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Illinois River Dredged Sediment and Biosolids Used as Greenhouse Soil Mixtures

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ABSTRACT

Accumulation of sediment in the Illinois River has greatly degraded the ecosystem. A large dredging project has been proposed to improve wildlife habitat and recreation in the Peoria Lakes reach of the river. Disposal of the dredged sediment is a concern because of the large quantities involved. The objective of this study was to determine if mixtures of dredged sediment with other materials, including biosolids, yard waste compost, and horse manure could serve as topsoil substitutes. Dredged sediment came from the Peoria Lakes portion of Illinois River, compost was obtained from the Urbana, Illinois municipal yard waste facility, and biosolids were obtained from the Metropolitan Water Reclamation District of Greater Chicago. Eighteen different mixtures were produced. Barley and snapbeans were grown in the mixtures in the greenhouse. Plant growth, total biomass, and heavy metals content were analyzed as well as physical and chemical properties of the soil mixtures. The experiment was carried out twice using the same soil material. Plants grew well in all treatments, except snapbeans were stunted by salts in unleached biosolid mixtures. The highest overall yield for barley was obtained in the treatment composed of 50% sediment and 50% biosolid. For snapbean, the highest yield was the treatment composed of 70% sediment and 30% biosolid. Heavy metals in plants tissue are within ranges considered normal, except for Mo in snapbean which is at a level of concern if the plants were used exclusively as animal fodder. Addition of biosolids to sediments decreased Mo plant availability. Compost did not have a significant effect on yield, but did significantly increase Mo uptake in snapbeans. Based on our results with this limited greenhouse experiment, the dredged sediment we used has no inherent chemical or physical properties that would preclude use as topsoil substitute. Adding dredged sediment to unleached biosolids improved plant growth and an optimum ratio of sediments to biosolids might be 80:20 to 70:30 in most situations.

INTRODUCTION

Dredged Sediment

Sedimentation of lakes and rivers is an environmental problem in many places; this is also the case of the Illinois River which traverses the state of Illinois from Chicago to its confluence with the Mississippi River in the southwest part of the state. Historically, the river has been an important means of transportation. In addition, it was also a very productive ecosystem with great recreation potential, functions that lately have been greatly affected by reduction in depth of the river (Darmody and Marlin, 2002). An ambitious dredging project has been proposed to enhance the river's ecological and recreational potential. This project will generate large amounts of sediment. Relocation of this sediment becomes an issue of concern due to the large quantities that will be produced. A beneficial use of the sediment is a goal of the work reported here.

Sediments have potential use as soil for agricultural purposes (Canet et al., 2003; Olson and Jones, 1987). Sediments have desirable soil characteristics such as favorable texture for optimal plant-available water, good level of cation exchange capacity, and high fertility. They, however, might contain high concentrations of heavy metals if contaminated by industrial pollutants, which may be a matter of concern due to potential plant uptake toxicity. Darmody and Marlin (2002) found that heavy metal levels in sediments from the Illinois River are somewhat elevated compared to reference soils. However, Illinois River sediment metal content has not yet been found to have any negative effect on plant growth or on the heavy metal content in plant tissues. Dredged Illinois River sediments from the Peoria Lakes reach have characteristics similar to naturally productive fine textured agricultural soils in Illinois. After sediments dewater and age, they can develop good tilth, which is associated with productive agricultural soils (Darmody and Marlin, 2002).

Biosolids

Unlike dredged sediments, studies of biosolids (anaerobically digested sewage sludge) related to agricultural use have been carried out extensively; most of these studies conclude that the nutrients level are high and thus, in many cases biosolids are treated as “organic” fertilizers (National Research Council, 2001). Disposal of sewage sludge has been a problem since the advent of large centralized sewage treatment plants and public awareness of the health and environmental pollution aspects of wastewater. The city of Chicago, until about 1870, dumped its untreated sewage directly into Lake Michigan, the source of its drinking water (Aldrich, 1980). In response to a cholera epidemic in 1870, Chicago reversed the flow of the untreated sewage, discharging it ultimately into the Illinois River. By the 1960’s the public attitude toward water quality began to change and regulations increasingly restricted discharge of pollutants. This was a result of improvements in wastewater treatment whereby the liquid phase is separated from the solid phase. The highly treated liquid phase is discharged into surface waters and the solid phase, high in organic matter and other components of sewage and the treatment process, is known as biosolid.

The National Research Council (2001) defines biosolid as sewage sludge that has been treated to meet regulatory requirements for land application set out in the Code of Federal Regulations, Title 40 (Part 503). The US Environmental Protection Agency (EPA) established the regulations and is responsible for the supervision of the national biosolids program.

Although biosolids have been used as fertilizers for the past 20 years, the potential pollution of soils, crop tissue, and ground water by excess of nutrients and trace elements causes the use of biosolids to remain controversial (Shober et al., 2003). Recent evaluations of regulated land application of biosolids lead to the conclusion that potential decreased crop quality or increased trace elements entering the food chain through crop uptake are acceptable risks (Shober et al., 2003).

However disposal of both sediments and biosolids is not without problems. Both are heavy and expensive to transport. In addition, fears about risks of heavy metals, pathogens, and other problematic substances in both materials evoke the NIMBY (not in my back yard) response among some people. In this study we studied the use of biosolids and dredged sediments for plant growth since the level of nutrients and the physical and chemical characteristics of the materials are desirable. Some problems associated with one material used alone might be mitigated by the addition of other materials, thus creating mixtures that offer good plant growth properties.

MATERIALS AND METHODS

Materials

The experiment was carried out in a controlled environment greenhouse, with two common crops; snapbeans *(Phaseolus vulgaris* var. Bush Blue Lake 274) and Barley (*Hordeum vulgare)*. The crops were growth in plastic pots of 5 inches standard and 6 inches standard respectively for barley and snapbean, and located on one bench of 10 m^2 and 90 cm above the floor.

The materials for the soil mixtures included dredged sediment, biosolids, municipal yard waste compost, and horse manure. The dredged sediments were collected from the Peoria Lake portion of the Illinois River (Fig.1). Biosolids were obtained from the Metropolitan Water Reclamation District of Greater Chicago, compost was from the Urbana, Illinois municipal yard waste facility, and horse manure from a local farm.

Materials were passed through 10 mm mesh sieves to disaggregate clumps and to remove coarse debris that may have been present in the materials. Plant growth was monitored periodically as well as Nitrogen concentration in barley leaves using the Minolta© SPAD-502 Chlorophyll Meter. The SPAD is used for quick assessment of N status of a crop based on leaf color (Singh et al., 2002; Yang et al., 2003). Soil surface penetration resistance was also measured using a pocket penetrometer. Soil moisture release curves were produced using the WP4 Dewpoint PotentiaMeter.

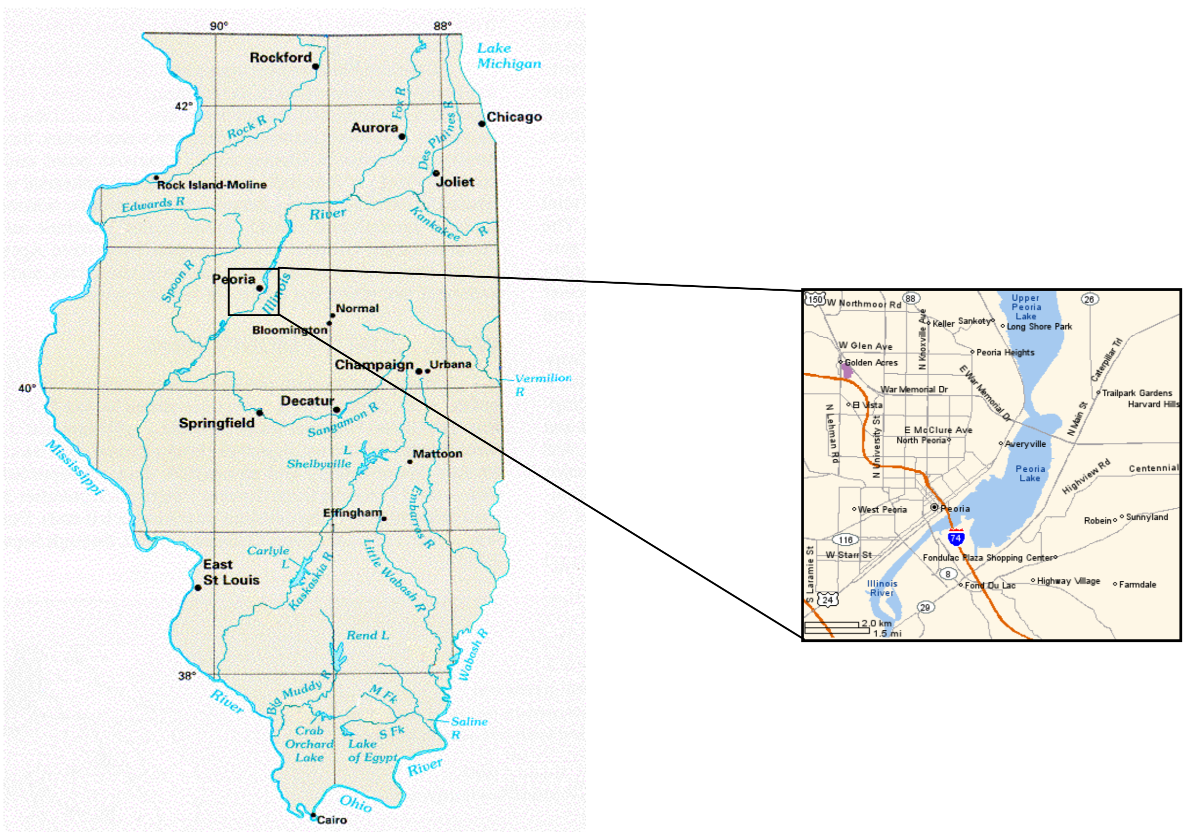

Figure 1. The Peoria Lakes portion of the Illinois River.

Methods

The sediment was dredged with a clamshell bucket from Peoria Lake in May 2000, loaded on dump trucks, and transported for storage in a gravel pit near Peoria. About 100 gallons of dried sediment were collected by hand from the pit in November 2002. By then the sediment had dried to a depth of about 3 feet, with signs of weathering, iron oxidation, soil structure formation, etc. due to dewatering and exposure to the environment. Sediment was transported and stored in large plastic tubs. Biosolid used was class “A,” which passes the regulatory requirements established by the Environmental Protection Agency (EPA) (National Research Council, 2001). Class A biosolids have undetectable pathogens are suitable for land application. The materials were mixed on a volume basis, producing 17 mixtures (Table 1). Appendix 1 gives the weight equivalents of the volumetric ratios. A standard greenhouse soil mix, a mixture of soil, perlite, and compost in equal proportions, served as the control.

Table 1. Soil mixtures used in experiment, % by volume.

Treatment #	Sediment	Biosolids	Compost	Other
	----------------------------	---- % ----	----------------------------	
1	100	0	0	-
2	80	10	10	-
3	60	20	20	-
4	40	30	30	-
5	20	40	40	-
6	70	30	0	-
7	50	50	0	-
8	30	70	0	-
9	50	0	50	-
10	0	100	0	-
11	80	20	0	-
12	70	20	10	-
13	0	0	100	-
14	80	0	0	20 ^{h}
15	70	0	10	20 ^{h}
16	-	-	-	100 ^{s}
17	60	0	10	30 ^{p}
18	60	15	15	10 ^{p}

^{h} = Horse Manure, ^{s} = Standard Greenhouse Mix, ^{p} = Perlite

The soil mixtures were placed in plastic pots and placed on a table in the greenhouse. Planting of crops was completed the same day; each pot was planted with 3 seeds of snapbean or 5 seeds of barley. Pots were irrigated as needed. No fertilizers or other amendments were applied; therefore crop growth depended on the inherent fertility of the mixtures. Pest control was performed as needed. After germination and establishment, the number of plants per pot was thinned to one plant for snapbean and 3 plants for barley.

Plant heights were measured periodically and were allowed to grow until flowering (6-7 weeks). Plants were harvested with special care to avoid contamination with soil, since heavy metal content in plant tissue is one of the parameters to be measured. Plant samples were rinsed five times with distilled water, placed in paper bags, and oven-dried at 65 C° for 48 hours, prior to obtaining the total dry biomass.

The experiment was repeated a second time using the same soil material after removing plant residues, mixing, and relocation in new pots. This allowed leaching of salts that were observed efflorescing on the pots with treatments that included biosolids. The experimental procedure was followed in the same way as with the first batch of samples.

Three soil sample sets were collected; before planting, after the first harvest, and after the second harvest. Soil texture of the initial materials was determined by hydrometer and sieving. Fertility-related characteristics and elements such as pH, organic matter, soluble sulfur, extractable P, K, Ca, Mg, K, Na, B, Fe, Mn, Cu, Zn, Al, soluble salts, and total C and N was determined at Brookside Labs of New Knoxville, OH. Soil pH was determined in 1:1 soil:water suspension, and organic matter was determined by 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). Cation exchange capacity (CEC) was estimated by summation of exchangeable bases. Soluble salts were determined by electrical conductivity of a saturated paste. Soil texture was determined by the hydrometer method, previously the organic matter was removed using 30% hydrogen peroxide (H_2O_2) (Gee and Bauder, 1996).

After oven drying, plant samples were weighed, then ground to pass a 1-mm sieve and stored in 20 ml scintillation glass vials (Richards, 1993). Plant and soil samples were sent to the Illinois Waste Management and Research Center (WMRC) laboratories for heavy metal analyses. 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 US EPA Method 3051 (USEPA, 1994), was utilized to dissolve the plants and soils before analysis.

Statistical Analysis

There were a total of 18 treatments, two plant types, and five replications to give a total of 180 experimental units per run (Table 2). The experiment was run twice, the first time with fresh materials, the second time after the materials were leached while serving as the material for the first experimental run. Data was analyzed using Proc Mixed procedure in SAS statistical program (SAS Institute, 2000). For the analysis, the model used a repeated measured in time (Littell et al., 1996; Littell et al., 2002) using the factor time as repeated to take into account the effect of using the soil repeatedly on the treatments. Unless otherwise noted, significance was reported at $\alpha = 0.05$.

Table 2. Total number of experimental units per experimental run.

Treatments	Plant types	Replications	Experimental units
18	2	5	180

RESULTS

Soil Properties and Fertility

There are some fundamental differences between dredged sediments and biosolids. These include soluble salts, essential elements associated with fertility, pH, heavy metals, and physical properties including texture, structure, compaction, and organic matter content, among others.

Soil Compaction and Resistance

A concern with utilization of dredged sediments for agriculture is their undesirable propensity to hard-set upon drying which makes water and plant root penetration difficult. This appears to be only a temporary phenomenon. Because the sediments we used had gone through several drying and wetting cycles and were weathered in the field for a few years, they had developed some soil structure that gave them relatively low soil strength as measured by surface penetration (Fig. 2). A remarkable effect of the treatments can be observed, with a low resistance for treatments with 100% sediment (1), 100% biosolid (10), and the standard greenhouse mixture (16). A good effect of perlite can be observed, especially treatment 17 (30% perlite). However, in general terms soil compaction cannot be considered as a limiting factor for plant growth in any of the mixtures produced for this experiment.

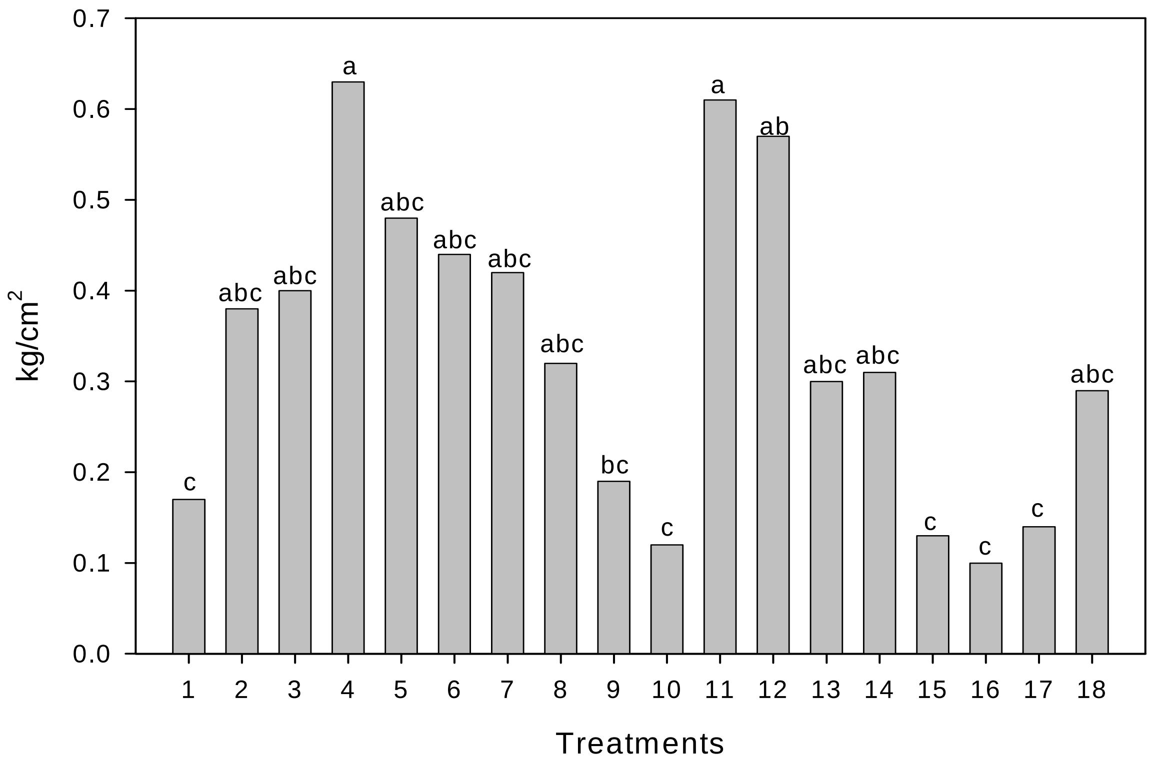

Figure 2. Penetrometer resistance of the soil mixtures for barley. Values with the same letter are not statistically different.

Texture

The mixtures are rather similar in texture, most of then are silt loam or silty clay loam (Fig. 3). Pure sediment is silty clay loam, biosolid is silt, and the compost is silt loam, with the mixtures being intermediate (Table 3). The greenhouse mix is the coarsest because of the added sand. Typical highly productive Mollisols in Illinois have silt loam or silty clay loam textures, which are very desirable for agricultural production, and similar to our mixtures.

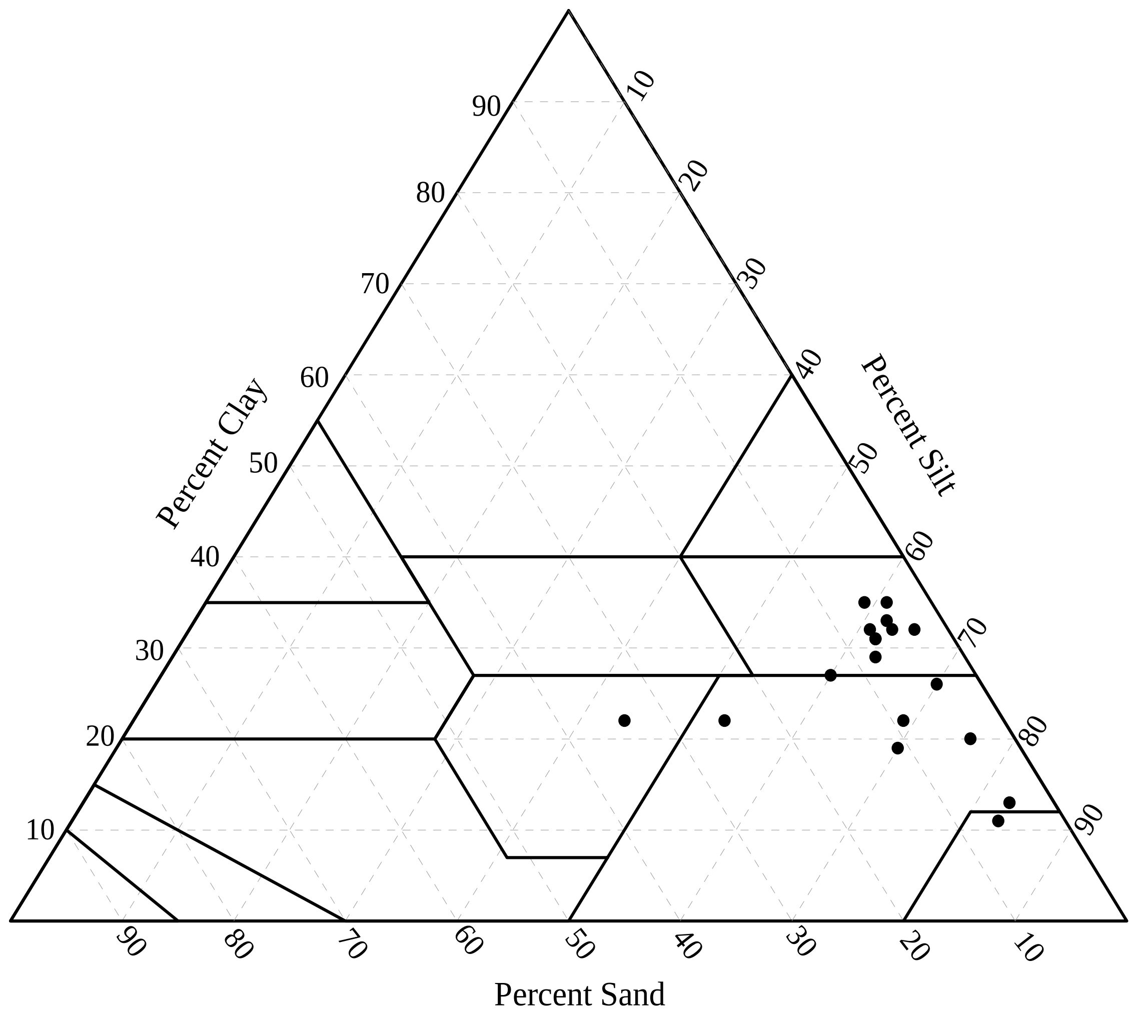

Figure 3. Soil mixture textural classes.

Table 3. Soil texture of greenhouse mixes.

Sample	Class*	Sand†	Silt	Clay	VCoS	CoS	MS	FS	VFS	CoSi	FSi
1	SiCL	4	61	35	-	-	-	-	-	17	44
2	SiCL	5	63	32	-	-	-	-	-	23	40
3	SiCL	7	62	31	-	-	-	-	-	24	38
4	SiL	9	69	22	-	-	-	-	-	40	29
5	SiL	11	70	19	-	-	-	-	-	47	23
6	SiL	4	70	26	-	-	-	-	-	32	38
7	SiL	4	76	20	-	-	-	-	-	44	32
8	SiL	4	83	13	-	-	-	-	-	62	21
9	SiCL	13	60	27	2	3	3	3	2	24	36
10	Si	6	83	11	-	-	-	-	-	76	7
11	SiCL	3	65	32	-	-	-	-	-	25	40
12	SiCL	5	62	33	-	-	-	-	-	24	38
13	SiL	25	53	22	4	4	7	7	2	30	23
14	SiCL	6	59	35	-	-	-	-	-	19	40
15	SiCL	7	62	31	-	-	-	-	-	23	39
16	L	34	44	22	5	8	14	6	1	18	26
17	SiCL	7	61	32	-	-	-	-	-	21	40
18	SiCL	8	63	29	-	-	-	-	-	26	37

* USDA soil texture class names including: SiCL, silty clay loam; SiL, silt loam; Si, Silt; L, loam.

† Content (%) of soil separates in USDA texture classes including: VCoS, very coarse sand; CoS, coarse sand; MS medium sand; FS fine sand; CoSi, coarse silt; FSi, fine silt.

Water Holding Capacity

The water potential was determined by vapor equilibration measured by the WP4 Dewpoint PotentiaMeter. The biosolid has the highest water holding capacity (WHC) (Fig. 4), perhaps enhanced by the high organic matter content. Standard greenhouse mixture and the sediment have similar WHC while the compost has an intermediate value. The scale used is pF which is defined as the logarithm potential expressed as cm of H_2O; there are 10200 cm of H_2O in one MPa (units of WP4 readings). Equation 1 was used for transformation of the original readings.

$$pF = \log(-10200 \text{x} MPa) \qquad [1]$$

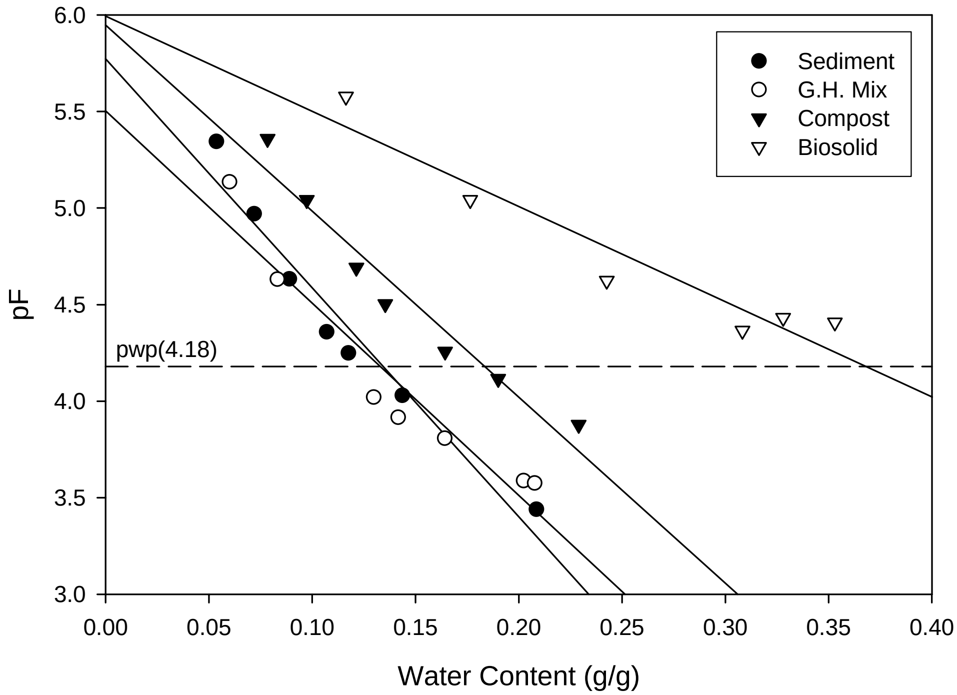

Figure 4. Water content of soil at permanent wilting point (-1.5 MPa / 4.18 pF).

Compared to a reference silty clay loan Mollisol from Illinois (Drummer, Fine-silty, mixed, superactive, mesic Typic Endoaquolls) (upper 17 cm) the WHC of the treatments are very good. The contribution of biosolids to WHC is obvious, the high organic content holds considerable amount of water (Table 4). This soil property is one of the most important for the management of problems related to plant-soil-water relationship. Cornelis et al. (2001) considered the moisture retention curve as the soil's fingerprint since the slope and shape of the curve is related to various physical and chemical properties that are unique for each soil; particle-size distribution, organic matter content, and bulk density are the most influential properties. The slope can be used to determine the expansive soil classification (Table 4); higher absolute values of slope correspond to less expansive soils (McKeen, 1992). Biosolids are highly expansive with low physical stability, in contrast, dredged sediment show properties more similar to local soils (Table 4).

Table 4. Moisture content of samples at permanent wilting point (4.18 pF)

Treatment	Sediment	Biosolids	Compost	Other	Moisture (g/g)	Slope
	------------------------ % ----------------------					
1	100	0	0	-	0.14	-18.76
2	80	10	10	-	0.17	-10.12
3	60	20	20	-	0.19	-9.99
4	40	30	30	-	0.22	-6.79
5	20	40	40	-	0.27	-4.02
6	70	30	0	-	0.20	-9.48
7	50	50	0	-	0.25	-5.69
8	30	70	0	-	0.24	-3.41
9	50	0	50	-	0.17	-11.07
10	0	100	0	-	0.37	-4.93
11	80	20	0	-	0.19	-9.38
12	70	20	10	-	0.18	-9.93
13	0	0	100	-	0.18	-9.63
14	80	0	0	20 ^{h}	0.18	-9.50
15	70	0	10	20 ^{h}	0.18	-8.99
16	-	-	-	100 ^{s}	0.13	-9.98
17	60	0	10	30 ^{p}	0.18	-8.24
18	60	15	15	10 ^{p}	0.18	-10.46
Reference Mollisol					0.10	-28.63

^{h} = Horse Manure, ^{s} = Standard Greenhouse Mix, ^{p} = Perlite

Salt Content

The level of soluble salts was one of the main factors that appears to have had a negative influence on plant growth during the first experimental run. Salt is associated with reduced plant growth and the snapbeans were more affected than the barley as would be expected given their salinity tolerances (Table 5). Salt toxicity was detected only in the first planting because the salts were allowed to leach from the soil mixes before they were used for the second experimental run (Fig. 5). Decreases in salt content were due to leaching with irrigation water. Because the pots were up on a bench that drained to the floor, the leached salts had no way to return to the soil mixes in the pots. This is unlike a field application where some of the drainage water that is dissolving salts may wick back up and redeposit salt in the root zone and be a problem for plants

Table 5. Relative tolerance of crop plants to salt.

High Salt Tolerance EC_e=16*	Medium Salt Tolerance EC_e=10	Low Salt Tolerance EC_e=4
Barley	Rye	Green Beans
Sugar beet	Wheat	Celery
Rape	Oats	Field beans
Cotton	Rice	
	Sorghum	
	Corn	
	Flax	
	Sunflower	
	Castor beans	

*EC_e = Electrical conductivity measured in millimhos/cm.

From: Agriculture handbook No. 60. USDA (1954).

for an extended period of time. In the greenhouse, we simulated several years of leaching in two growing cycles and the salts were reduced as much as about 66% (Fig. 5). Salt levels in compost and sediments are low, it is the biosolids that contribute the problem salts, and higher percentage of biosolids in a mixture is associated with increased initial salt content (Table 6). For sediment the initial level of salt was low and the reduction over the course of the experiment is not as marked as with the biosolid. Unlike sediments from more saline environments, salt is not a concern for plant growth in sediments from the Illinois River. Diluting biosolid with dredged sediment reduced the levels of salts in the final mixture, salt in treatments with 50% or less biosolid is below the limit of toxicity for snapbean of 4 millimhos/cm (Fig. 5). The treatments with 0% biosolid are the standard greenhouse mix (control) and the 100% dredged sediment; the levels of salts in these treatments are very low and not significantly different.

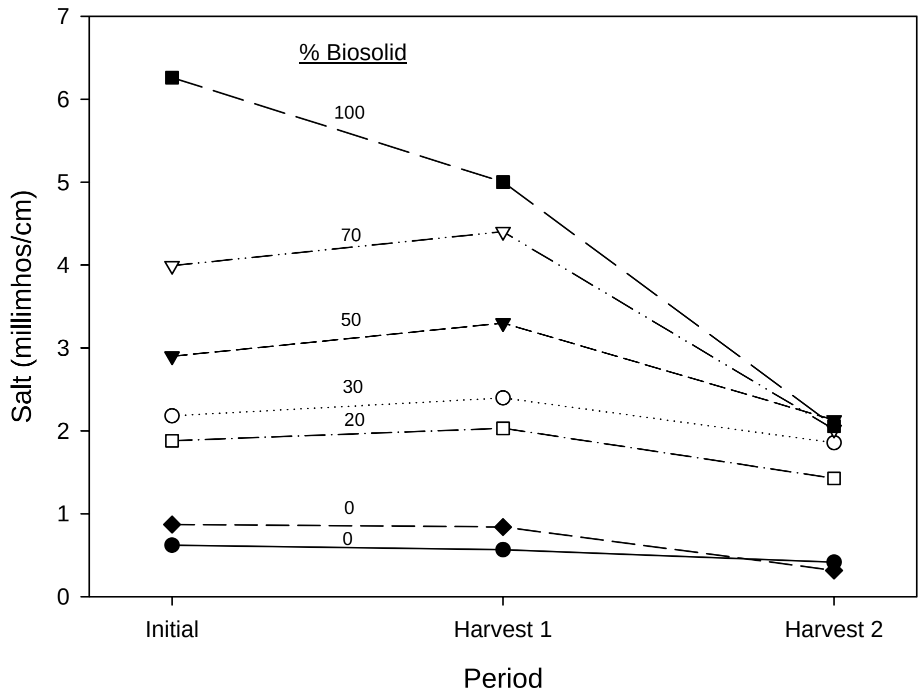

Figure 5. Soluble salt contents in selected mixtures of biosolid and sediment. Note the strong relationship of biosolid content to salinity and the decrease in salinity due to leaching.

Soil Chemistry

The pH of the mixtures is related to the proportion of sediment and biosolid. Dredged sediment from the Illinois River has pH values in the range of about 7.5 to 8.1 (Darmody and Marlin, 2002), a result of the presence of free carbonates i.e. mollusk shells, etc. (Darmody et al., 2004). Soil pH in the greenhouse mixtures ranged from 6.0 for 100 % biosolids to 7.6 for 100 % sediment. (Table 6; Fig. 6; Appendix 2). According to Havlin et al. (1998), the ideal pH range for barley and snapbean growth is in the range of moderately acid, pH 5.5 to 6.5. Sediments are above that pH range, but we did not observe any deleterious effects of high pH on our plants. The higher pH value were for compost, with values up to 8.2, this exceeded the pH values found for dredged sediment.

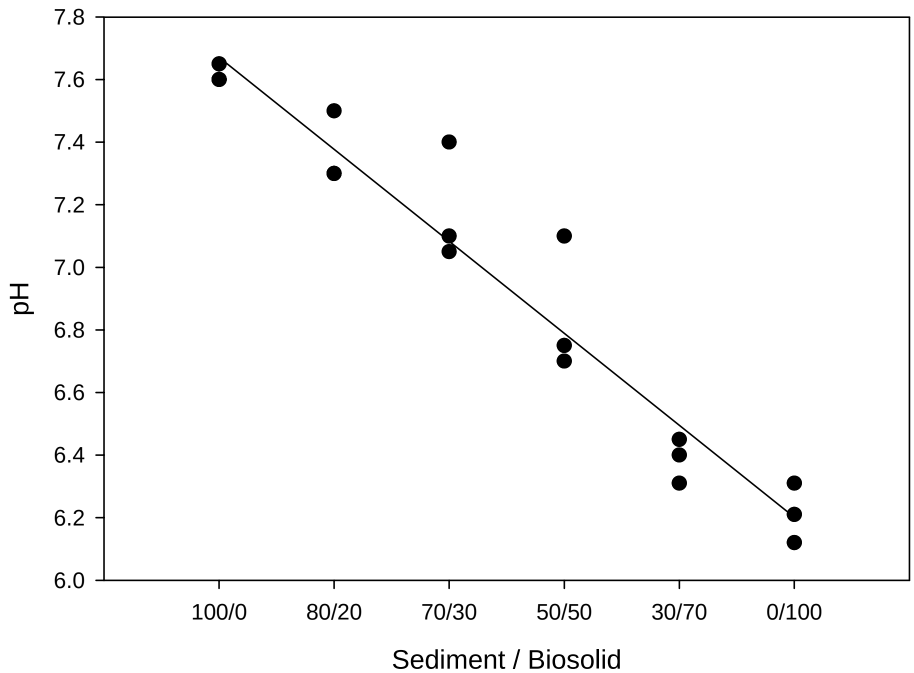

Figure 6. Relation between pH levels and the ratio of sediment to biosolid. Note, all three pH measurements (before planting and after first and second harvest) for each treatment shown.

Biosolids generally have a higher level of plant nutrients than sediments (Table 6). Sediment organic matter (OM) content initially was 4.5%, about the same as highly fertile Illinois topsoil. Biosolids had 30% OM, and mixtures of the two had intermediate contents of OM. Compost came in at 17 % OM and treatments with horse manure in the composition had about 7% OM (Treatments 14 and 15) (Appendices 2, 3, 4). Total exchange capacity (TEC) is strongly related to OM content, so the TEC values generally followed the biosolid proportion of mixtures.

Soluble sulfur is also more concentrated in the biosolids, 100% biosolids had about 2826 mg kg^{-1} S, compared to 167 mg kg^{-1} in the sediment and 646 mg kg^{-1} in the control (Table 6). Soluble S dropped after leaching, down to 1297 mg kg^{-1} in the 100% biosolid treatment. Levels of phosphorus are also considerably higher in biosolids with values of 2247 mg kg^{-1}, compared to 144 mg kg^{-1} for sediment, and 318 mg kg^{-1} for the control and 352 mg kg^{-1} for compost. Iron content is higher in sediment while Ca is high in all materials. Levels of Mg, K, Na, B, Mn, Cu, Zn, and Al are higher in biosolids than sediments. Some of the chemicals in biosolids are concentrated from the original sewage, and some may be added as part of the sewage treatment process. Additives to sewage can include clarifying agents, i.e. flocculants, which remove particulate matter from the waste stream so that the resultant effluent is as clean as possible so that it can be discharged into water bodies. Anything left behind ends up in the sludge to become an attribute of the biosolids.

Carbon and N content of the materials generally follows the OM content, which is most strongly related to the portion of the mixtures that comes from biosolids because of its high OM content. There is a difference in C:N ratios, however, organic matter with high C:N ratio is less reactive and more stable because the relatively low N content inhibits C compound decomposition, fresh organic matter tends to have low C:N ratios. Typical topsoil C:N ratios are about 12:1. The standard greenhouse mix has a C:N ratio of 22, indicating that it will not quickly decompose, pure sediments have a C:N ratio of 16, compared to 10 for the 100% biosolids. This indicates that the OM in the biosolids is “fresher,” and will decompose more quickly that the OM in the other materials and may provide more N to the growing plants, a benefit for the barley plants, but not for the N fixing snapbeans. A C:N ratio greater than 25 is generally considered deleterious to plant growth. All of the materials we used had C:N ratios within the desirable range.

Table 6. Soil chemistry of selected treatments initially and after the first and second harvest.

Treatments #	Sedi.	Bio.	Period	TEC	pH water	OM %	Soluble Sulfur	Salts* EC	C %	N %	C/N Ratio	P mg kg^{-1}
1	100	0	Initial	34.9	7.6	4.5	167	0.6				144
1	100	0	First	36.5	7.6	4.1	179	0.6				165
1	100	0	Second	35.7	7.5	4.2	85	0.4	4.4	0.3	15.6	156
11	80	20	Initial	40.1	7.5	7.9	761	1.9				474
11	80	20	First	45.7	7.3	7.3	681	2				532
11	80	20	Second	43.7	7.3	7.3	475	1.4	7.7	0.7	11.9	684
6	70	30	Initial	35.9	7.4	8.4	809	2.2				565
6	70	30	First	49.1	7.1	9.2	809	2.4				767
6	70	30	Second	47.3	7.1	9.0	744	1.9	7.4	0.6	11.5	838
7	50	50	Initial	39.2	7.1	13.6	1237	2.8				926
7	50	50	First	61.0	6.7	13.9	1484	3.7				1290
7	50	50	Second	54.4	6.8	13.2	1057	2.1	10.2	1.0	10.6	1151
8	30	70	Initial	53.2	7.0	18.3	2390	3.6				1557
8	30	70	First	63.1	6.3	18.9	1945	4.7				1631
8	30	70	Second	50.8	6.6	18.1	1230	2.0	12.8	1.3	10.2	1298
10	0	100	Initial	40.1	6.3	30.0	2826	6.3				2247
10	0	100	First	64.6	6.0	29.3	2096	5.0				2010
10	0	100	Second	53.2	6.1	28.4	1297	2.1	19.1	1.9	10.2	1612
16	Control		Initial	22.1	6.9	5.3	646	0.9				318
16	Control		First	24.6	6.7	7.1	521	0.8				302
16	Control		Second	17.1	7.3	6.9	74	0.3	5.0	0.2	21.8	214

#	Sedi.	Bio.	Period	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
				mg kg^{-1}									
1	100	0	Initial	5678	693	226	40	1.9	535	36	6.7	55	235
1	100	0	First	5853	742	232	106	1.7	442	40	8.2	58	244
1	100	0	Second	5725	712	206	145	1.8	449	36	13.5	58	304
11	80	20	Initial	6141	957	365	116	2.5	498	60	8.2	75	468
11	80	20	First	7198	1003	275	144	2.2	394	49	13.5	90	459
11	80	20	Second	7079	855	188	150	2.3	371	32	18.8	103	624
6	70	30	Initial	5379	898	381	122	2.5	466	52	9.4	80	472
6	70	30	First	7687	1099	317	163	2.5	365	49	16.6	112	575
6	70	30	Second	7509	1003	231	176	2.9	359	36	22.3	125	684
7	50	50	Initial	5738	1016	481	185	2.9	443	62	11.5	95	589
7	50	50	First	9348	1448	444	243	3.1	320	58	26.3	167	748
7	50	50	Second	8596	1171	306	214	3.4	320	39	30.4	165	772
8	30	70	Initial	7075	1482	713	294	4.1	364	88	18.8	160	760
8	30	70	First	8779	1761	599	298	3.9	270	63	37.0	212	798
8	30	70	Second	7378	1291	407	243	3.8	296	42	35.7	188	751
10	0	100	Initial	5083	1371	714	319	4.4	262	93	37.2	203	978
10	0	100	First	7549	2253	726	339	5.0	218	82	49.0	251	825
10	0	100	Second	6558	1541	447	254	4.7	242	47	46.1	228	777
16	Control		Initial	3196	688	93	27	1.2	358	72	2.3	3	394
16	Control		First	3390	831	108	112	1.1	331	51	3.3	4	469
16	Control		Second	2165	655	79	144	1.1	326	49	2.4	3	508

* millimhos cm^{-1}

Metal Content

Selected soil mixtures sampled before planting were analyzed for metal content. Metals reported here are equivalent to a total recoverable analysis, which is essentially, but not quite the true total metal content, and is the accepted US EPA method for this type of analyses. It also should not be confused with the extractable metal content, which may be more representative of the metals that are available to plants and is similar to a soil fertility evaluation.

Biosolids had higher concentrations of Cr, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Ba, Pb, and Hg, than the other materials tested (Table 7). In sediments, levels of Mn and Be are higher than the rest of treatments. Levels of Ti, V, and Co were significantly higher in mixture of sediment and horse manure (80%-20%), most likely increased by the addition of horse manure, especially for Ti and V. Levels of metals found in the soil mixtures do not exceeded ceiling concentration limits established in the Guide for land appliers on the requirements of the federal standards for the use or disposal of sewage sludge, 40 CFR Part 504 (EPA, 1994).

Table 7. Total recoverable metal contents of selected soil treatments.

Treatment	Sediment	Biosolid	Compost	Be	B	Ti	V	Cr	Mn	Co	Ni	Cu
	--------------------%	-------------------		--mg kg^{-1}	---							
1	100	0	0	1.2 a†	28 d	214 b	43.0 b	65 de	826 a	10.0 ab	50.3 ab	42 e
3	60	20	20	1.2 a	37 dc	256 ab	43.7 b	96 cd	773 ab	9.3 ab	49.3 bc	95 d
6	70	30	0	1.3 a	30 dc	226 b	43.7 b	105 c	800 ab	9.9 ab	51.7 ab	104 d
7	50	50	0	1.4 a	39 dc	201 b	43.7 b	173 b	756 abc	9.8 ab	54.7 ab	202 c
8	30	70	0	1.3 a	41 bc	206 b	41.3 bc	198 b	676 bc	9.3 ab	51.0 ab	236 b
9	50	0	50	1.1 a	36 dc	236 ab	42.7 b	48 ef	746 abc	8.1 bc	38.7 d	37 e
10	0	100	0	0.9 ab	51 ab	189 b	31.0 d	296 a	618 dc	8.5 ab	55.3 a	376 a
13	0	0	100	0.5 b	61 a	256 ab	29.0 b	20 f	520 de	5.5 d	15.0 e	19 ef
14	80	0	20‡	0.8 ab	36 dc	328 a	58.0 a	62 de	753 abc	10.3 a	44.3 c	36 e
16	control			0.5 b	7 e	240 ab	33.3 cd	19 f	470 e	6.4 cd	10.3 e	10 f

Sediment	Biosolid	Compost	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Pb	Hg
---------------------%	-------------------		--mg kg^{-1}	---								
100	0	0	270 d	13.0 a	< 3	0.8 f	1.0 bcd	3.5 cd	190 cd	0.6 a	66 de	0.24 cd
60	20	20	356 c	12.0 a	< 3	2.9 de	5.1 abc	3.6 c	207 c	0.6 ab	78 cd	0.35 c
70	30	0	386 c	13.0 a	< 3	3.2 d	5.6 ab	4.0 c	220 c	0.6 ab	85 c	0.38 c
50	50	0	587 b	12.3 a	2.1 b	7.5 c	4.4 abcd	5.0 b	273 b	0.5 ab	120 b	0.68 b
30	70	0	646 b	11.3 ab	3.1 b	9.9 b	4.5 abcd	5.3 ab	290 b	0.5 ab	126 b	0.74 b
50	0	50	206 d	9.5 b	< 3	0.9 ef	1.0 bcd	2.9 d	163 d	0.5 bc	50 f	0.15 cd
0	100	0	886 a	13.3 a	5.8 a	17.3 a	6.4 a	5.7 a	333 a	0.4 c	160 a	1.24 a
0	0	100	70 e	6.5 c	< 3	0.9 ef	0.1 d	0.4 e	116 e	0.2 d	26 g	0.06 d
80	0	20‡	212 d	12.3 a	< 3	1.0 ef	0.7 cd	3.5 cd	193 cd	0.6 a	59 ef	0.19 cd
control			33 e	5.6 c	< 3	0.4 f	0.2 d	0.2 e	111 e	0.2 d	13 g	0.02 d

† Values in a column with different letters are statistically different.

‡ Horse manure

Metals in Snapbean Tissue

Trends of heavy metal contents in snapbean tissue are similar to those observed in the soil mixtures; however this is not true for all elements analyzed. Levels of Ni, Cu, Zn, and As, originally high in the biosolid are also present in snapbean tissue in high levels (Table 8). Mn and Be, initially high in 100% sediment were not accumulated in the plant, instead, these elements are in highest concentration in treatments with 100% biosolids. Ti and V, high in soil mixtures with horse manure in the composition also shows higher concentrations in plants grown on biosolids. No differences among treatments were found in the concentrations of Cr, Ag, Pb, and Hg.

According to published concentrations of trace elements in mature leaf tissues generalized for various species of plants (Kabata-Pendias and Pendias, 1991), most metals analyzed in snapbean tissue are in the range considered normal. However, levels of Mn and Zn observed in plants grown on biosolids are considered excessive. Levels considered excessive for Mo were also observed in plants grown on 100% sediment, 100% compost, the mixture of both (50-50), and sediment mixed with horse manure (80-20). A ratio of Cu to Mo of 2:1 in forages is the minimum recommended for ruminants diet in order to avoid Cu deficiencies caused by high Mo levels (Molybdenosis) (McBride et al., 2000). However this ratio was not met for any of the snapbean tissues analyzed, including plants grown on the control standard greenhouse mix.

Table 8. Total recoverable metal content in snapbean tissue for selected treatments.

Treatments		B	Ti	V	Cr	Mn	Ni	Cu	Zn
		mg kg^{-1}							
1	(100-0-0)†	30 c§	16 ab	0.06 bcd	0.34	13 d	3.6 ab	5.1 cd	31 de
3	(60-20-20)	61 b	11 ab	0.06 cd	0.35	19 cd	1.5 b	5.8 bc	43 cd
6	(70-30-0)	39 c	13 ab	0.06 d	0.24	20 cd	2.0 b	5.5 bcd	52 bc
7	(50-50-0)	48 bc	13 ab	0.06 bcd	0.18	44 cd	3.6 ab	6.5 b	58 b
8	(30-70-0)	68 b	17 ab	0.08 ab	0.21	140 b	4.0 ab	6.2 bc	61 b
9	(50-0-50)	97 a	6 b	0.08 bc	0.18	22 cd	4.3 ab	4.4 de	29 def
10	(0-100-0)	117 a	20 a	0.11 a	0.28	433 a	8.0 a	8.6 a	101 a
13	(0-0-100)	106 a	4 b	0.08 abc	0.29	24 cd	0.8 b	2.7 f	17 f
14	(80-0-20‡)	39 c	4 b	0.11 a	0.15	13 d	1.5 b	2.8 f	20 ef
16	control	48 bc	10 ab	0.08 bcd	0.21	95 c	2.1 b	3.2 ef	22 ef
		As	Mo	Ag	Cd	Ba	Pb	Hg	
		mg kg^{-1}							
1	(100-0-0)	0.22 b	15 bc	0.10	0.23 b	11 bc	0.81	0.0036	
3	(60-20-20)	0.19 b	6 cd	0.12	0.19 bc	5 d	0.38	0.0025	
6	(70-30-0)	0.22 b	5 d	0.06	0.19 bc	3 d	0.29	0.0027	
7	(50-50-0)	0.19 b	5 d	0.09	0.14 c	3 d	0.26	0.0017	
8	(30-70-0)	0.23 b	6 cd	0.07	0.14 c	3 d	0.30	0.0022	
9	(50-0-50)	0.30 b	25 a	0.03	0.19 bc	17 a	0.81	0.0020	
10	(0-100-0)	0.71 a	9 cd	0.08	0.24 b	3 d	0.68	0.0033	
13	(0-0-100)	0.21 b	19 ab	0.05	0.05 d	13 b	0.40	0.0013	
14	(80-0-20‡)	0.12 b	13 bcd	0.06	0.35 a	10 bc	0.44	0.0014	
16	control	0.18 b	7 cd	0.06	0.05 d	8 c	0.34	0.0014	

† (%Sediment - % Biosolid - % Compost)
‡ Horse manure
§ Values in a column with different letters are statistically different.

Metals in Barley Tissues

Concentrations of metals found in barley tissue are, in general, lower than those found in snapbean (Table 8 and 9). Levels of B, Ti, Mn, Ni, Cu, Zn, and As are higher in plants grown on biosolids, Mo and Ag levels are higher in barley grown on compost. High concentration of Ba, V, and Hg were found in barley grown on the mixture of sediment and compost (50-50). No difference between the treatments were found for Cr and Pb. B was found at levels above 100 mg kg^{-1} DW in plants grown on 100% biosolids and 100% compost, which can be considered excessive or toxic (Kabata-Pendias and Pendias, 1991; Davis et al., 1978), however, all other elements are within levels considered normal. Plants grown on 100% compost and the mixture of compost-sediment (50-50) did not meet the minimum ratio Cu to Mo of 2 for ruminants, the rest of treatments show values above the minimum.

Table 9. Metal content in barley tissue for selected treatments.

Treatments		B	Ti	V	Cr	Mn	Ni	Cu	Zn
		mg kg^{-1}							
1	(100-0-0) †	18 b‡	8.4 de	0.11 ab	0.25	12 d	0.60 ab	5.4 def	43 b
3	(60-20-20)	37 b	8.9 de	0.11 ab	0.21	18 d	0.48 ab	6.9 dc	44 b
6	(70-30-0)	20 b	8.2 de	0.05 b	0.24	23 cd	0.51 ab	6.0 cde	46 b
7	(50-50-0)	31 b	10.7 cd	0.06 b	0.30	39 bc	0.73 ab	7.5 bc	64 a
8	(30-70-0)	89 a	13.0 bc	0.05 b	0.21	55 b	0.83 ab	8.9 ab	75 a
9	(50-0-50)	97 a	7.5 e	0.05 b	0.22	13 d	0.61 ab	4.6 ef	32 bc
10	(0-100-0)	108 a	18.7 a	0.11 ab	0.23	79 a	1.18 a	10.5 a	67 a
13	(0-0-100)	105 a	6.4 e	0.16 a	0.24	13 d	0.20 b	3.9 f	31 bc
14	(80-0-20*)	25 b	7.7 e	0.16 a	0.23	12 d	0.39 b	5.9 cde	45 b
16	control	27 b	13.7 b	0.06 b	0.26	89 a	0.42 ab	4.6 ef	21 c
		As	Mo	Ag	Cd	Ba	Pb	Hg	
		mg kg^{-1}							
1	(100-0-0)	0.20 b	1.8 de	0.08 ab	0.7 a	8.5 a	0.32	0.0021 c	
3	(60-20-20)	0.18 b	3.2 bc	0.08 ab	0.7 a	2.4 c	0.23	0.0023 c	
6	(70-30-0)	0.47 ab	3.6 abc	0.05 b	0.7 a	1.4 c	0.30	0.0024 bc	
7	(50-50-0)	0.27 ab	4.2 ab	0.10 ab	0.8 a	1.5 c	0.30	0.0029 ab	
8	(30-70-0)	0.27 ab	3.8 abc	0.06 ab	0.5 b	1.1 c	0.23	0.0032 ab	
9	(50-0-50)	0.20 b	3.2 abc	0.08 ab	0.4 b	9.2 a	0.49	0.0041 a	
10	(0-100-0)	0.64 a	3.8 ab	0.07 ab	0.1 c	0.8 c	0.26	0.0028 ab	
13	(0-0-100)	0.33 ab	4.7 a	0.13 a	0.1 c	8.7 a	0.55	0.0038 ab	
14	(80-0-20*)	0.14 b	2.7 cd	0.10 ab	0.8 a	8.4 a	0.34	0.0027 ab	
16	control	0.13 b	1.1 e	0.09 ab	0.2 c	5.8 b	0.27	0.0031 ab	

† (%Sediment - % Biosolid - % Compost)
* Horse manure
‡ Values in a column with different letters are statistically different.

Metals Uptake by Crops

The uptake of metals by plants from the soil mixtures is expressed as the ratio of metal concentration in plant tissue (dry weigh basis) to the elemental concentration in dry soil (Table 11). Higher ratios for Ti, V, Co, and As were observed in plants grown on 100% biosolids. Cr, Ag, Ba, and Hg ratios were higher in plants grown on 100% compost. In contrast, ratios for Ni, Cu, Zn, Cd, Pb and B were significantly higher for the control greenhouse mix. Uptake of Mn was higher for biosolids in snapbean, but for barley, levels were higher in the greenhouse mix. Marked uptake of B and Mo in both crops were observed, for B higher uptake was observed in the control, in contrast Mo uptake was higher in the mixture of sediment-compost (50-50) for snapbean, while higher uptake in the 100% compost treatment was observed for barley. However, overall Mo uptake was significantly higher in snapbean compared to barley.

The metal uptake in barley and snapbean for most elements was similar; however, this is not the case for Ni, Mo, and Cd (Table 10). The case of Mo is perhaps the most marked (Table 11). Levels of Mo observed in snapbean are considered excessive in terms of use of the plants for animal forage, but Mo concentrations in barley are within the normal range (Kabata-Pendias and Pendias, 1991). Bioavailability of Mo to corn, a grass, has been shown to be low in biosolids (O’Connor et al., 2001). In addition, the Cu : Mo ratio in barley, unlike snapbean, exceeded the minimum established of 2:1, which theoretically prevents Cu deficiencies (McBride et al., 2000).

Table 10. Differences in metal uptake comparing barley and snapbean.

Element	α	Element	α	Element	α
B	0.1650	Ni	< 0.0001	Ag	0.2005
Ti	0.4541	Cu	0.2149	Cd	0.0080
V	0.1106	Zn	0.4756	Ba	0.0693
Cr	0.9877	As	0.5556	Pb	0.4029
Mn	0.0616	Mo	< 0.0001	Hg	0.1284

Table 11. Ratio of metal content in plants relative to levels in the soil from selected treatments.

Treatments (Soil Mixtures)		B		Ti		V		Cr		Mn	
		S§	B¥	S	B	S	B	S	B	S	B
		mg kg^{-1}									
1	(100-0-0)†	1.06 e‡	0.66 d	0.07 ab	0.039 c	0.001 c	0.003 bc	0.005 bc	0.004 c	0.02 c	0.01 e
3	(60-20-20)	1.65 cde	0.99 cd	0.04 abc	0.035 cd	0.001 c	0.003 bc	0.004 bc	0.002 d	0.03 c	0.02 e
6	(70-30-0)	1.29 de	0.66 d	0.06 abc	0.036 cd	0.001 c	0.001 c	0.002 c	0.002 d	0.02 c	0.03 de
7	(50-50-0)	1.23 de	0.80 cd	0.06 abc	0.054 b	0.001 c	0.001 bc	0.001 c	0.002 de	0.06 c	0.05 d
8	(30-70-0)	1.65 cde	2.16 b	0.08 ab	0.063 b	0.002 bc	0.001 c	0.001 c	0.001 de	0.21 b	0.08 c
9	(50-0-50)	2.70 b	2.69 b	0.02 bc	0.032 cd	0.002 bc	0.001 bc	0.004 bc	0.005 c	0.03 c	0.02 e
10	(0-100-0)	2.29 bc	2.12 b	0.10 a	0.099 a	0.003 a	0.004 ab	0.001 c	0.001 b	0.70 a	0.13 b
13	(0-0-100)	1.74 cd	1.72 bc	0.02 bc	0.025 d	0.003 ab	0.005 a	0.015 a	0.012 b	0.05 c	0.02 e
14	(80-0-20*)	1.09 de	0.69 d	0.01 c	0.023 d	0.002 bc	0.003 bc	0.003 c	0.004 c	0.02 c	0.02 e
16	control	6.79 a	3.87 a	0.04 abc	0.056 b	0.002 bc	0.002 bc	0.011 ab	0.014 a	0.20 b	0.19 a

		Co		Ni		Cu		Zn		As	
		S	B	S	B	S	B	S	B	S	B
		mg kg^{-1}									
1	(100-0-0)†	0.01 c	LOD¶	0.07 b	0.012 b	0.12 b	0.13 c	0.11 cd	0.16 cd	0.02 b	0.02 bc
3	(60-20-20)	0.01 c	LOD	0.03 b	0.010 b	0.06 cd	0.07 d	0.12 cd	0.12 cd	0.02 b	0.02 bc
6	(70-30-0)	0.01 c	LOD	0.04 b	0.010 b	0.05 cde	0.06 d	0.14 cd	0.12 d	0.02 b	0.04 abc
7	(50-50-0)	0.02 c	LOD	0.07 b	0.013 b	0.03 de	0.04 d	0.10 cd	0.11 d	0.02 b	0.02 abc
8	(30-70-0)	0.03 c	LOD	0.08 b	0.016 ab	0.03 de	0.04 d	0.09 d	0.12 d	0.02 b	0.02 abc
9	(50-0-50)	0.01 c	LOD	0.11 ab	0.015 ab	0.12 b	0.13 c	0.14 c	0.15 cd	0.03 ab	0.02 abc
10	(0-100-0)	0.10 a	LOD	0.14 ab	0.022 ab	0.02 e	0.03 d	0.11 cd	0.08 d	0.05 a	0.05 ab
13	(0-0-100)	0.01 c	LOD	0.05 b	0.014 b	0.14 b	0.21 b	0.24 b	0.44 b	0.03 ab	0.05 a
14	(80-0-20*)	0.01 c	LOD	0.03 b	0.009 b	0.08 c	0.16 bc	0.09 cd	0.21 c	0.01 b	0.01 c
16	control	0.06 b	LOD	0.20 a	0.041 a	0.32 a	0.46 a	0.67 a	0.63 a	0.03 ab	0.02 abc

† (%Sediment - % Biosolid - % Compost) * Horse manure § Snapbean ¥ Barley ‡ Values in a column with different letters are statistically different
¶ limit of detection

Table 11. Ratio of metal content in plants relative to levels in the soil from selected treatments (continued).

Treatments (Soil Mixtures)		Mo		Ag		Cd		Ba		Pb		Hg	
		S§	B¥	S	B	S	B	S	B	S	B	S	B
		---mg kg^{-1}---											
1	(100-0-0)†	18.5 ab‡	2.3 c	0.10 c	0.08 c	0.07 d	0.20 bc	0.06 b	0.045 b	0.012 ab	0.005 b	0.018 a	0.011 cd
3	(60-20-20)	2.2 cd	1.1 d	0.00 c	0.02 c	0.05 de	0.19 bc	0.02 c	0.012 c	0.005 ab	0.003 b	0.006 cb	0.006 e
6	(70-30-0)	1.7 d	1.1 d	0.01 c	0.01 c	0.05 de	0.18 bcd	0.02 c	0.006 c	0.003 b	0.003 b	0.007 abc	0.006 de
7	(50-50-0)	0.7 d	0.6 de	0.02 c	0.02 c	0.03 e	0.16 bcd	0.01 c	0.005 c	0.002 b	0.002 b	0.002 cb	0.004 ef
8	(30-70-0)	0.6 d	0.4 de	0.02 c	0.01 c	0.03 e	0.09 de	0.01 c	0.004 c	0.002 b	0.002 b	0.003 cb	0.005 ef
9	(50-0-50)	28.1 a	3.6 b	0.00 c	0.08 c	0.06 d	0.13 cd	0.10 a	0.057 ab	0.016 ab	0.010 b	0.010 abc	0.020 b
10	(0-100-0)	0.5 d	0.2 e	0.01 c	0.01 c	0.04 de	0.02 e	0.01 c	0.002 c	0.004 ab	0.002 b	0.003 cb	0.002 ef
13	(0-0-100)	20.9 ab	5.2 a	0.53 a	1.27 a	0.13 b	0.20 bc	0.12 a	0.075 a	0.015 ab	0.021 a	0.013 ab	0.038 a
14	(80-0-20*)	13.1 bc	2.7 c	0.09 c	0.15 c	0.10 c	0.23 d	0.05 b	0.043 b	0.007 ab	0.006 b	0.007 abc	0.014 c
16	control	18.5 ab	2.7 c	0.30 b	0.46 b	0.24 a	0.81 a	0.07 b	0.052 b	0.026 a	0.021 a	0.000 c	0.000 f

† (%Sediment - % Biosolid - % Compost) * Horse manure, § Snapbean, ¥ Barley ‡ Values in a column with different letters are statistically different.

Molybdenum availability is affected mainly by soil pH as well as Al and Fe oxides (Havlin et al., 1999). Levels of MoO_4^{2-} (form absorbed by plants) can increase up to 10-fold in activity per unit increase in soil pH (Vlek and Lindsay, 1977). In contrast, high levels of SO_4^{2-} in the soil solution depress Mo uptake by plants (Havlin et al., 1999). The influence of soil pH and S content on plant uptake of Mo was well expressed in our samples (Fig. 7). Treatment 10, 100% biosolids, is high in S and has relatively low pH, which reduces Mo uptake; in contrast treatment 13, 100% compost, with low S and high pH (Appendix 2) shows the greatest Mo plant uptake. In general, compost addition increased Mo uptake. Treatment 16, the standard greenhouse control; does not follow the same trend. Analysis of variance confirms that 88% of the variability in Mo uptake in this experiment is due to changes in soil pH and soluble sulfur levels. In general terms, the level of Mo we found is not a matter of concern for barley, however levels found in snapbean can be considered unsafe for ruminants feeding. Mixing of sediment and biosolid certainly reduces metal uptake by crops; overall lower levels were found in mixtures of 70-30 (sediment-biosolid).

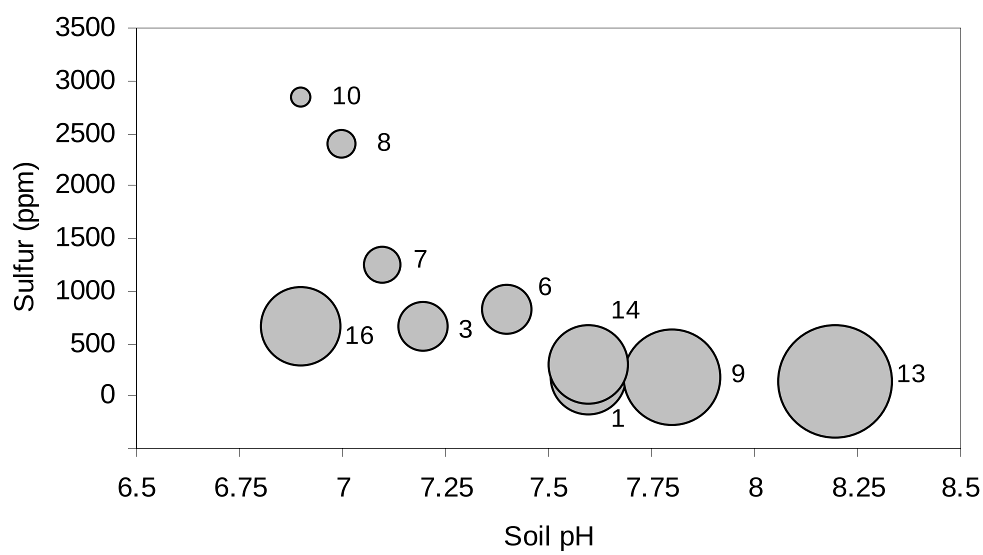

Figure 7. Mo uptake as a function of soil pH and sulfur content for barley.

Snapbean Yield

Snapbean yield was measure as the total dry biomass at 6-7 weeks after planting (Table 12). Lower yields were observed for the first harvest in general with a very poor growth and some mortality of the plants in the 100 % biosolids. This is attributed to the high levels of salt in the biosolids. Yields increased in the second harvest particularly in the treatments with high amounts of biosolids (Fig. 8). Treatment 10 (100% biosolids) went from the lowest yield in the first harvest to one of the highest in the second harvest. The 100 % sediment treatment (Trt.1) did not change significantly between harvests while the control (Trt. 16) exhibited a small decrease in snapbean yield. Large differences in yields between harvests are primarily due to salt contents; however, small differences can be attributed to slightly different environmental conditions in the greenhouse because the experimental runs were sequential, not simultaneous. Overall, the second snapbean crop out-yielded the first (Table 12).

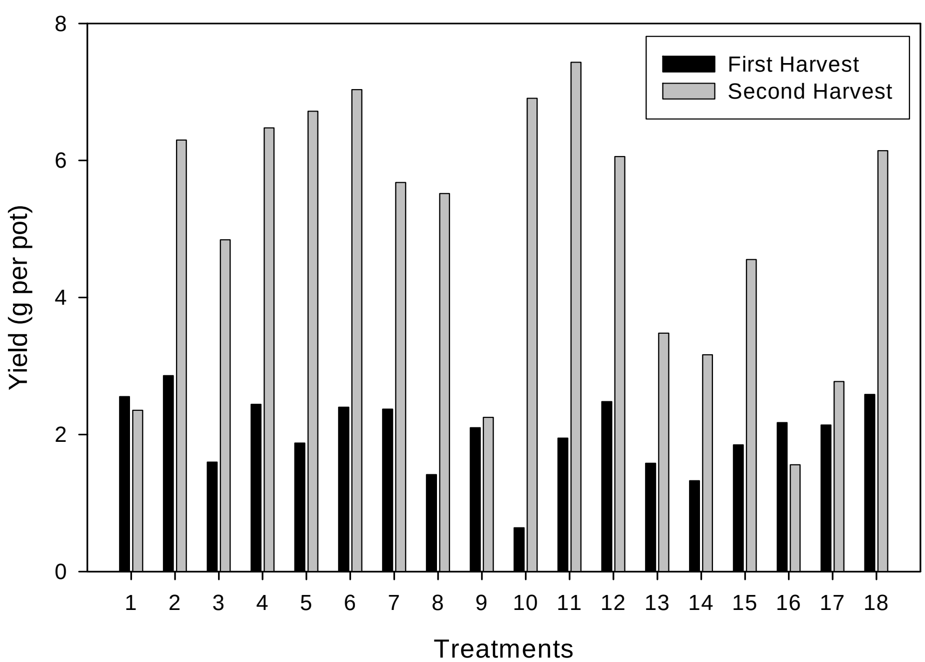

Figure 8. Snapbean yield for all treatments, first and second harvests.

Table 12. Yield of plants (g per pot) grown in sediment mixtures, first and second harvest.

Treatment	Barley			Snapbeans		
	First	Second	Both	First	Second	Both
1	1.95 def †	2.49 gh	2.22 ef	2.55 abc	2.35 gh	2.46 def
2	2.17 cde	5.01 de	3.59 cd	2.86 a	6.30 abc	4.58 a
3	2.29 cd	5.00 de	3.65 cd	1.60 bcdef	4.84 cde	3.22 bcde
4	1.95 def	7.29 ab	4.62 abc	2.44 abc	6.48 ab	4.46 ab
5	1.67 efg	7.87 a	4.77 ab	1.88 abcde	6.72 ab	4.30 ab
6	2.88 b	6.60 bc	4.74 ab	2.40 abcd	7.03 ab	4.72 a
7	3.43 a	7.56 ab	5.50 a	2.37 abcd	5.68 bcd	4.03 ab
8	2.90 b	6.59 bc	4.75 ab	1.41 def	5.52 bcd	3.47 abcd
9	1.66 efg	2.35 gh	2.01 ef	2.10 abcde	2.25 gh	2.18 ef
10	1.97 def	7.24 ab	4.60 abc	0.64 f	6.91 ab	3.77 abc
11	2.55 bc	7.02 abc	4.78 ab	1.95 abcde	7.43 a	4.69 a
12	2.67 bc	6.52 bc	4.60 abc	2.48 abc	6.06 abcd	4.27 ab
13	1.21 g	3.42 fg	2.31 ef	1.58 cdef	3.48 efg	2.53 cdef
14	1.25 g	3.51 fg	2.38 ef	1.32 ef	3.16 fg	2.24 def
15	1.63 fg	4.28 ef	2.96 de	1.85 bcde	4.56 def	3.20 bcde
16	1.97 def	1.33 h	1.65 f	2.18 abcde	1.56 h	1.87 f
17	1.99 def	1.72 h	1.85 f	2.14 abcde	2.77 gh	2.46 def
18	2.69 bc	6.05 cd	4.37 bc	2.59 ab	6.15 abc	4.37 ab
Mean *	2.16	5.10	-	2.02	4.99	-

† L.S. Means of 5 reps per treatment, values in a column followed by the same letters are not statistically different.
* Overall L.S. Means, first and second harvests are statistically different for both plants.

Yield increase between harvests was also observed in compost treatments, in particular treatment 13 (100% compost). Adding large amounts of fresh organic matter such as horse manure, biosolids, or compost, in some situations, may pose problems for plant growth. In our experiment, in addition to the beneficial effects of salt leaching, decomposition of the organic rich materials during the first growing cycle apparently lead to higher plant growth during the second growth period. This was observed in the mixtures with large amounts of compost, manure and biosolids, but not in the sediment or control treatments.

Considering the treatments with sediments and biosolids only, the treatment with the highest average combined snapbean yield was composed of 70% sediment and 30% biosolids (Table 13).

Table 13. Least square means of snapbean yields, combined harvests, selected treatments.

Treatment	Sediment	Biosolid	LS Means (g / pot)	t Grouping	
	------------- % -------------				
6	70	30	4.7	a	
11	80	20	4.7	a	
7	50	50	4.0	a	b
10	0	100	3.8	a	b
8	30	70	3.5	a	b
1	100	0	2.5	c	b
16	Control		1.9	c	

Barley Yield

Barley yield trends were similar to snapbeans, with an increase in the second harvest especially for the treatments with biosolids in the composition; there was also a yield increase for the treatments with compost and horse manure in the mix (Table 12; Fig. 9). As with snapbeans, addition of perlite in the composition (treatments 17 and 18) did not increase crop yields.

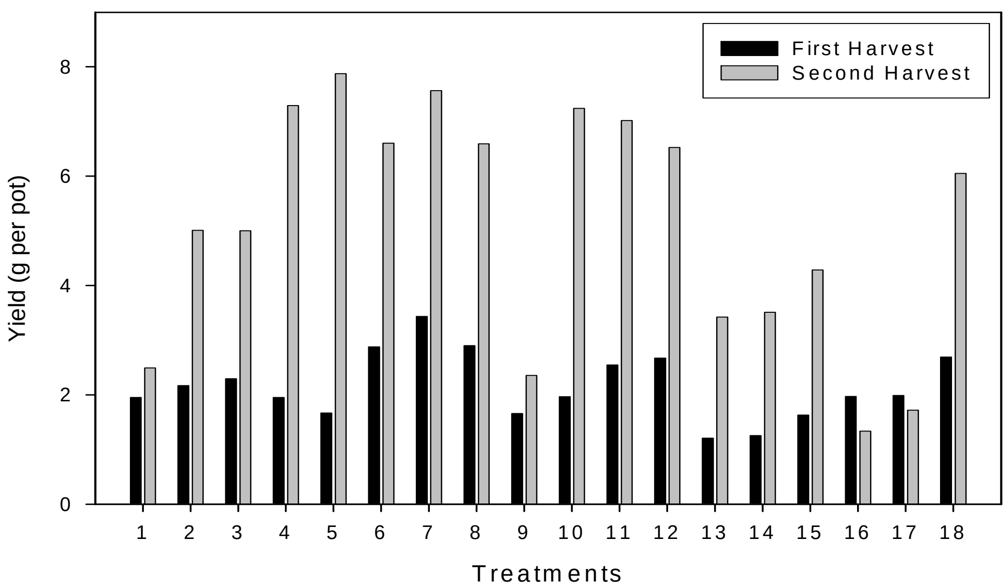

Figure 9. Barley yield for all treatments, both harvests.

We attribute most of the yield increase in the second harvest to the leaching and weathering of the mixes, particularly those with biosolids. Barley is also more affected by the level of Nitrogen than snapbean, so as we mention before the C:N ratio in biosolid could contribute to a good amount of N to be release as the organic matter is decomposed in the second run. The relative increase in barley yields were not as marked as with snapbean because of the greater salt tolerance of barley. Treatment 7 (50%- 50% sediment-biosolid) produced the highest yield when both growing cycles were included (Table 14). Similar to snapbeans, standard greenhouse mix (control) produced the lowest yield, most likely because fertilizer was not applied; which is the usual practice with this soil mixture.

Table 14. Least square means of barley yields, combined harvests, selected treatments.

Treatment	Sediment	Biosolid	LS Means	t Grouping
	------------ %	------------	(g / pot)	
7	50	50	5.4	a
11	80	20	4.8	b
8	30	70	4.7	b
6	70	30	4.7	b
10	0	100	4.6	b
1	100	0	2.2	c
16	Control		1.6	c

SPAD chlorophyll readings were correlated with barley total biomass production. Treatment 7 (50%-50% sediment-biosolid) had both the highest SPAD value and overall yield; the control (standard greenhouse mix) had low yield as well as low SPAD values, indicating lack of nutrient, particularly N deficiency (Fig. 10). Because snapbeans are a legume that fixes its own N, SPAD readings were not taken.

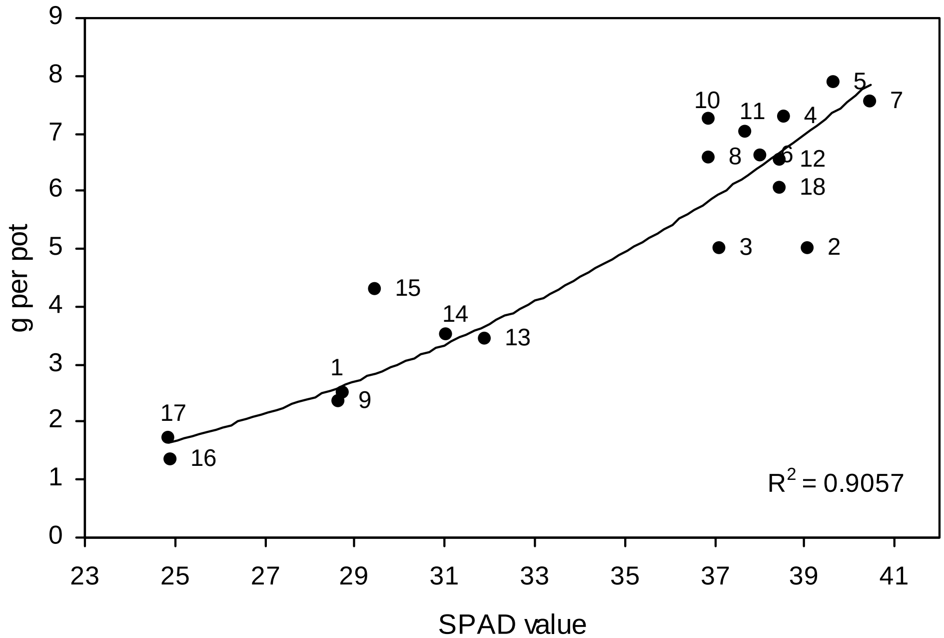

Figure 10. Barley yield and SPAD values for all the treatments (second harvest).

CONCLUSIONS

In terms of standard agronomic parameters such as plant growth, our results confirm previous work that established that sediments from the Peoria Lakes reach of the Illinois River make excellent topsoil material. Both legume and grass plants grew well in all sediment mixtures and improved the plant growth potential of unleached biosolids. The quantity of biosolids available to mix with sediments is essentially limitless. Chicago alone produces 190,000 dry tons of biosolids per year (Tom Granato, 2004, personal communication). Although sediment tested was well suited as topsoil substitute alone it may be worth the cost of mixing biosolids with sediments. This could be accomplished in the field with tillage equipment or with soil blending devices. In addition to providing an outlet for some portion of the biosolids produced, combining biosolids with sediment mitigates some of the problem with growing plants directly in sediments or biosolids. Pure sediments may initially have poor physical characteristics, at least initially under some field conditions. Pure biosolids have excessive salts that inhibit plant growth, particularly legumes, as evidenced by death of some snapbean plants on 100% biosolids. The sediments may experience improved tilth and higher plant nutrient content under field conditions when mixed with biosolids. The biosolids release less of their load of potentially toxic heavy metals and the injurious salt content is diluted by sediment addition. Mo uptake from sediments is decreased by biosolid addition.

Elevated Mo in some plants grown on pure sediments is not a real problem in most situations where sediments may be utilized as topsoil. The unlikely situation when it may be a problem would be where legumes are grown on pure, unamended sediment as a forage to be fed exclusively to ruminants. Under these conditions, addition of gypsum to the sediment may have a favorable effect on Mo uptake and supplemental dietary Cu should mitigate any potential for Mo toxicity. Under the more likely scenario where sediment is for topsoil in parks, lawns, or other areas where the use is more recreational and less agricultural, it is doubtful if Mo would be important. Direct ingestion by humans of large quantities of legumes grown on pure sediments to the exclusion of other food is difficult to imagine, and Mo toxicity is more of an issue with ruminants than with humans. It is interesting to note that our treatments with compost showed significant increase in plant Mo uptake, yet compost is typically marketed to homeowners as a soil supplement for gardens etc. with no concern for Mo toxicity.

An optimum sediment to biosolid mix in the field we feel would be about 80:20 to 70:30 sediments:biosolid on a volume basis. This mixing ratio was also shown to reduce uptake of metals by crops, perhaps due to dilution as well as to modifications of soil properties, such as pH. In addition, the microbial population, which remains uninvestigated, may differ between the mixtures and may contribute to variable metal uptake.

We recommend that sediments be dried before use as topsoil. They can be applied directly to places where they are needed if only a thin layer is added, perhaps 12 inches or less; drying can then take place on-site. Much thicker layers would not dry quickly at depth and may require special handling to avoid near-term problems with differential settling, tilth, and trafficability. A preferred technique would be to spread a thin layer, let it dry, and then push it into piles for later use. Thin layers would dry quickly under favorable climatic conditions. Growing plants on the stockpiles would enhance the development of favorable soil structure and encourage soil microorganisms that would promote better plant growth.

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APPENDICES

Appendix 1. Weight equivalents of volumetric mixtures.

Treatment	Sediment	Biosolid	Compost	Other
1	100	0	0	-
2	84	8	8	-
3	67	16	16	-
4	48	26	26	-
5	26	37	37	-
6	76	24	0	-
7	58	42	0	-
8	37	63	0	-
9	58	0	42	-
10	0	100	0	-
11	85	15	0	-
12	76	16	8	-
13	0	0	100	-
				Horse manure
14	92	0	0	8
15	83	0	9	8
				Perlite
17	85	0	10	5
18	78	7	14	1

Note: Missing treatment 16 is the standard greenhouse mix used as a control.

Appendix 2. Soil fertility of mixtures before planting.

Treatment	TEC	pH	Organic Matter %	Salts* Mmho cm^{-1}	ENR	Soluble Sulfur	P	Ca	Mg	K	Na
							---------------------------- mg kg^{-1} --------------------------				
1	34.92	7.6	4.51	0.62	95	167	144	5678	693	226	40
2	36.77	7.4	6.44	1.33	107	354	354	5577	884	495	58
3	44.58	7.2	10.04	2.11	125	654	527	6704	1076	650	98
4	44.60	7.1	14.24	3.25	127	1030	868	6333	1230	790	151
5	49.69	6.8	17.22	4.29	129	1296	1182	7175	1307	853	170
6	35.89	7.4	8.42	2.18	117	809	565	5379	898	381	122
7	39.19	7.1	13.56	2.75	127	1237	926	5738	1016	481	185
8	53.17	7.0	18.34	3.61	129	2390	1557	7075	1482	713	294
9	36.42	7.8	9.79	0.9	124	158	289	5337	936	692	36
10	40.06	6.9	30.02	6.26	> 130	2826	2247	5083	1371	714	319
11	40.12	7.5	7.93	1.88	115	761	474	6141	957	365	116
12	39.76	7.4	8.77	1.8	119	747	442	5997	975	449	114
13	40.47	8.2	17.17	0.86	129	122	352	5440	1135	1416	41
14	35.81	7.6	6.31	1.48	107	295	224	5516	689	827	85
15	36.79	7.6	7.50	1.42	112	247	291	5450	756	1124	83
16	22.07	6.9	5.32	0.87	102	646	318	3196	688	93	27
17	31.51	7.8	5.91	0.62	105	162	188	5002	661	316	42
18	36.33	7.4	8.60	1.6	118	507	404	5429	902	504	87

	Ca	Mg	K	Na	H	B	Fe	Mn	Cu	Zn	Al
	---------------------------------- % --					------------------------------------ mg kg^{-1} --------------------------------					
1	81.30	16.54	1.66	0.50	0.00	1.88	535	36	6.71	55.36	235
2	75.84	20.03	3.45	0.69	0.00	2.84	494	47	7.72	65.09	263
3	75.19	20.11	3.74	0.96	0.00	3.62	477	54	9.08	73.30	381
4	71.00	22.98	4.54	1.47	0.00	4.76	445	63	11.89	83.86	505
5	72.20	21.92	4.40	1.49	0.00	5.20	392	60	15.39	98.99	608
6	74.94	20.85	2.72	1.48	0.00	2.51	466	52	9.37	79.57	472
7	73.21	21.60	3.15	2.05	0.00	2.94	443	62	11.52	95.23	589
8	66.53	23.23	3.44	2.40	0.00	4.10	364	88	18.84	159.83	760
9	73.27	21.42	4.87	0.43	0.00	4.95	512	46	5.49	38.33	137
10	63.44	28.52	4.57	3.46	0.00	4.41	262	93	37.21	202.70	978
11	76.53	19.88	2.33	1.26	0.00	2.53	498	60	8.23	74.61	468
12	75.41	20.44	2.90	1.25	0.00	2.99	489	55	7.88	67.25	411
13	67.21	23.37	8.97	0.44	0.00	8.01	344	65	3.11	15.17	70
14	77.02	16.03	5.92	1.03	0.00	2.14	534	39	5.39	45.26	130
15	74.07	17.12	7.83	0.98	0.00	2.61	531	44	5.62	48.19	122
16	72.41	25.98	1.08	0.53	0.00	1.17	358	72	2.34	2.66	394
17	79.37	17.48	2.57	0.58	0.00	2.47	539	39	5.42	41.62	196
18	74.72	20.69	3.56	1.04	0.00	3.51	494	52	6.88	54.45	311

Appendix 3. Soil fertility after first harvest.

Treatment		TEC	pH	Organic Matter %	ENR	Soluble Sulfur	Salts Mmho cm^{-1}	P	Ca	Mg	K	Na
								mg kg				
Barley	1	37	7.5	4.1	91	197	0.49	154	5888	743	205	92
Barley	2	44	7.4	7.2	111	461	1.30	377	6730	1075	407	119
Barley	3	49	7.3	10.8	125	638	1.55	593	7404	1216	505	158
Barley	4	51	7.0	13.8	127	1055	2.77	879	7313	1392	682	209
Barley	5	61	6.8	17.2	129	1045	2.92	1382	9185	1395	805	206
Barley	6	51	7.1	9.3	122	954	2.61	640	7836	1195	310	174
Barley	7	62	6.8	14.2	127	1482	3.58	1089	9296	1536	425	273
Barley	8	60	6.4	19.5	130	1856	4.38	1523	8455	1771	558	316
Barley	9	41	7.7	10.6	125	184	0.95	350	6031	1093	633	97
Barley	10	68	6.0	29.1	> 130	2606	5.51	1976	8077	2405	719	379
Barley	11	53	7.3	7.3	112	940	2.36	461	8286	1169	265	159
Barley	12	55	7.2	8.5	118	816	2.09	470	8533	1245	349	185
Barley	13	38	8.1	17.9	129	110	0.78	312	4867	1158	1218	99
Barley	14	39	7.7	6.2	106	262	0.94	236	5954	770	823	150
Barley	15	35	7.8	7.2	111	208	0.99	276	5149	741	1011	135
Barley	16	23	6.6	7.6	113	512	0.83	285	3153	791	93	91
Barley	17	32	7.9	5.8	104	160	0.50	189	4897	712	232	115
Barley	18	44	7.3	9.5	122	634	1.50	463	6720	1048	340	153
Snapbean	1	36	7.7	4.0	90	162	0.64	175	5818	741	259	119
Snapbean	2	44	7.4	7.0	110	314	0.98	677	6933	971	445	118
Snapbean	3	53	7.1	9.7	123	529	1.96	1022	8327	1084	542	141
Snapbean	4	60	6.8	14.1	127	983	3.23	1276	9313	1275	688	201
Snapbean	5	52	6.7	17.8	129	951	3.35	1363	7802	1273	755	199
Snapbean	6	48	7.0	9.2	121	665	2.18	893	7538	1002	323	152
Snapbean	7	60	6.6	13.5	127	1487	3.72	1490	9400	1359	462	213
Snapbean	8	66	6.2	18.4	129	2034	4.93	1739	9103	1751	640	280
Snapbean	9	39	7.7	10.5	125	159	0.79	335	5695	1038	661	109
Snapbean	10	61	5.9	29.5	> 130	1587	4.49	2044	7021	2101	733	299
Snapbean	11	39	7.3	7.3	112	423	1.70	602	6109	837	284	128
Snapbean	12	57	7.1	7.5	113	667	1.96	932	9328	1079	373	176
Snapbean	13	43	8.0	16.9	128	126	0.88	394	5700	1308	1304	114
Snapbean	14	40	7.6	5.9	104	285	1.10	239	6242	780	773	175
Snapbean	15	43	7.6	7.0	110	268	1.18	371	6335	908	1179	155
Snapbean	16	26	6.7	6.5	107	531	0.85	319	3626	871	123	133
Snapbean	17	36	7.8	5.4	102	192	0.66	225	5682	756	301	139
Snapbean	18	58	7.2	9.2	121	660	1.59	1062	9377	1092	451	173

Appendix 3. Soil fertility after first harvest (continued).

Treatment		Ca	Mg	K	Na	H	B	Fe	Mn	Cu	Zn	Al
		------------------------------------- pct				--------------------------------------	------------------------------------ mg kg					--------------------------------------
Barley	1	80.5	16.9	1.4	1.1	0.0	1.6	458	42	8	58	233
Barley	2	76.2	20.3	2.4	1.2	0.0	2.7	421	52	11	80	401
Barley	3	75.3	20.6	2.6	1.4	0.0	3.6	390	53	14	93	432
Barley	4	72.0	22.8	3.4	1.8	0.0	4.5	362	58	16	105	518
Barley	5	75.9	19.2	3.4	1.5	0.0	5.1	313	56	24	145	674
Barley	6	77.3	19.7	1.6	1.5	0.0	2.6	398	56	14	103	537
Barley	7	75.5	20.8	1.8	1.9	0.0	3.2	362	69	21	142	683
Barley	8	70.1	24.5	2.4	2.3	0.8	3.8	305	70	31	185	777
Barley	9	73.0	22.1	3.9	1.0	0.0	5.1	438	48	8	45	216
Barley	10	59.4	29.5	2.7	2.4	6.0	5.1	198	93	59	270	805
Barley	11	78.9	18.5	1.3	1.3	0.0	2.4	399	59	12	90	491
Barley	12	77.9	19.0	1.6	1.5	0.0	3.1	391	58	12	86	469
Barley	13	64.8	25.7	8.3	1.2	0.0	7.2	223	59	3	14	61
Barley	14	76.4	16.5	5.4	1.7	0.0	2.0	437	39	7	50	160
Barley	15	73.4	17.6	7.4	1.7	0.0	2.2	432	37	8	53	119
Barley	16	68.6	28.7	1.0	1.7	0.0	1.2	306	48	3	3	455
Barley	17	77.7	18.8	1.9	1.6	0.0	2.3	452	40	7	45	171
Barley	18	76.6	19.9	2.0	1.5	0.0	3.2	401	50	11	71	383
Snapbean	1	79.8	16.9	1.8	1.4	0.0	1.8	425	37	8	59	255
Snapbean	2	78.1	18.2	2.6	1.2	0.0	2.6	352	42	16	103	533
Snapbean	3	79.1	17.2	2.6	1.2	0.0	3.4	321	44	20	123	610
Snapbean	4	77.8	17.8	3.0	1.5	0.0	4.2	298	43	23	140	680
Snapbean	5	74.4	20.2	3.7	1.7	0.0	4.4	291	42	21	130	656
Snapbean	6	79.3	17.6	1.7	1.4	0.0	2.4	331	41	19	120	613
Snapbean	7	77.8	18.7	2.0	1.5	0.0	3.1	277	47	32	192	812
Snapbean	8	69.1	22.2	2.5	1.9	4.4	4.0	234	56	43	239	818
Snapbean	9	72.5	22.0	4.3	1.2	0.0	4.5	429	40	8	47	225
Snapbean	10	57.4	28.7	3.1	2.1	8.7	4.8	238	71	39	232	844
Snapbean	11	78.7	18.0	1.9	1.4	0.0	2.0	389	39	15	89	426
Snapbean	12	81.3	15.7	1.7	1.3	0.0	2.9	349	49	20	122	668
Snapbean	13	65.9	25.2	7.7	1.2	0.0	7.8	262	66	4	19	65
Snapbean	14	77.2	16.1	4.9	1.9	0.0	2.0	451	40	8	55	251
Snapbean	15	73.8	17.6	7.0	1.6	0.0	2.6	434	45	8	62	243
Snapbean	16	69.0	27.6	1.2	2.2	0.0	1.1	355	53	4	5	483
Snapbean	17	78.7	17.5	2.1	1.7	0.0	2.4	460	44	8	50	278
Snapbean	18	81.0	15.7	2.0	1.3	0.0	3.4	346	49	22	129	692

Appendix 4. Soil fertility after second harvest.

Treatment		TEC	pH	Organic Matter (%)	ENR	Soluble Sulfur	Salts Mmho cm^{-1}	P	Ca	Mg	K	Na
								mg kg^{-1}				
Barley	1	37	7.9	4.1	91	105	0.4	176	5975	725	162	162
Barley	2	37	7.4	6.9	109	514	1.4	663	5660	869	247	174
Barley	3	40	7.4	9.5	122	473	1.2	729	5961	1016	345	194
Barley	4	37	7.1	14.0	127	508	1.9	906	5516	919	342	198
Barley	5	50	6.9	17.2	129	1155	2.7	1444	7523	1214	423	236
Barley	6	50	7.1	9.0	120	1159	2.6	909	7838	1147	196	202
Barley	7	60	6.8	14.0	127	1640	2.9	1302	9349	1380	245	261
Barley	8	50	6.6	18.8	129	1505	2.5	1354	7196	1430	294	275
Barley	9	38	7.9	10.1	125	88	0.5	300	5617	1014	539	129
Barley	10	50	6.1	28.9	> 130	1410	2.3	1781	6219	1573	352	260
Barley	11	44	7.3	7.0	110	735	1.9	693	7032	943	165	149
Barley	12	50	7.2	8.5	117	1052	2.1	746	7923	1061	202	210
Barley	13	48	8.0	18.2	129	111	0.7	466	6377	1520	962	153
Barley	14	39	7.9	5.7	104	134	0.6	244	6056	764	671	188
Barley	15	35	8.0	7.0	110	132	0.6	249	5115	767	957	199
Barley	16	18	7.4	7.2	111	53	0.2	243	2264	693	73	153
Barley	17	29	8.0	5.6	103	75	0.4	154	4538	671	191	155
Barley	18	33	7.5	9.2	121	639	1.4	309	4725	910	168	225
Snapbean	1	34	7.8	4.3	93	66	0.4	136	5474	698	249	128
Snapbean	2	39	7.5	6.6	108	139	0.6	540	6170	817	301	133
Snapbean	3	49	7.3	9.6	123	240	0.9	729	7877	954	450	160
Snapbean	4	45	7.0	13.3	127	386	1.2	955	7101	951	469	148
Snapbean	5	49	6.9	17.1	129	389	1.2	1120	7686	967	516	163
Snapbean	6	44	7.1	9.0	120	329	1.1	766	7179	858	265	150
Snapbean	7	49	6.7	12.4	126	474	1.4	999	7842	961	366	167
Snapbean	8	51	6.5	17.5	129	956	1.6	1242	7560	1151	519	211
Snapbean	9	40	7.8	9.5	122	79	0.6	239	5787	1043	654	135
Snapbean	10	56	6.1	28.0	> 130	1185	1.8	1442	6896	1509	541	248
Snapbean	11	43	7.3	7.6	113	216	1.0	674	7126	767	210	150
Snapbean	12	43	7.3	8.7	118	147	0.7	656	7040	774	262	143
Snapbean	13	35	8.1	14.3	127	101	0.6	418	4573	1074	843	160
Snapbean	14	35	7.8	5.4	102	63	0.5	191	5407	679	699	133
Snapbean	15	34	7.8	7.0	110	100	0.7	241	4901	709	951	160
Snapbean	16	16	7.2	6.6	108	96	0.4	184	2066	617	84	135
Snapbean	17	32	7.8	4.7	97	65	0.4	156	4931	739	253	168
Snapbean	18	41	7.3	7.7	113	129	0.7	626	6675	808	273	145

Appendix 4. Soil fertility after second harvest (continued).

Treatment		Ca	Mg	K	Na	H	B	Fe	Mn	Cu	Zn	Al	Carbon (%)	Nitrogen (%)	C/N Ratio
		pct					mg kg^{-1}								
Barley	1	81	16	1	2	0	2.0	447	35	9	59	321	4.1	0.3	16
Barley	2	77	20	2	2	0	2.7	387	32	15	89	525	5.6	0.4	13
Barley	3	75	21	2	2	0	3.6	386	38	15	91	520	7.2	0.6	12
Barley	4	75	21	2	2	0	3.6	381	30	16	92	553	10.6	1.0	11
Barley	5	75	20	2	2	0	5.4	299	30	23	136	725	14.7	1.4	10
Barley	6	78	19	1	2	0	3.3	366	36	22	123	673	7.6	0.7	11
Barley	7	78	19	1	2	0	3.9	325	41	30	166	786	9.0	0.9	10
Barley	8	72	24	2	2	1	3.9	316	42	30	162	740	15.2	1.6	9
Barley	9	73	22	4	1	0	4.7	452	40	7	42	203	8.6	0.6	15
Barley	10	62	26	2	2	8	4.6	249	49	39	201	815	18.7	1.8	10
Barley	11	80	18	1	1	0	2.4	378	31	17	97	573	8.8	0.8	11
Barley	12	79	18	1	2	0	3.1	367	36	17	101	586	6.8	0.6	11
Barley	13	67	27	5	1	0	7.9	312	74	5	23	76	16.2	1.2	14
Barley	14	77	16	4	2	0	2.4	436	36	8	53	270	6.4	0.4	15
Barley	15	72	18	7	2	0	2.8	445	37	7	55	236	6.1	0.4	14
Barley	16	63	32	1	4	0	1.2	344	55	3	4	549	4.9	0.2	22
Barley	17	77	19	2	2	0	2.2	467	39	8	46	183	4.5	0.3	15
Barley	18	72	23	1	3	0	3.2	426	33	12	62	263	6.5	0.5	13
Snapbean	1	80	17	2	2	0	1.6	451	37	18	58	286	4.7	0.3	15
Snapbean	2	79	17	2	1	0	2.6	389	37	16	93	597	5.8	0.4	14
Snapbean	3	80	16	2	1	0	3.3	344	36	19	116	616	8.9	0.7	13
Snapbean	4	78	18	3	1	0	3.8	339	36	22	127	697	10.8	0.9	12
Snapbean	5	79	17	3	1	0	4.3	311	32	25	144	711	13.6	1.1	12
Snapbean	6	81	16	2	1	0	2.6	352	35	23	128	694	7.2	0.6	12
Snapbean	7	80	16	2	1	0	3.0	314	37	31	165	757	11.3	1.0	11
Snapbean	8	74	19	3	2	3	3.7	276	41	41	214	762	10.4	0.9	11
Snapbean	9	73	22	4	1	0	4.3	436	41	7	45	233	8.5	0.6	14
Snapbean	10	61	22	2	2	12	4.9	235	45	53	254	738	19.6	2.0	10
Snapbean	11	82	15	1	2	0	2.2	363	33	20	110	674	6.7	0.5	13
Snapbean	12	82	15	2	1	0	2.6	371	34	18	100	643	7.0	0.5	13
Snapbean	13	66	26	6	2	0	6.4	388	44	9	46	118	12.6	1.0	13
Snapbean	14	77	16	5	2	0	1.8	453	35	6	52	281	4.8	0.3	14
Snapbean	15	73	18	7	2	0	2.3	442	34	7	54	228	6.1	0.4	14
Snapbean	16	63	32	1	4	0	1.1	308	43	2	2	467	5.2	0.2	22
Snapbean	17	77	19	2	2	0	2.3	447	38	7	48	212	4.9	0.3	16
Snapbean	18	81	16	2	2	0	2.9	370	33	16	91	598	6.8	0.5	14

Appendix 5. Barley and Snapbean yields (grams per pot).

Treatment	Replication	Barley		Snapbean	
		Harvest 1	Harvest 2	Harvest 1	Harvest 2
1	1	1.72	2.65	1.26	2.70
1	2	1.71	2.49	2.09	4.35
1	3	1.95	2.26	5.80	1.36
1	4	1.60	2.38	1.71	*
1	5	2.78	2.68	1.90	1.76
2	1	1.84	4.93	1.20	5.56
2	2	2.43	4.26	2.42	7.05
2	3	1.87	4.82	2.87	5.51
2	4	2.02	5.34	4.64	4.94
2	5	2.68	5.68	3.16	8.43
3	1	1.94	3.71	1.36	6.00
3	2	1.98	5.17	1.91	4.73
3	3	2.79	4.76	3.21	6.96
3	4	2.68	5.62	1.50	1.98
3	5	2.08	5.73	*	4.54
4	1	1.86	8.70	3.13	5.23
4	2	1.89	6.14	2.47	5.48
4	3	1.88	6.87	3.26	6.11
4	4	2.18	7.97	1.73	6.76
4	5	1.94	6.76	1.61	8.80
5	1	1.61	7.53	2.52	6.46
5	2	1.98	6.34	2.50	5.96
5	3	1.42	8.77	1.03	7.67
5	4	1.78	8.63	2.31	6.12
5	5	1.54	8.09	1.02	7.39
6	1	3.58	5.76	2.47	7.94
6	2	2.62	6.57	1.06	7.63
6	3	2.93	6.42	3.96	4.98
6	4	2.48	7.59	2.89	7.08
6	5	2.78	6.66	1.62	7.54
7	1	3.27	7.77	2.05	4.83
7	2	4.40	8.72	0.74	7.37
7	3	2.51	6.48	3.47	4.06
7	4	3.67	7.24	1.93	7.27
7	5	3.32	7.60	3.67	4.86
8	1	3.50	7.69	1.16	6.39
8	2	2.15	7.35	1.91	5.91
8	3	3.50	7.33	0.51	5.99
8	4	2.90	3.91	2.53	5.11
8	5	2.45	6.67	0.96	4.20
9	1	1.40	2.26	2.42	1.95
9	2	1.64	2.19	1.50	2.40
9	3	1.61	2.71	2.35	2.16
9	4	1.57	2.64	2.16	2.39
9	5	2.08	1.97	2.07	2.35

* no living plants due to accidental plant damage.

Appendix 5. Barley and Snapbean yields (grams per pot) (continued).

Treatment	Replication	Barley		Snapbean	
		Harvest 1	Harvest 2	Harvest 1	Harvest 2
10	1	1.69	8.02	0.12	6.12
10	2	1.94	5.39	0.96	5.45
10	3	1.63	8.48	0.51	8.14
10	4	1.45	8.65	0.77	7.62
10	5	3.12	5.65	0.83	7.21
11	1	2.76	7.48	2.98	7.69
11	2	2.59	6.74	2.67	6.57
11	3	2.44	6.18	0.56	7.54
11	4	2.19	8.01	1.67	9.80
11	5	2.75	6.67	1.85	5.57
12	1	2.38	6.87	3.35	4.73
12	2	2.29	8.05	2.73	4.67
12	3	3.33	5.89	2.42	7.55
12	4	2.63	7.24	1.70	5.25
12	5	2.74	4.57	2.21	8.09
13	1	1.50	2.60	1.89	3.40
13	2	0.95	4.82	1.09	3.93
13	3	1.29	4.85	1.94	2.78
13	4	1.39	2.57	0.51	3.57
13	5	0.91	2.26	2.47	3.72
14	1	1.21	3.18	1.55	2.30
14	2	0.90	3.52	1.64	4.49
14	3	1.20	3.36	1.83	3.35
14	4	1.32	3.65	1.08	3.79
14	5	1.64	3.83	0.52	1.89
15	1	1.58	4.17	1.23	4.51
15	2	1.08	4.14	1.68	3.72
15	3	2.14	4.65	1.34	4.33
15	4	1.87	4.23	3.27	5.50
15	5	1.49	4.22	1.72	4.72
16	1	2.03	0.89	1.47	1.06
16	2	2.16	1.13	2.55	1.74
16	3	2.49	1.75	2.13	2.11
16	4	1.63	1.32	2.08	1.90
16	5	1.54	1.58	2.65	0.99
17	1	1.90	1.90	2.91	2.42
17	2	2.17	1.71	2.43	2.98
17	3	1.68	1.79	2.90	2.52
17	4	2.08	1.70	1.44	2.55
17	5	2.11	1.50	1.01	3.40
18	1	2.04	3.98	3.63	6.24
18	2	2.39	5.91	2.71	3.30
18	3	2.76	5.78	2.44	6.46
18	4	2.97	7.28	0.82	7.00
18	5	3.29	7.29	3.33	7.73

* no living plants due to accidental plant damage.

Appendix 6. Barley and snapbean heights (cm) at harvest, first and second harvest.

Treatment	Replication	Barley		Snapbean	
		Harvest 1	Harvest 2	Harvest 1	Harvest 2
1	1	42	30	17	23
1	2	43	32	20	27
1	3	45	34	16	15
1	4	39	40	14	*
1	5	51	16	24	15
2	1	45	42	14	24
2	2	42	34	18	23
2	3	42	43	17	27
2	4	45	40	28	23
2	5	41	38	20	28
3	1	43	38	18	18
3	2	42	42	18	22
3	3	42	46	21	28
3	4	46	38	19	16
3	5	44	35	*	18
4	1	46	43	21	20
4	2	47	41	18	22
4	3	43	41	20	19
4	4	48	38	19	17
4	5	48	47	16	23
5	1	50	42	18	22
5	2	46	38	20	18
5	3	45	43	14	27
5	4	50	44	22	20
5	5	50	44	18	26
6	1	51	45	18	28
6	2	44	45	12	24
6	3	43	44	20	26
6	4	41	42	19	24
6	5	49	43	19	26
7	1	55	51	15	23
7	2	54	50	9	24
7	3	55	48	23	18
7	4	57	44	20	16
7	5	49	46	17	16
8	1	49	44	17	18
8	2	49	50	20	26
8	3	53	43	13	15
8	4	51	32	19	24
8	5	48	39	12	23
9	1	35	32	23	22
9	2	35	36	17	22
9	3	39	36	26	20
9	4	40	33	21	22
9	5	36	30	19	23

* No living plants due to accidental plant damage.

Appendix 6. Plant heights (cm) at harvest (continued).

Treatment	Replication	Barley		Snapbean	
		Harvest 1	Harvest 2	Harvest 1	Harvest 2
10	1	43	52	3	25
10	2	43	41	11	17
10	3	37	42	2	32
10	4	40	46	8	32
10	5	52	41	10	24
11	1	43	40	21	27
11	2	48	45	20	20
11	3	43	42	8	25
11	4	42	36	20	23
11	5	44	42	17	18
12	1	43	48	22	26
12	2	37	49	23	23
12	3	47	40	15	26
12	4	40	48	18	21
12	5	45	38	18	29
13	1	42	30	22	27
13	2	33	36	22	29
13	3	43	34	24	28
13	4	42	37	13	27
13	5	33	32	25	27
14	1	41	41	19	24
14	2	33	37	21	31
14	3	38	38	19	25
14	4	42	34	19	24
14	5	48	42	14	21
15	1	42	40	20	27
15	2	38	41	21	39
15	3	46	44	16	30
15	4	43	46	25	32
15	5	43	46	17	26
16	1	48	26	14	15
16	2	49	36	23	18
16	3	48	33	22	20
16	4	46	40	21	17
16	5	46	34	21	11
17	1	44	37	19	20
17	2	42	36	26	23
17	3	41	46	18	22
17	4	42	30	15	20
17	5	48	31	12	25
18	1	47	42	22	28
18	2	41	37	18	17
18	3	46	39	19	18
18	4	48	48	13	32
18	5	48	42	22	33

* No living plants due to accidental plant damage.

Appendix 7. Soil strength as measured with pocket penetrometer.

t Grouping				Mean	N	Trt.
Barley						
		A		0.63	5	4
B		A		0.61	5	11
B		A	C	0.57	5	12
B	D	A	C	0.48	5	5
B	D	A	C	0.44	5	6
B	D		C	0.42	5	7
	D		C	0.4	5	3
	D	E	C	0.38	5	2
F	D	E		0.32	5	8
F	D	E		0.31	5	14
F	D	E	G	0.30	5	13
F	D	E	G	0.29	5	18
F		E	G	0.19	5	9
F			G	0.17	5	1
F			G	0.14	5	17
F			G	0.13	5	15
F			G	0.12	5	10
			G	0.1	5	16

t Grouping				Mean	N	Trt.
Snapbean						
		A		0.47	5	11
	B	A		0.41	5	9
	B	A	C	0.38	5	4
	B	D	C	0.34	5	18
	B	D	C	0.31	5	7
	B	D	C	0.30	5	8
	B	D	C	0.29	5	12
		D	C	0.28	5	10
E		D	C	0.26	5	5
E		D	C	0.26	5	13
E		D	C	0.26	5	14
E		D		0.25	5	1
E		D		0.25	5	17
E		D		0.24	5	6
E		D		0.24	5	15
E		D		0.24	5	2
E		D		0.23	5	3
E				0.15	5	16

Appendix 7. Soil strength as measured with pocket penetrometer (continued).

Barley and Snapbean						
t Grouping				Mean	N	Trt.
		A		0.54	10	11
		A		0.51	10	4
B		A		0.43	10	12
B		C		0.37	10	5
B		C		0.37	10	7
B		C	D	0.34	10	6
B	E	C	D	0.32	10	18
B	E	C	D	0.32	10	3
B	E	C	D	0.31	10	8
B	E	C	D	0.31	10	2
B	E	C	D	0.30	10	9
	E	C	D	0.29	10	14
	E	C	D	0.28	10	13
	E	F	D	0.21	10	1
	E	F		0.20	10	10
	E	F		0.20	10	17
	E	F		0.19	10	15
		F		0.13	10	16

Appendix 8. Total recoverable metals of selected greenhouse mixes.

ID	WMRC #	Soil	treat.	rep	Be	B	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Pb	Hg
Soil, Tr 1, Rep A	03-3797	Soil	1	A	1.2	26	203	42	66	810	10	51	42	270	13	1.5	0.8	0.9	3.6	190	0.6	68	0.25
Soil, Tr 1, Rep B	03-3798	Soil	1	B	1.1	28	210	42	65	830	10	51	43	270	13	1.5	0.8	1.0	3.5	190	0.6	65	0.23
Soil, Tr 1, Rep C	03-3799	Soil	1	C	1.3	31	230	45	64	840	10	49	43	270	13	1.5	0.9	1.0	3.5	190	0.6	66	0.24
Soil, Tr 3, Rep A	03-3800	Soil	3	A	1.2	35	230	42	94	770	10	50	87	340	12	1.5	2.6	5.1	3.7	208	0.6	81	0.29
Soil, Tr 3, Rep B	03-3801	Soil	3	B	1.4	41	300	47	99	780	9	49	108	380	12	1.5	3.1	4.5	3.7	210	0.6	79	0.44
Soil, Tr 3, Rep C	03-3802	Soil	3	C	1.1	36	240	42	97	770	9	49	90	350	12	1.5	2.9	5.7	3.4	204	0.5	75	0.33
Soil, Tr 6, Rep A	03-3803	Soil	6	A	1.3	33	270	46	107	810	10	52	105	390	13	1.5	3.3	4.3	3.9	230	0.6	86	0.37
Soil, Tr 6, Rep B	03-3804	Soil	6	B	1.5	29	230	44	105	780	10	50	97	380	14	1.5	3.1	5.7	3.8	220	0.6	86	0.35
Soil, Tr 6, Rep C	03-3805	Soil	6	C	1.2	28	180	41	104	810	10	53	110	390	12	1.5	3.2	6.9	4.4	210	0.5	85	0.42
Soil, Tr 7, Rep A	03-3806	Soil	7	A	1.2	40	190	41	170	750	9	57	220	630	13	3.2	7.5	5.8	5.3	270	0.5	120	0.74
Soil, Tr 7, Rep B	03-3807	Soil	7	B	1.3	39	206	45	160	740	10	53	180	530	12	1.5	6.6	3.5	4.6	260	0.5	110	0.58
Soil, Tr 7, Rep C	03-3808	Soil	7	C	1.7	38	208	45	190	780	10	54	208	602	12	1.5	8.3	3.8	5.0	290	0.6	130	0.72
Soil, Tr 8, Rep A	03-3809	Soil	8	A	1.6	49	240	45	210	780	10	55	240	680	12	3.9	11.0	3.4	5.2	310	0.6	130	0.80
Soil, Tr 8, Rep B	03-3810	Soil	8	B	1.4	39	200	40	206	640	10	48	240	670	11	3.8	9.6	6.4	5.3	290	0.5	130	0.75
Soil, Tr 8, Rep C	03-3811	Soil	8	C	0.8	36	180	39	180	610	8	50	230	590	11	1.5	9.0	3.8	5.5	270	0.4	120	0.68
Soil, Tr 9, Rep A	03-3812	Soil	9	A	0.8	33	230	43	52	720	9	38	37	210	8.2	1.5	0.9	1.2	2.8	160	0.5	52	0.16
Soil, Tr 9, Rep B	03-3813	Soil	9	B	1.2	39	280	46	50	809	8	41	38	220	11	1.5	1.0	1.1	3.2	170	0.5	51	0.15
Soil, Tr 9, Rep C	03-3814	Soil	9	C	1.4	36	200	39	44	709	7	37	36	190	9.2	1.5	0.8	0.8	2.6	160	0.4	49	0.15
Soil, Tr 10, Rep A	03-3815	Soil	10	A	0.7	49	180	28	280	605	8	55	370	880	13	5.2	16.6	5.8	5.4	320	0.4	160	1.09
Soil, Tr 10, Rep B	03-3816	Soil	10	B	1.2	48	180	30	280	620	8	55	380	890	12	6.0	16.1	11.4	6.0	340	0.4	150	1.52
Soil, Tr 10, Rep C	03-3817	Soil	10	C	0.7	57	208	35	330	630	10	56	380	890	15	6.3	18.8	2.5	5.6	340	0.3	170	1.11
Soil, Tr 13, Rep A	03-3818	Soil	13	A	0.3	66	230	27	18	510	6	15	21	70	6.4	1.5	0.9	0.2	0.4	110	0.2	28	0.06
Soil, Tr 13, Rep B	03-3819	Soil	13	B	0.3	61	270	29	21	530	5	15	19	73	6.4	1.5	0.8	0.1	0.4	120	0.2	26	0.06
Soil, Tr 13, Rep C	03-3820	Soil	13	C	0.3	56	270	31	21	520	5	15	18	68	6.6	1.5	1.1	0.1	0.3	120	0.2	26	0.05
Soil, Tr 14, Rep A	03-3821	Soil	14	A	0.8	37	340	58	62	770	10	46	37	220	12	1.5	1.0	0.7	3.6	190	0.6	59	0.20
Soil, Tr 14, Rep B	03-3822	Soil	14	B	0.8	35	304	56	63	740	11	42	34	208	12	1.5	1.1	0.8	3.5	190	0.6	58	0.19
Soil, Tr 14, Rep C	03-3823	Soil	14	C	0.8	37	340	60	62	750	10	45	37	210	13	1.5	1.0	0.7	3.4	200	0.6	61	0.18
Soil, Tr 16, Rep A	03-3824	Soil	16	A	0.3	5	280	37	22	420	6	11	10	34	6.0	1.5	0.4	0.1	0.2	120	0.3	13	0.02
Soil, Tr 16, Rep B	03-3825	Soil	16	B	0.3	13	200	30	18	570	6	10	10	33	5.2	1.5	0.6	0.3	0.1	107	0.2	15	0.02
Soil, Tr 16, Rep C	03-3826	Soil	16	C	0.3	5	240	33	18	420	7	10	10	34	5.5	1.5	0.4	0.1	0.2	107	0.2	13	0.01

Appendix 9. Total recoverable metals of barley plants grown in selected greenhouse mixes.

WMRC #	Crop	treat.	rep	Be	B	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Pb	Hg
3857	Barley	1	2	0.3	18	8	0.14	0.3	11	0.02	0.5	5.2	41	0.2	0.2	1.9	0.09	0.7	10.1	0.02	0.3	0.002
3858	Barley	1	3	0.3	20	8	0.10	0.2	12	0.02	0.6	6.0	48	0.2	0.2	1.9	0.08	0.8	7.4	0.02	0.4	0.002
3859	Barley	1	5	0.3	17	9	0.09	0.2	12	0.02	0.7	5.1	39	0.2	0.2	1.6	0.06	0.6	8.1	0.02	0.3	0.002
3860	Barley	3	1	0.3	39	9	0.16	0.2	14	0.02	0.5	6.4	42	0.2	0.2	3.3	0.09	0.7	2.7	0.02	0.2	0.002
3861	Barley	3	3	0.3	35	9	0.13	0.2	21	0.02	0.5	8.2	47	0.1	0.2	3.3	0.06	0.7	2.0	0.02	0.3	0.002
3862	Barley	3	5	0.3	36	9	0.05	0.2	18	0.02	0.4	6.2	43	0.2	0.2	3.0	0.09	0.6	2.5	0.02	0.2	0.003
3863	Barley	6	3	0.3	17	8	0.05	0.2	25	0.02	0.5	6.0	47	0.9	0.4	3.9	0.05	0.7	1.4	0.02	0.2	0.002
3864	Barley	6	4	0.3	24	8	0.05	0.2	23	0.02	0.5	5.7	43	0.2	0.4	3.4	0.06	0.7	1.3	0.02	0.3	0.002
3865	Barley	6	5	0.3	19	8	0.05	0.3	22	0.02	0.5	6.2	47	0.3	0.6	3.6	0.05	0.8	1.4	0.02	0.4	0.003
3866	Barley	7	1	0.3	28	11	0.05	0.2	38	0.02	0.7	7.7	65	0.2	0.5	4.1	0.05	0.8	1.6	0.02	0.2	0.002
3867	Barley	7	3	0.3	35	11	0.06	0.2	43	0.02	0.7	7.7	65	0.3	0.6	4.6	0.07	0.9	1.7	0.02	0.4	0.002
3868	Barley	7	4	0.3	30	10	0.05	0.5	37	0.02	0.8	7.1	61	0.3	0.4	4.0	0.16	0.7	1.2	0.02	0.3	0.004
3869	Barley	8	2	0.3	94	14	0.06	0.2	60	0.02	0.9	9.2	76	0.3	0.4	4.1	0.08	0.5	1.1	0.02	0.2	0.003
3870	Barley	8	3	0.3	80	12	0.05	0.2	51	0.02	0.8	8.4	78	0.3	0.5	3.5	0.05	0.5	1.0	0.02	0.2	0.004
3871	Barley	8	4	0.3	92	13	0.05	0.2	55	0.02	0.8	9.0	70	0.2	0.4	3.7	0.07	0.5	1.1	0.02	0.3	0.003
3872	Barley	9	1	0.3	99	7	0.06	0.2	10	0.02	0.2	4.6	32	0.2	0.2	3.0	0.09	0.4	8.7	0.02	0.3	0.004
3873	Barley	9	2	0.3	88	7	0.05	0.2	10	0.02	1.4	4.5	30	0.2	0.2	2.9	0.09	0.4	8.9	0.02	0.9	0.005
3874	Barley	9	3	0.3	104	9	0.05	0.2	20	0.02	0.2	4.8	33	0.2	0.2	3.8	0.07	0.3	10.3	0.02	0.3	0.004
3875	Barley	10	2	0.3	150	20	0.06	0.2	87	0.14	1.3	10.9	82	0.7	0.6	4.4	0.07	0.2	0.8	0.02	0.2	0.003
3876	Barley	10	3	0.3	107	20	0.17	0.3	86	0.19	1.3	10.6	61	0.8	0.8	4.0	0.08	0.1	0.8	0.02	0.4	0.003
3877	Barley	10	5	0.3	68	16	0.10	0.2	64	0.10	0.9	9.5	58	0.5	0.6	3.1	0.06	0.1	0.6	0.02	0.2	0.003
3878	Barley	13	2	0.3	120	6	0.15	0.2	14	0.02	0.2	3.9	32	0.4	0.2	4.7	0.13	0.1	9.2	0.02	0.4	0.003
3879	Barley	13	3	0.3	104	7	0.17	0.2	13	0.02	0.2	4.2	26	0.3	0.2	5.0	0.10	0.1	6.9	0.02	0.5	0.004
3880	Barley	13	4	0.3	91	6	0.15	0.3	12	0.02	0.2	3.7	34	0.3	0.2	4.3	0.15	0.1	10.1	0.02	0.7	0.004
3881	Barley	14	3	0.3	28	7	0.15	0.2	12	0.02	0.3	5.8	46	0.1	0.2	2.6	0.10	0.9	9.0	0.02	0.4	0.003
3882	Barley	14	4	0.3	26	8	0.16	0.2	13	0.02	0.5	6.8	50	0.2	0.2	3.0	0.11	0.7	8.0	0.02	0.4	0.003
3883	Barley	14	5	0.3	21	8	0.16	0.2	11	0.02	0.3	5.1	39	0.1	0.2	2.4	0.09	0.7	8.2	0.02	0.2	0.003
3884	Barley	16	1	0.3	27	14	0.07	0.3	88	0.02	0.3	4.4	20	0.1	0.2	1.0	0.09	0.2	5.1	0.08	0.3	0.003
3885	Barley	16	2	0.3	24	13	0.06	0.3	86	0.02	0.3	4.4	19	0.1	0.2	1.0	0.11	0.2	5.0	0.08	0.3	0.003
3886	Barley	16	3	0.3	30	14	0.06	0.3	94	0.02	0.7	5.1	23	0.2	0.2	1.3	0.08	0.2	7.2	0.08	0.2	0.003

Appendix 10. Total recoverable metals of snapbean plants grown in selected greenhouse mixes.

WMRC #	Crop	treat.	rep	Be	B	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Pb	Hg
3827	Snapbean	1	2	0.3	28	30	0.06	0.4	12	0.10	2.1	5.0	36	0.3	0.2	18.5	0.05	0.2	9.2	0.02	0.3	0.002
3828	Snapbean	1	3	0.3	29	9	0.07	0.3	15	0.12	6.2	5.2	29	0.2	0.2	16.6	0.04	0.3	11.6	0.02	1.7	0.006
3829	Snapbean	1	4	0.3	32	8	0.06	0.3	13	0.09	2.6	5.1	28	0.2	0.2	9.4	0.20	0.2	11.1	0.02	0.4	0.002
3830	Snapbean	3	2	0.3	56	11	0.07	0.5	22	0.12	1.6	5.9	47	0.2	0.2	4.9	0.09	0.2	4.7	0.02	0.4	0.002
3831	Snapbean	3	3	0.3	67	10	0.05	0.3	17	0.12	1.4	5.6	36	0.2	0.2	7.9	0.20	0.2	4.8	0.02	0.5	0.003
3832	Snapbean	3	4	0.3	61	13	0.06	0.3	19	0.12	1.4	5.9	45	0.2	0.2	6.5	0.06	0.2	4.8	0.02	0.3	0.002
3833	Snapbean	6	1	0.3	32	11	0.05	0.3	18	0.13	1.7	5.5	52	0.2	0.2	4.5	0.04	0.2	3.0	0.02	0.3	0.002
3834	Snapbean	6	3	0.3	42	11	0.05	0.2	22	0.14	2.1	5.8	57	0.3	0.6	7.1	0.08	0.2	3.4	0.02	0.3	0.004
3835	Snapbean	6	4	0.3	42	16	0.07	0.2	19	0.15	2.1	5.1	48	0.2	0.5	4.5	0.06	0.2	3.4	0.02	0.3	0.001
3836	Snapbean	7	1	0.3	49	13	0.06	0.1	40	0.17	2.6	6.1	61	0.2	0.2	4.6	0.11	0.2	3.0	0.02	0.2	0.002
3837	Snapbean	7	3	0.3	46	13	0.06	0.2	44	0.23	5.1	6.7	60	0.2	0.4	6.0	0.09	0.1	2.5	0.02	0.3	0.002
3838	Snapbean	7	5	0.3	49	12	0.06	0.2	48	0.18	3.1	6.8	53	0.2	0.4	4.3	0.08	0.1	3.0	0.02	0.3	0.002
3839	Snapbean	8	1	0.3	75	17	0.08	0.2	120	0.22	3.7	7.1	61	0.2	0.5	5.3	0.08	0.2	2.6	0.02	0.3	0.001
3840	Snapbean	8	2	0.3	65	18	0.09	0.2	120	0.26	3.9	6.2	60	0.2	0.2	5.8	0.08	0.1	2.9	0.02	0.3	0.002
3841	Snapbean	8	4	0.3	63	15	0.08	0.3	180	0.21	4.3	5.3	61	0.2	0.2	8.0	0.06	0.1	2.0	0.02	0.3	0.003
3842	Snapbean	9	1	0.3	100	6	0.08	0.2	21	0.07	1.3	4.4	26	0.5	0.2	25.5	0.02	0.2	16.1	0.02	0.3	0.002
3843	Snapbean	9	3	0.3	105	7	0.08	0.2	22	0.14	7.6	4.2	28	0.2	0.2	31.3	0.02	0.2	16.6	0.02	1.9	0.002
3844	Snapbean	9	4	0.3	86	5	0.08	0.2	22	0.10	4.0	4.6	32	0.1	0.2	19.1	0.04	0.2	17.7	0.02	0.3	0.002
3845	Snapbean	10	2	0.3	110	20	0.11	0.2	500	0.73	5.4	8.4	102	0.7	0.2	10.2	0.07	0.3	3.3	0.02	0.3	0.005
3846	Snapbean	10	4	0.3	130	19	0.11	0.3	420	1.13	12.9	9.2	110	0.8	0.2	8.2	0.08	0.2	1.8	0.02	1.4	0.003
3847	Snapbean	10	5	0.3	110	20	0.10	0.3	380	0.69	5.6	8.3	91	0.6	0.2	8.5	0.09	0.2	2.5	0.02	0.3	0.003
3848	Snapbean	13	1	0.3	99	4	0.07	0.2	24	0.06	0.7	2.3	15	0.2	0.2	20.8	0.06	0.1	11.4	0.02	0.4	0.001
3849	Snapbean	13	3	0.3	110	5	0.09	0.4	24	0.08	1.0	3.0	18	0.2	0.2	17.8	0.06	0.1	15.4	0.02	0.4	0.001
3850	Snapbean	13	5	0.3	110	4	0.08	0.3	25	0.07	0.7	2.7	17	0.2	0.2	17.8	0.05	0.0	13.4	0.02	0.4	0.002
3851	Snapbean	14	1	0.3	44	4	0.12	0.2	11	0.08	1.5	2.9	21	0.1	0.2	14.5	0.05	0.4	9.7	0.02	0.4	0.001
3852	Snapbean	14	2	0.3	39	5	0.10	0.1	19	0.08	2.1	3.2	22	0.1	0.2	13.9	0.08	0.3	10.7	0.02	0.4	0.001
3853	Snapbean	14	3	0.3	34	4	0.10	0.2	8.5	0.06	1.0	2.2	17	0.2	0.2	10.9	0.07	0.3	9.1	0.02	0.5	0.002
3854	Snapbean	16	2	0.3	39	11	0.07	0.2	56	0.31	2.2	2.9	23	0.1	0.2	4.3	0.09	0.0	7.0	0.05	0.4	0.001
3855	Snapbean	16	3	0.3	49	10	0.08	0.3	120	0.41	2.0	3.4	22	0.2	0.2	9.0	0.05	0.0	8.6	0.05	0.3	0.001
3856	Snapbean	16	5	0.3	55	10	0.08	0.2	110	0.40	2.1	3.3	21	0.2	0.2	8.9	0.04	0.0	8.3	0.05	0.3	0.001

Appendix 11. Typical concentrations of trace elements in mature leaf tissue generalized for various species (mg kg^{-1} DW). †

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	400-1000
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). Note: Values are not given for very sensitive or highly tolerant plant species.

Appendix 12. 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 - 3000	600
B	2 - 200	80	Mo	0.02 - 5	-
Ba	200 - 1500	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 - 10000	3000
Cr	7 - 1500	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).