	0	60	1.6	4.9	0.2	11	45	219	41	39	6	0.6	102	29	0.8	1.0	312
WB2E	30	7	36.9	7.5	3.5	119	111	6217	625	185	31	1.2	413	54	7.5	63.0	276
WB2E	30	15	35.7	7.5	3.7	192	108	5976	629	150	40	1.2	433	57	7.4	66.2	311
WB2E	30	30	40.0	7.6	3.8	272	101	6663	729	160	54	1.3	418	57	7.8	71.3	260
WB2E	30	45	31.2	7.5	2.9	200	123	5253	534	123	38	1.1	456	47	6.7	55.4	258
WB2E	30	60	19.4	7.6	1.1	107	138	3323	295	75	22	1.0	543	37	4.5	29.4	297

Table B-2 (cont'd.). Soil fertility analysis at the end of year 2.

Plot#	Trt. (cm)	Depth (cm)	TEC	pH	OM %	S	P	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
						----------------mg kg^{-1}----------------											
WB2W	30	7	27.9	7.6	3.2	64	135	4607	516	172	19	1.2	452	42	8.6	54.5	235
WB2W	30	15	28.7	7.6	2.9	104	127	4726	542	147	30	1.2	467	39	8.8	58.5	293
WB2W	30	30	33.1	7.6	3.4	139	115	5391	661	171	38	1.4	463	46	8.1	66.3	311
WB2W	30	45	5.8	7.6	0.4	36	109	883	146	39	13	0.7	396	26	2.2	8.6	319
WB2W	30	60	3.6	7.7	0.1	28	80	525	105	34	9	0.8	248	26	1.3	3.8	310
WB3E	15	7	30.6	7.6	2.8	42	97	5316	438	119	15	1.2	479	52	4.5	17.0	198
WB3E	15	15	34.8	7.8	3.1	65	77	5963	555	108	24	1.4	475	51	4.6	19.1	150
WB3E	15	30	7.6	7.7	0.5	27	105	1231	157	43	12	1.0	265	34	1.9	3.6	322
WB3E	15	45	3.8	7.4	0.3	19	82	566	99	34	8	0.7	163	29	1.1	1.8	348
WB3E	15	60	3.8	7.4	0.2	27	74	573	89	39	9	0.6	147	29	0.9	1.5	367
WB3W	15	7	28.9	7.9	2.8	44	93	4877	492	150	15	1.3	490	45	5.0	17.4	190
WB3W	15	15	29.0	7.9	2.9	50	87	4880	506	105	19	1.3	516	44	4.7	16.6	192
WB3W	15	30	2.6	7.1	0.3	18	102	381	73	30	9	0.8	149	25	0.8	1.3	376
WB3W	15	45	2.5	7.4	0.2	17	69	355	77	28	7	0.8	146	22	0.7	1.4	324
WB3W	15	60	2.6	7.1	0.2	17	51	367	73	33	9	0.7	123	22	0.7	0.9	317
WB4E	7.6	7	30.6	7.7	2.3	39	94	5311	434	123	14	1.2	457	52	4.4	16.1	170
WB4E	7.6	15	13.8	7.8	0.9	28	105	2344	222	51	14	0.9	398	42	2.3	6.6	316
WB4E	7.6	30	2.7	6.3	0.3	19	109	407	60	34	8	0.6	148	28	0.9	1.8	398
WB4E	7.6	45	3.3	7.1	0.2	18	89	489	87	35	8	0.6	155	26	1.0	1.5	357
WB4E	7.6	60	2.4	6.7	0.1	18	63	348	60	34	8	0.6	116	22	0.8	1.0	325
WB4W	7.6	7	25.1	8.0	2.0	36	96	4337	365	124	12	1.1	486	45	4.1	12.7	197
WB4W	7.6	15	10.3	7.8	0.7	23	107	1746	173	45	9	0.9	377	30	2.7	5.6	287
WB4W	7.6	30	2.8	6.9	0.2	17	88	413	70	28	8	0.6	150	21	1.0	1.4	354
WB4W	7.6	45	2.2	6.6	0.3	16	74	322	60	28	7	0.8	123	21	0.8	0.8	336
WB4W	7.6	60	4.3	7.6	0.2	18	63	652	111	36	9	0.7	194	24	1.1	1.6	291

Appendix C: Soil Factors at the Sand Farm

Table C-1. Soil texture (%) at the sand farm sediment research site, 2001.

Plot	Depth (cm)	Treatment	Class†	Sand	Silt	Clay	VCoS	CoS	MS	FS	VFS
EB1E	0-7	30	L	44	44	12	1.5	2.9	18.2	18.1	3.4
EB1E	7-15	30	SiL	25	55	20	1.8	3.0	7.5	9.1	4.0
EB1E	15-30	30	LS	80	12	8	0.5	2.2	40.4	34.9	2.3
EB1E	30-50	30	S	92	4	4	0.2	1.6	57.9	30.8	1.6
EB1E	50-60	30	S	94	2	4	0.1	1.0	62.4	28.3	2.2
EB1E	60-80	30	S	94	2	4	0.1	1.3	60.7	29.9	1.7
EB1E	80-100	30	S	90	5	5	0.1	2.0	60.8	26.0	1.6
EB1W	0-7	30	SiL	28	53	19	2.0	2.9	9.0	9.9	3.9
EB1W	7-15	30	SiL	21	57	22	1.5	2.4	5.7	7.5	4.0
EB1W	15-30	30	SiL	32	50	18	1.3	2.5	10.9	13.3	3.6
EB1W	30-50	30	S	95	2	3	0.0	0.8	64.5	27.8	2.0
EB1W	50-60	30	S	96	2	2	0.0	0.7	63.6	29.6	2.1
EB1W	60-80	30	S	96	2	2	0.1	1.3	55.5	37.3	1.9
EB1W	80-100	30	S	96	2	2	0.0	0.8	66.1	27.2	1.6
EB2E	0-7	15	SiL	26	57	17	1.9	2.7	8.2	9.9	3.7
EB2E	7-15	15	SiL	25	54	21	1.5	2.7	7.2	9.4	3.8
EB2E	15-30	15	FSL	74	18	8	0.6	2.0	38.1	31.0	2.3
EB2E	30-50	15	S	92	5	3	0.1	1.6	62.5	26.9	1.4
EB2E	50-60	15	S	96	2	2	0.0	0.9	58.9	34.0	2.2
EB2E	60-80	15	S	95	3	2	0.1	1.1	62.1	30.6	1.6
EB2E	80-100	15	S	92	5	3	0.1	1.0	58.4	30.6	2.2
EB2W	0-7	15	SiL	25	54	21	2.6	3.4	6.8	8.4	4.1
EB2W	7-15	15	SiL	23	57	20	2.0	3.0	5.6	7.7	4.3
EB2W	15-30	15	FSL	69	19	12	0.7	1.6	32.4	31.3	2.8
EB2W	30-50	15	S	95	2	3	0.0	1.4	63.9	28.0	1.5
EB2W	50-60	15	S	96	4	0	0.0	1.0	62.8	29.8	2.1
EB2W	60-80	15	S	96	2	2	0.1	1.1	64.8	28.9	1.3
EB2W	80-100	15	S	96	2	2	0.0	0.8	57.4	35.6	1.8
EB3E	0-7	7.6	SiL	27	55	18	1.7	2.4	8.9	10.9	3.7
EB3E	7-15	7.6	SL	67	23	10	0.8	2.8	32.1	28.8	2.7
EB3E	15-30	7.6	S	95	2	3	0.0	1.3	63.8	28.5	1.8
EB3E	30-50	7.6	S	95	2	3	0.0	1.3	61.1	30.6	2.0
EB3E	50-60	7.6	S	96	2	2	0.0	0.6	61.6	31.9	1.9
EB3E	60-80	7.6	S	96	2	2	0.1	1.0	64.6	28.3	1.7
EB3E	80-100	7.6	S	96	2	2	0.0	1.0	63.0	30.0	1.8
EB3W	0-7	7.6	SiL	20	60	20	1.6	2.4	5.0	6.8	4.2
EB3W	7-15	7.6	L	41	44	15	0.7	1.7	16.0	18.6	3.7
EB3W	15-30	7.6	LS	87	8	5	0.1	1.2	47.2	36.0	2.1
EB3W	30-50	7.6	S	95	3	2	0.0	1.1	67.5	24.6	1.4
EB3W	50-60	7.6	S	96	2	2	0.0	0.6	60.6	32.5	2.4
EB3W	60-80	7.6	S	96	2	2	0.0	0.7	70.3	23.9	1.3
EB3W	80-100	7.6	S	96	2	2	0.0	0.7	68.7	25.2	1.2
EB4E	0-7	0	S	98	0	2	0.0	3.5	57.4	36.7	0.6
EB4E	7-15	0	S	97	0	3	0.0	1.7	54.2	39.3	1.7
EB4E	15-30	0	S	96	2	2	0.0	1.8	66.0	27.3	1.1
EB4E	30-50	0	S	96	2	2	0.0	1.6	59.1	34.0	1.6
EB4E	50-60	0	S	97	1	2	0.0	1.6	67.9	25.5	1.7
EB4E	60-80	0	S	97	1	2	0.0	1.5	71.1	22.8	1.4
EB4E	80-100	0	S	96	2	2	0.0	0.9	63.2	30.2	1.5

Table C-1 (cont'd). Soil texture (%) at the sand farm sediment research site, 2001.

Plot	Depth (cm)	Treatment	Class	Sand	Silt	Clay	VCoS	CoS	MS	FS	VFS
EB4W	0-7	0	S	97	1	2	0.0	1.8	58.0	36.3	1.0
EB4W	7-15	0	S	98	0	2	0.0	1.3	52.1	41.8	2.4
EB4W	15-30	0	S	95	3	2	0.0	0.9	68.5	24.9	0.8
EB4W	30-50	0	S	96	2	2	0.0	0.7	67.2	27.0	1.5
EB4W	50-60	0	S	97	1	2	0.0	0.8	66.9	26.6	2.1
EB4W	60-80	0	S	97	1	2	0.0	1.0	61.1	32.9	1.6
EB4W	80-100	0	S	95	3	2	0.0	0.9	66.0	27.1	1.2
WB1E	0-7	0	S	97	1	2	0.0	2.1	68.0	25.2	1.5
WB1E	7-15	0	S	96	1	3	0.0	3.9	61.9	28.0	1.8
WB1E	15-30	0	S	95	2	3	0.0	2.3	74.2	17.4	1.5
WB1E	30-50	0	S	96	1	3	0.0	1.5	75.4	17.7	1.4
WB1E	50-60	0	S	95	2	3	0.0	0.7	75.1	17.6	1.3
WB1E	60-80	0	S	95	3	2	0.0	0.9	71.1	21.4	1.5
WB1E	80-100	0	S	94	3	3	0.0	1.0	50.3	40.4	2.2
WB1W	0-7	0	S	96	2	2	0.1	5.5	71.5	18.1	1.0
WB1W	7-15	0	S	96	2	2	0.0	1.8	52.4	39.6	1.9
WB1W	15-30	0	S	95	2	3	0.0	1.2	79.2	13.1	1.3
WB1W	30-50	0	S	95	2	3	0.0	1.1	48.6	43.9	1.9
WB1W	50-60	0	S	96	1	3	0.0	1.3	69.4	22.7	2.1
WB1W	60-80	0	S	95	3	2	0.0	0.7	64.7	27.8	1.7
WB1W	80-100	0	S	93	4	3	0.0	1.1	62.4	27.4	2.0
WB3E	0-7	15	SiL	25	54	21	1.9	2.6	7.9	9.0	3.8
WB3E	7-15	15	SiL	29	50	21	1.6	2.5	9.8	11.5	4.0
WB3E	15-30	15	LS	83	14	3	0.3	1.8	52.7	26.8	1.7
WB3E	30-50	15	S	87	9	4	0.1	1.5	52.0	32.4	1.3
WB3E	50-60	15	S	90	7	3	0.0	0.9	55.7	31.5	2.0
WB3E	60-80	15	S	89	7	4	0.1	1.0	56.2	30.2	1.3
WB3E	80-100	15	S	96	0	4	0.0	1.2	64.1	28.7	1.5
WB3W	0-7	15	SiL	29	52	19	1.5	2.6	9.6	11.1	3.9
WB3W	7-15	15	SiL	28	52	20	1.7	2.3	9.3	10.8	3.8
WB3W	15-30	15	S	94	3	3	0.1	2.3	68.0	21.7	1.5
WB3W	30-50	15	S	96	2	2	0.1	3.0	72.7	18.6	1.2
WB3W	50-60	15	S	93	4	3	0.0	0.9	50.7	39.2	2.1
WB3W	60-80	15	S	96	1	3	0.0	1.4	75.6	17.7	1.4
WB3W	80-100	15	S	95	1	4	0.0	0.8	48.4	43.5	2.0
WB4E	0-7	7.6	L	38	44	18	1.4	2.6	15.8	15.2	3.0
WB4E	15-30	7.6	S	94	3	3	0.0	1.3	67.0	23.5	1.9
WB4E	30-50	7.6	S	93	4	3	0.0	0.9	58.1	32.1	1.8
WB4E	50-60	7.6	S	96	2	2	0.0	1.0	71.7	21.2	1.6
WB4E	60-80	7.6	S	95	2	3	0.0	1.3	80.1	13.2	0.7
WB4E	80-100	7.6	S	95	2	3	0.0	0.9	49.0	42.8	2.0
WB4W	0-7	7.6	L	37	45	18	1.6	2.2	15.3	14.7	3.5
WB4W	7-15	7.6	SL	62	25	13	1.2	2.3	28.7	26.9	3.4
WB4W	15-30	7.6	S	95	1	4	0.0	1.4	67.1	25.4	1.5
WB4W	30-50	7.6	S	95	1	4	0.0	1.6	67.2	24.7	1.5
WB4W	50-60	7.6	S	96	0	4	0.0	0.7	64.9	28.7	2.0
WB4W	60-80	7.6	S	95	2	3	0.1	1.2	69.3	23.0	1.3
WB4W	80-100	7.6	S	95	2	3	0.0	0.7	62.0	31.0	1.5

Table C-2. Particle size of soil by depth at the Sand Farm sediment research site, 2002.

Plot	Depth (in)	Trt. (cm)	Class	Sand	Silt	Clay	VCoS	CoS	MS	FS	VFS
EB1E	0-3	30	L	32	48	20	3.3	3.2	10.7	10.8	4.0
EB1E	3-6	30	SiL	26	50	24	3.8	3.4	7.1	7.8	4.0
EB1E	6-12	30	L	36	44	20	3.3	2.9	13.5	13.1	3.4
EB1E	12-18	30	S	95	3	3	0.1	0.8	48.0	43.7	1.9
EB1E	18-24	30	S	95	2	3	0.0	0.7	46.8	45.4	2.2
EB1W	0-3	30	L	34	47	20	2.7	3.2	12.1	11.5	4.0
EB1W	3-6	30	SiL	26	52	22	3.5	3.0	7.4	7.9	4.0
EB1W	6-12	30	L	33	47	21	2.4	2.4	12.3	12.1	3.4
EB1W	12-18	30	S	95	3	3	0.1	1.3	46.8	44.0	2.4
EB1W	18-24	30	S	95	3	2	0.1	0.9	51.5	41.2	1.8
EB2E	0-3	15	L	28	48	24	1.7	2.6	10.1	10.3	3.7
EB2E	3-6	15	L	41	40	19	2.9	3.2	16.3	15.1	3.5
EB2E	6-12	15	S	95	2	3	0.1	0.9	50.0	42.1	1.8
EB2E	12-18	15	S	95	2	3	0.1	0.7	47.8	44.5	2.1
EB2E	18-24	15	S	95	2	3	0.4	1.0	47.8	45.2	1.1
EB2W	0-3	15	SiL	26	51	23	3.5	3.1	7.2	8.0	4.0
EB2W	3-6	15	SiL	23	53	24	3.7	3.4	5.7	6.3	3.8
EB2W	6-12	15	LS	83	11	7	0.5	1.4	41.4	36.9	2.4
EB2W	12-18	15	S	95	3	2	0.1	0.9	50.4	41.4	1.8
EB2W	18-24	15	S	96	3	2	0.1	0.8	50.6	42.5	1.7
EB3E	0-3	7.6	L	40	40	20	2.2	2.8	16.2	15.5	3.5
EB3E	3-6	7.6	S	89	7	5	0.4	1.4	44.4	40.0	2.6
EB3E	6-12	7.6	S	96	2	2	0.1	0.9	49.5	43.4	1.7
EB3E	12-18	7.6	S	95	2	3	0.1	1.2	50.8	41.6	1.5
EB3E	18-24	7.6	S	92	5	3	0.2	1.0	48.1	41.1	1.9
EB3W	0-3	7.6	L	31	48	21	2.9	3.1	10.6	10.8	3.7
EB3W	3-6	7.6	FSL	55	31	15	1.0	1.9	26.3	22.5	2.9
EB3W	6-12	7.6	S	95	2	3	0.2	1.4	54.4	37.6	1.6
EB3W	12-18	7.6	S	95	3	2	0.1	0.9	50.3	42.4	1.5
EB3W	18-24	7.6	S	96	2	2	0.1	0.7	50.6	42.8	1.8
EB4E	0-3	0	S	94	3	3	0.2	1.7	46.7	43.0	2.4
EB4E	3-6	0	S	96	2	2	0.1	1.7	51.0	41.9	1.4
EB4E	6-12	0	S	97	1	2	0.1	1.4	53.7	39.9	1.3
EB4E	12-18	0	S	96	2	2	0.1	1.9	58.8	34.3	1.1
EB4E	18-24	0	S	97	2	2	0.1	1.1	54.8	39.2	1.4
EB4W	0-3	0	S	95	3	2	0.2	1.6	53.4	38.8	1.4
EB4W	3-6	0	S	96	2	2	0.1	1.3	50.9	41.8	1.7
EB4W	6-12	0	S	96	2	2	0.1	1.1	50.8	42.3	1.7
EB4W	12-18	0	S	96	2	2	0.1	1.4	49.9	42.8	1.9
EB4W	18-24	0	S	96	2	2	0.1	1.1	48.9	44.1	2.1
WB1E	0-3	0	S	95	4	2	0.1	1.6	49.9	41.5	1.6
WB1E	3-6	0	S	96	2	2	0.1	1.3	52.8	40.1	1.7
WB1E	6-12	0	S	95	2	2	0.1	0.8	47.7	44.5	2.3
WB1E	12-18	0	S	96	2	2	0.1	0.8	48.9	44.4	1.8
WB1E	18-24	0	S	96	2	2	0.1	0.9	50.2	42.4	2.2

Table C-2 (cont'd). Particle size of soil by depth at the Sand Farm sediment research site, 2002.

Plot	Depth (in)	Trt. (cm)	Class	Sand	Silt	Clay	VCoS	CoS	MS	FS	VFS
WB1W	0-3	0	S	94	3	3	0.6	2.1	49.2	40.1	1.8
WB1W	3-6	0	S	96	1	3	0.6	1.5	52.7	39.7	1.3
WB1W	6-12	0	S	95	2	3	0.1	1.2	48.8	43.2	1.8
WB1W	12-18	0	S	96	2	2	0.1	1.4	50.6	42.2	1.6
WB1W	18-24	0	S	95	3	2	0.2	1.4	49.1	42.5	2.1
WB2E	0-3	30	SiCL	14	57	29	1.5	1.7	4.7	4.7	1.7
WB2E	3-6	30	SiCL	15	52	33	0.3	0.8	5.5	6.2	2.2
WB2E	6-12	30	SiCL	13	54	34	0.7	1.2	3.7	4.8	2.2
WB2E	12-18	30	L	36	39	25	0.4	0.7	16.5	16.7	2.2
WB2E	18-24	30	FSL	74	14	12	0.2	0.8	35.2	35.8	2.3
WB2W	0-3	30	L	32	46	23	0.5	1.1	14.6	13.6	2.2
WB2W	3-6	30	L	31	45	24	1.0	0.7	13.3	14.5	1.9
WB2W	6-12	30	L	32	45	23	0.7	2.5	14.5	12.8	1.5
WB2W	12-18	30	S	89	6	5	0.1	1.1	47.9	38.3	1.5
WB2W	18-24	30	S	94	3	3	0.2	1.0	48.2	42.7	1.9
WB3E	0-3	15	L	33	45	23	2.5	2.5	11.9	12.2	3.6
WB3E	3-6	15	L	29	45	27	2.6	2.8	9.1	10.1	4.0
WB3E	6-12	15	LS	84	10	6	0.8	1.9	44.9	34.8	1.9
WB3E	12-18	15	S	94	3	3	0.1	1.2	50.6	40.2	1.6
WB3E	18-24	15	S	93	4	4	0.2	1.2	51.4	38.6	1.5
WB3W	0-3	15	L	34	46	20	1.7	2.2	12.5	13.5	3.9
WB3W	3-6	15	L	49	34	17	2.1	2.2	21.5	19.9	3.2
WB3W	6-12	15	S	95	3	2	0.1	1.4	54.4	37.8	1.3
WB3W	12-18	15	S	95	3	2	0.2	1.4	52.0	39.8	1.5
WB3W	18-24	15	S	95	3	2	0.1	0.7	44.5	47.7	2.2
WB4E	0-3	7.6	L	51	33	16	2.1	2.6	21.9	20.7	3.5
WB4E	3-6	7.6	LS	84	9	7	2.4	3.4	43.2	33.1	1.8
WB4E	6-12	7.6	S	96	2	2	0.3	1.9	53.1	38.9	1.5
WB4E	12-18	7.6	S	94	3	3	0.2	1.4	52.7	38.6	1.6
WB4E	18-24	7.6	S	96	1	2	-0.3	0.5	52.2	42.7	1.0
WB4W	0-3	7.6	L	51	32	17	2.3	2.4	21.7	21.0	3.5
WB4W	3-6	7.6	LS	81	12	8	0.4	1.1	40.9	36.3	2.1
WB4W	6-12	7.6	S	96	2	2	0.1	1.1	48.6	44.5	1.5
WB4W	12-18	7.6	S	95	3	2	0.2	1.4	51.5	41.1	1.3
WB4W	18-24	7.6	S	94	4	2	0.2	1.0	46.9	43.7	1.8
MP(1-2)E	0-3	0	S	95	4	2	0.3	0.9	48.3	43.3	2.1
MP(1-2)E	3-6	0	S	95	3	2	0.1	0.8	50.0	42.5	2.0
MP(1-2)E	6-12	0	S	96	2	3	0.4	1.3	53.0	39.3	1.6
MP(1-2)E	12-18	0	S	96	2	2	0.2	1.4	54.2	38.4	1.6
MP(1-2)E	12-24	0	S	96	2	2	0.2	1.0	50.2	42.6	1.9
MP(1-2)W	0-3	0	S	95	2	3	0.9	2.9	51.5	38.3	1.4
MP(1-2)W	3-6	0	S	96	2	3	0.1	1.0	49.7	43.3	1.4
MP(1-2)W	6-12	0	S	96	2	2	0.1	1.6	51.2	41.3	1.4
MP(1-2)W	12-18	0	S	96	2	3	0.1	1.3	50.8	41.8	1.7
MP(1-2)W	18-24	0	S	96	3	2	0.2	1.4	51.2	41.2	1.7

Table C-3. Particle size of soil by depth at the Sand Farm sediment research site, 2003.

Plot	Depth (in)	Trt. (cm)	Class	Sand	Silt	Clay	VCoS	CoS	MS	FS	VFS
EB1E	0-3	30	L	36	43	21	2.9	2.3	12.4	14.6	4.1
EB1E	3-6	30	SiL	27	52	21	3.1	3.5	7.0	8.9	4.5
EB1E	6-12	30	SL	70	20	10	0.2	1.6	35.5	29.4	3.0
EB1E	12-18	30	S	95	0	5	0.1	1.0	51.9	40.2	1.7
EB1E	18-24	30	S	95	0	5	0.1	1.1	51.2	41.1	1.7
EB1W	0-3	30	L	33	45	22	0.8	3.4	12.9	12.1	3.8
EB1W	3-6	30	FSL	66	22	12	0.6	2.3	29.7	30.4	3.5
EB1W	6-12	30	L	36	43	21	2.4	2.0	12.4	16.1	3.5
EB1W	12-18	30	S	96	0	4	0.1	1.1	52.7	41.1	0.9
EB1W	18-24	30	S	96	0	4	0.1	1.1	51.5	42.2	1.2
EB2E	0-3	15	SiL	26	51	23	3.2	3.3	7.3	8.5	3.8
EB2E	3-6	15	SiL	26	50	24	0.7	2.6	8.4	10.0	4.0
EB2E	6-12	15	LS	87	9	5	0.1	1.3	47.0	36.9	1.7
EB2E	12-18	15	S	96	2	2	0.2	1.4	52.4	40.2	1.4
EB2W	0-3	15	SiL	24	54	23	2.7	4.0	6.6	7.0	3.5
EB2W	6-12	15	LS	79	14	7	0.6	1.7	36.5	36.9	3.1
EB2W	12-18	15	S	96	3	2	0.1	1.0	48.3	44.4	1.8
EB2W	18-24	15	S	95	3	2	0.2	1.0	50.0	42.7	1.6
EB3E	0-3	7.6	L	41	42	17	4.5	4.1	16.1	12.8	3.1
EB3E	3-6	7.6	S	95	3	2	0.1	1.2	51.5	40.7	1.1
EB3E	6-12	7.6	S	96	2	2	0.0	1.2	52.5	41.1	1.2
EB3E	12-18	7.6	S	95	2	2	0.0	1.0	52.8	40.4	1.2
EB3E	18-24	7.6	S	95	3	2	0.1	1.5	52.5	39.9	1.3
EB3W	0-3	7.6	L	34	46	20	0.4	2.6	12.7	14.9	3.7
EB3W	3-6	7.6	L	30	47	23	7.1	5.9	6.5	6.5	3.7
EB3W	6-12	7.6	S	96	3	1	0.2	1.2	54.1	39.9	0.8
EB3W	12-18	7.6	S	96	3	1	0.0	1.0	53.4	40.9	1.0
EB3W	18-24	7.6	S	96	3	2	0.0	0.9	48.2	44.6	2.0
EB4E	0-3	0	S	96	2	3	0.2	2.7	58.2	33.7	0.7
EB4E	3-6	0	S	96	2	2	0.1	1.2	53.1	39.9	1.4
EB4E	6-12	0	S	96	1	3	0.1	1.2	48.9	44.9	1.3
EB4E	12-18	0	S	100	-2	2	0.8	1.7	52.7	42.6	2.2
EB4E	18-24	0	S	97	2	2	0.1	1.4	56.5	37.0	1.7
EP4W	0-3	0	S	94	1	4	0.0	0.6	47.2	44.4	2.1
EP4W	3-6	0	S	95	1	4	0.3	1.0	45.8	45.6	2.5
EP4W	6-9	0	FS	97	0	3	0.2	0.7	40.4	54.0	3.0
EP4W	12-18	0	S	97	0	3	0.1	0.8	49.1	44.4	2.1
EP4W	18-24	0	S	97	0	3	0.0	0.7	48.8	47.9	2.4
WB1E	0-3	0	LS	81	10	9	0.1	1.0	44.6	33.4	1.6
WB1E	3-6	0	S	96	0	4	0.1	1.6	64.2	29.6	0.4
WB1E	6-12	0	S	95	0	5	0.1	1.4	54.2	38.5	1.3
WB1E	12-18	0	S	96	0	4	0.0	1.0	51.3	42.0	1.6
WB1E	18-24	0	S	96	0	4	0.0	1.0	53.3	40.5	1.6
WB1W	0-3	0	S	95	2	2	0.2	3.2	51.2	38.9	1.8
WB1W	3-6	0	S	96	2	2	0.3	1.9	56.3	36.7	0.9
WB1W	6-12	0	S	95	2	3	0.1	1.2	50.7	41.3	1.8
WB1W	12-18	0	S	96	2	2	0.1	1.1	50.6	41.5	2.4
WB1W	18-24	0	S	97	2	2	0.2	1.5	55.5	38.2	1.3

Table C-3 (cont'd). Particle size of soil by depth at the sand farm sediment research site, 2003.

Plot	Depth (in)	Trt. (cm)	Class	Sand	Silt	Clay	VCoS	CoS	MS	FS	VFS
WB2E	0-3	30	SiCL	15	57	29	0.4	1.2	5.5	5.6	2.1
WB2E	3-6	30	SiCL	15	55	30	0.8	1.3	5.1	5.6	1.8
WB2E	6-12	30	SiCL	11	60	29	0.8	1.0	3.4	3.7	2.1
WB2E	12-18	30	SiCL	10	58	31	0.6	1.7	2.8	3.2	2.0
WB2E	18-24	30	SL	60	25	15	0.1	0.6	30.8	26.4	2.4
WB2W	0-3	30	L	37	39	24	0.5	1.1	17.6	16.0	1.9
WB2W	3-6	30	LS	84	8	9	0.2	1.1	48.0	32.8	1.3
WB2W	6-12	30	S	96	1	4	0.1	1.0	51.6	41.7	1.6
WB2W	12-18	30	S	96	0	4	0.0	1.1	51.5	42.2	1.5
WB2W	18-24	30	S	96	1	3	0.0	0.8	47.6	45.2	2.1
WB3E	0-3	15	L	28	49	23	2.0	3.0	9.5	9.6	3.5
WB3E	3-6	15	L	29	47	24	2.0	2.5	9.8	11.4	3.5
WB3E	6-12	15	LS	87	8	5	0.4	1.6	50.5	33.3	1.4
WB3E	12-18	15	S	95	3	2	0.0	0.7	46.6	45.2	2.7
WB3E	18-24	15	S	95	4	2	0.0	0.8	47.6	44.2	2.3
WB3W	0-3	15	L	36	43	21	1.1	2.3	14.3	14.0	3.8
WB3W	3-6	15	L	51	31	18	1.8	2.9	22.9	20.6	3.0
WB3W	6-12	15	S	94	2	4	0.2	1.6	50.0	40.8	1.1
WB3W	12-18	15	S	96	1	3	0.2	1.1	54.8	39.0	1.1
WB3W	18-24	15	S	96	0	4	0.0	1.0	52.9	41.4	0.8
WB4E	0-3	7.6	L	48	37	15	1.3	2.9	22.7	17.7	2.9
WB4E	3-6	7.6	S	96	3	2	0.1	1.0	56.5	37.3	0.7
WB4E	6-12	7.6	S	96	2	2	0.0	1.2	54.4	39.0	1.2
WB4E	12-18	7.6	S	96	2	2	0.2	1.2	56.4	37.3	1.3
WB4E	18-24	7.6	S	96	2	2	0.0	1.2	52.5	40.5	1.6
WB4W	0-3	7.6	L	43	40	18	1.8	3.3	17.7	16.2	3.7
WB4W	3-6	7.6	SL	63	25	12	1.7	2.8	30.8	25.6	2.6
WB4W	6-12	7.6	S	96	2	2	0.1	1.6	56.4	36.7	1.1
WB4W	12-18	7.6	S	96	2	2	0.1	1.4	58.0	35.8	1.0
WB4W	18-24	7.6	S	96	2	2	0.1	1.4	54.1	38.8	1.2
MP1E	0-3	0	S	95	0	5	0.3	1.8	57.4	34.6	1.0
MP1E	3-6	0	S	97	0	3	1.0	2.7	60.2	34.4	1.7
MP1E	6-12	0	S	96	0	4	0.1	1.3	57.1	35.9	1.2
MP1E	12-18	0	S	96	0	4	0.0	1.2	53.9	39.0	1.4
MP1E	18-24	0	S	95	0	5	0.0	1.2	51.8	39.9	1.8
MP1W	0-3	0	S	96	3	2	0.2	2.5	52.3	38.6	1.9
MP1W	3-6	0	S	96	2	2	0.0	1.9	57.7	35.6	0.7
MP1W	6-12	0	S	95	3	2	0.1	1.4	53.1	39.0	1.1
MP1W	12-18	0	S	96	2	2	0.0	1.6	56.3	36.8	1.2
MP1W	18-24	0	S	96	2	2	0.2	1.0	55.0	38.0	1.6
MP2E	0-3	0	S	94	3	3	0.0	2.4	55.4	34.0	1.7
MP2E	3-6	0	S	95	2	3	0.2	1.8	56.4	35.2	1.3
MP2E	6-12	0	S	96	2	2	0.1	1.9	59.5	33.2	1.0
MP2E	12-18	0	S	96	3	2	0.0	0.1	53.2	43.6	0.0
MP2E	18-24	0	S	96	2	2	0.1	1.6	56.3	36.6	1.3

Table C-3 (cont'd). Particle size of soil by depth at the sand farm sediment research site, 2003.

Plot	Depth (in)	Trt. (cm)	Class	Sand	Silt	Clay	VCoS	CoS	MS	FS	VFS
MP2W	0-3	0	S	94	0	3	0.2	1.2	51.7	39.0	1.6
MP2W	3-6	0	S	95	0	5	0.2	1.4	56.1	36.7	1.0
MP2W	6-12	0	S	95	0	5	0.0	2.0	58.6	33.9	1.0
MP2W	12-18	0	S	97	0	3	0.9	2.3	55.4	39.0	2.3
MP2W	18-24	0	S	96	0	7	0.0	1.7	53.3	39.4	1.4
MP3E	0-3	7.6	CL	23	46	31	1.2	2.4	9.0	8.1	2.0
MP3E	6-12	7.6	S	95	0	5	0.1	1.5	57.6	35.3	0.9
MP3E	12-18	7.6	S	95	0	5	0.0	1.5	56.6	36.1	1.1
MP3E	12-18	7.6	S	95	0	5	0.0	1.5	56.6	36.1	1.1
MP3E	18-24	7.6	S	96	0	6	0.1	1.1	55.8	37.5	1.6
MP3W	0-3	7.6	SL	64	25	11	0.4	1.6	34.6	25.8	1.7
MP3W	3-6	7.6	S	95	3	2	0.2	2.2	58.1	34.3	0.4
MP3W	6-12	7.6	S	95	2	2	0.1	1.0	50.0	42.7	1.6
MP3W	12-18	7.6	S	96	2	2	0.1	1.0	53.1	40.4	1.4
MP3W	18-24	7.6	S	96	2	2	0.1	1.2	53.7	39.7	1.2
MP4E	0-3	7.6	SCL	54	26	20	0.2	0.9	26.2	24.5	2.1
MP4E	3-6	7.6	S	93	0	7	0.1	1.3	54.6	35.7	0.7
MP4E	6-12	7.6	S	96	0	4	0.1	1.2	50.7	41.9	1.5
MP4E	12-18	7.6	S	96	0	4	0.1	1.4	56.2	36.5	1.3
MP4E	18-24	7.6	S	97	0	3	0.1	0.9	54.0	40.2	1.3
MP4W	0-3	7.6	SiL	24	51	26	0.9	1.2	10.5	9.4	1.6
MP4W	3-6	7.6	S	94	4	3	0.2	0.9	46.6	44.5	1.5
MP4W	6-12	7.6	S	96	2	3	0.1	1.9	54.4	38.3	0.9
MP4W	12-18	7.6	S	96	2	3	0.0	1.2	55.1	38.4	1.1
MP4W	18-24	7.6	S	95	3	3	0.1	1.4	53.7	38.3	1.2

† USDA Texture Class: S = Sand; SiL = Silt Loam; SCL = Sandy Clay Loam; CL = Clay Loam; SL = Sandy Loam; L = Loam; LS = Loamy Sand; SiCL = Silty Clay Loam; FS = Fine Sand; FSL = Fine Sandy Loam; VCoS = Very Coarse Sand; CoS = Coarse Sand; MS = Medium Sand; FS = Fine Sand; VFS = Very Fine Sand.

Appendix D: Crop Yield Data

Table D-1. Crop yields (g per plot) for the Sand Farm sediment research site.

Year	Plot	Sed. Depth (in)	Rep	# of Plants	Total Cobs	Barren Cobs	Good Ears	Corn Wt (g)	Mean Wt Corn	Soy Wt	Mean Wt Soy
2004	EB4	0	A	17	10	6	4	81	508	807	742
2004	EB4	0	B	18	15	12	3	150		745	
2004	WB1	0	A	22	11	8	3	106		671	
2004	WB1	0	B	24	22	8	14	793		1,119	
2004	MP2	0	A	25	17	6	11	803		595	
2004	MP2	0	B	29	26	9	17	1,115		518	
2004	EB3	3	A	33	27	4	23	2,094	1,778	696	795
2004	EB3	3	B	33	34	16	18	1,256		977	
2004	WB4	3	A	28	25	7	18	1,032		607	
2004	WB4	3	B	34	36	1	35	2,729		901	
2004	MP3	3	A	32	35	12	23	1,244	901	743	861
2004	MP3	3	B	35	26	11	15	829		839	
2004	MP4	3	A	22	20	12	8	441		860	
2004	MP4	3	B	29	28	8	20	1,089		1,004	
2004	WB3	6	A	33	19	7	12	1,299	1,353	761	844
2004	WB3	6	B	32	38	22	16	786		905	
2004	EB2	6	A	28	29	8	21	1,843		757	
2004	EB2	6	B	32	36	11	25	1,483		953	
2004	MP1	6	A	31	23	6	17	1,142	1,439	802	947
2004	MP1	6	B	36	36	16	20	1,736		1,093	
2004	EB1	12	A	35	31	8	23	1,592	1,392	861	981
2004	EB1	12	B	33	28	9	19	845		1,074	
2004	WB2	12	A	33	30	10	20	1,963		1,079	
2004	WB2	12	B	37	30	14	16	1,167		910	
2003	EB4	0	A					698	1269	910.7	974
2003	EB4	0	B					759		1,049.1	
2003	WB1	0	A					1,547		1,050.5	
2003	WB1	0	B					1,652		913.2	
2003	MP2	0	A					1,746		985.8	
2003	MP2	0	B					1,211		933.8	
2003	EB3	3	A					3,627	3,802	1,148.3	961
2003	EB3	3	B					3,721		1,195.4	
2003	WB4	3	A					4,220		869.3	
2003	WB4	3	B					3,641		632.8	
2003	MP3	3	A					3,527	3,164	960.3	848
2003	MP3	3	B					3,252		863.8	
2003	MP4	3	A					2,767		783.1	
2003	MP4	3	B					3,111		783.2	
2003	EB2	6	A					4,012	3,780	1,269.6	1,271
2003	EB2	6	B					3,098		1,118.6	
2003	WB3	6	A					3,868		1,585.9	
2003	WB3	6	B					4,142		1,110.0	
2003	MP1	6	A					5,396	5,902	1,475.1	1,549
2003	MP1	6	B					64,07		1,622.2	
2003	EB1	12	A					5,062	4,795	918.0	883
2003	EB1	12	B					4,671		1,218.0	
2003	WB2	12	A					4,224		644.6	
2003	WB2	12	B					5,221		750.4	

Table D-1 (cont'd). Crop yields (g per plot) for the Sand Farm sediment research site.

Year	Plot	Sed. Depth (in)	Rep	# of Plants	Total Cobs	Barren Cobs	Good Ears	Corn Wt (g)	Mean Wt Corn	Soy Wt	Mean Wt Soy
2002	EB4E-A	0	a					495.2	153	410.0	399
2002	EB4E-B	0	b					238.0		514.8	
2002	WB1E-A	0	a					105.1		822.8	
2002	WB1E-B	0	b					77.5		730.3	
2002	MP1E-A	0	a					27.6		154.8	
2002	MP1E-B	0	b					98.3		144.2	
2002	MP2E-A	0	a					53.3		256.3	
2002	MP2E-B	0	b					127.4		158.5	
2002	EB3E-A	3	a					77.5	55	363.3	255
2002	EB3E-B	3	b					58.4		182.4	
2002	WB4E-A	3	a					38.0		220.3	
2002	WB4E-B	3	b					46.1		252.1	
2002	MP3E-A	3	a					41.8	63	101.4	93
2002	MP3E-B	3	b					59.6		83.2	
2002	MP4E-A	3	a					47.2		52.2	
2002	MP4E-B	3	b					101.5		134.9	
2002	WB3E-A	6	a					50.4	79	439.6	363
2002	WB3E-B	6	b					58.2		432.2	
2002	EB2E-A	6	a					101.4		284.3	
2002	EB2E-B	6	b					104.8		296.1	
2002	EB1E-A	12	a					1.2	29	267.2	320
2002	EB1E-B	12	b					9.2		216.0	
2002	WB2E-A	12	a					68.2		319.9	
2002	WB2E-B	12	b					39.4		475.9	
2001	EB4	0	a					209.5	398.8	4.3	9.2
2001	EB4	0	b					104.5			
2001	WB1	0	a					589.2		10.8	
2001	WB1	0	b					558.8			
2001	WB2	0	a					421.8		12.6	
2001	WB2	0	b					508.9			
2001	EB3	3	a					72.9	96.1	12.5	10.6
2001	EB3	3	b					0.0			
2001	WB4	3	a					135.2		8.8	
2001	WB4	3	b					176.2			
2001	EB2	6	a					21.3	87.0	17.8	17.5
2001	EB2	6	b					13.2			
2001	WB3	6	a					101.9		17.2	
2001	WB3	6	b					211.5			
2001	EB1	12	a					45.0	54.4	53.5	53.5
2001	EB1	12	b					63.8			

Appendix E: Crop Tissue Analysis

Table E-1. Metal concentration in soybean leaves and grain (year 3).

Plot	Trt. (cm)	Material	Be	B	Ti	V	Cr	Mn	Co	Ni	Cu	Pb
EB4	0	Leaves	< 0.5	18	5.5	0.12	0.51	200	0.17	0.92	2.2	0.97
EB4	0	Leaves	< 0.5	23	6.0	0.13	0.59	190	0.16	0.55	2.0	0.56
EB4	0	Leaves	< 0.5	17	6.1	0.12	0.50	180	0.13	0.55	1.7	1.2
MP1	15	Leaves	< 0.5	38	4.8	0.11	0.45	92	0.11	0.52	3.5	0.49
MP1	15	Leaves	< 0.5	42	4.3	0.13	0.51	79	0.082	0.49	2.9	0.97
WB2	30	Leaves	< 0.5	32	5.2	0.12	0.57	44	0.065	0.61	3.1	0.65
WB2	30	Leaves	< 0.5	32	5.2	0.093	0.42	45	0.089	3.8	3.9	1.4
WB2	30	Leaves	< 0.5	39	5.2	0.11	0.49	50	0.069	0.54	3.3	0.54
EB4	0	Grain	< 0.5	9.7	10	< 0.04	< 0.1	54	0.23	2.3	3.5	< 0.04
EB4	0	Grain	< 0.5	9.4	10	< 0.04	< 0.1	55	0.21	2.5	3.9	< 0.04
MP1	15	Grain	< 0.5	32	10	< 0.04	0.10	29	0.083	3.0	9.2	< 0.04
MP1	15	Grain	< 0.5	28	11	< 0.04	< 0.1	30	0.097	3.1	9.5	0.044
WB2	30	Grain	< 0.5	34	9.7	< 0.04	0.10	28	0.063	2.5	7.9	0.070
WB2	30	Grain	< 0.5	34	10	< 0.04	< 0.1	28	0.065	2.6	8.4	0.047

Plot	Trt. (cm)	Material	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Hg
EB4	0	Leaves	11	0.18	< 0.4	0.077	< 0.04	0.081	97	< 0.04	0.0099
EB4	0	Leaves	8.9	0.19	< 0.4	0.083	0.049	0.056	104	< 0.04	0.0152
EB4	0	Leaves	7.8	0.15	< 0.4	0.081	< 0.04	0.040	140	< 0.04	0.0215
MP1	15	Leaves	43	0.13	< 0.4	2.1	< 0.04	0.49	10	< 0.04	0.0185
MP1	15	Leaves	41	0.24	< 0.4	2.1	< 0.04	0.55	12	< 0.04	0.0123
WB2	30	Leaves	36	0.20	< 0.4	4.5	< 0.04	0.47	12	< 0.04	0.0147
WB2	30	Leaves	42	0.18	< 0.4	4.0	< 0.04	0.58	8.8	< 0.04	0.1145
WB2	30	Leaves	36	0.18	< 0.4	4.2	< 0.04	0.48	8.5	< 0.04	0.0429
EB4	0	Grain	24	< 0.04	< 0.4	1.7	< 0.04	0.063	19	< 0.04	0.0006
EB4	0	Grain	23	< 0.04	< 0.4	1.3	< 0.04	0.064	19	< 0.04	0.0004
MP1	15	Grain	40	< 0.04	< 0.4	23	< 0.04	0.31	2.9	< 0.04	0.0006
MP1	15	Grain	40	< 0.04	< 0.4	22	< 0.04	0.25	2.2	< 0.04	0.0005
WB2	30	Grain	40	< 0.04	< 0.4	20	< 0.04	0.40	1.6	< 0.04	0.0011
WB2	30	Grain	40	< 0.04	< 0.4	21	< 0.04	0.34	1.9	< 0.04	0.0005

Appendix F: Typical Concentrations of Trace Elements in Mature Leaf Tissues

Table F-1. Typical concentrations of trace elements in mature leaf tissues.

Element	Deficient	Sufficient or Normal	Excessive or Toxic
	---------------------------mg kg^{-1}	-------------------------------	
Ag	-	0.5	5-10
As	-	1-1.7	5-20
B	5-30	10-100	50-200
Ba	-	-	500
Be	-	< 1-7	10-50
Cd	-	0.05-0.2	5-30
Co	-	0.02-1	15-50
Cr	-	0.1-0.5	5-30
Cu	2-5	5-30	20-100
F	-	5-30	50-500
Hg	-	-	1-3
Li	-	3	5-50
Mn	10-30	30-300	400-1,000
Mo	0.1-0.3	0.2-5	10-50
Ni	-	0.1-5	10-100
Pb	-	5-10	30-300
Se	-	0.01-2	5-30
Sn	-	-	60
Sb	-	7-50	15
Ti	-	-	50-200
Tl	-	-	20
V	-	0.2-1.5	5-10
Zn	10-20	27-150	100-400
Zr	-	-	15

† Adapted from “Trace elements in soils and plants” (Kabata-Pendias and Pendias, 1992). Values are not given for very sensitive or highly tolerant plant species.

Appendix G: Typical Metal Content of Surface Soils

Table G-1. Typical metal content of surface soils.†

Element	Range	Mean	Element	Range	Mean
	--------mg kg^{-1}--------			-------mg kg^{-1}--------	
Ag	0.2 - 3.2	-	Li	0.7 - 16	5.5
As	< 1 - 93	7	Mn	20 – 3,000	600
B	2 - 200	80	Mo	0.02 - 5	-
Ba	200 – 1,500	675	Ni	< 5 - 150	19
Be	0.04 - 2.54	0.54	Pb	< 10 - 70	26
Cd	0.4 - 0.5	-	Se	< 0.1 - 4	0.3
Co	1 - 70	8	Ti	500 – 10,000	3000
Cr	7 – 1,500	50	Tl	0.02 - 2.8	-
Cu	1 - 40	9	V	0.7 - 98	-
Hg	0.02 - 1.5	0.17	Zn	10 - 300	50

† Compiled from Kabata-Pendias and Pendias (1992) and Havlin et al. (1999).

Appendix H: Pollutant Limits for Land Application of Sewage Sludge

Table H-1. Pollutant limits for land application of sewage sludge.

Pollutant†	Ceiling Concentrations[§] (mg kg^{-1})	Pollutant Concentrations Monthly Average (mg kg^{-1})
Arsenic	75	41
Cadmium	85	39
Chromium	3,000	1,200
Copper	4,300	1,500
Lead	840	300
Mercury	57	17
Molybdenum[‡]	75	--
Nickel	420	420
Selenium	100	36
Zinc	7,500	2,800

† From the Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503. United States Environmental Protection Agency (USEPA), 1994b.

§ Concentrations are considered totals (Method 3051, USEPA, 1994a).

‡ The pollutant concentration limit for molybdenum was deleted from Part 503 effective February 19, 1994. USEPA will reconsider establishing these limits at a later date.

Appendix I: Irrigation Record at the Sand Farm Research Plots, 2003

Table I-1. Irrigation record at the Sand Farm sediment research plots, 2003.

Irrigation	Hours	Julian Day
22-Apr	3	112
29-Apr	3	119
13-May	2	133
27-May	4	147
24-Jun	5	175
1-Jul	5	182
16-Jul	5	187
5-Aug	5	217
14-Aug	4	226
20-Aug	4	232
28-Aug	4	240