SYNTHETIC SOILS FROM INDUSTRIAL & MUNICIPAL WASTES[1]

by

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ABSTRACT

Numerous experiments have already demonstrated that wastes like fly ash, lime sludge, kiln dust, sewage sludge and gypsum can be land-applied with little detriment to soils. However, constraints are sufficiently restrictive (large acreages, thin applications, timing between crops, heavy metals, regulations, liability and NIMBY) that most such bulk wastes are still landfilled. This project launches our investigation of creating synthetic soils entirely from wastes, with the intent of using them for mineland reclamation and other restorations. If successful, such projects could accommodate large volumes of wastes, while producing environmental benefits.

Native midwestern silty soils were used as a reference for plant growth controls. The following five bulk wastes, available in the Iowa City, Iowa area, were selected as having potential to provide soil components within a synthetic blend: fly ash, bottom ash, lime sludge, sewage sludge incinerator ash and landfill compost.

Thirty seven waste blends were prepared, at least 1 blend containing 10%, 20%, 25%, 33%, 40%, 50%, 60% or 100% of each of the 5 components. Three different local native soils were used as controls. Lettuce, tomatoes, green beans, and onions were grown in a greenhouse, using 5" pots of the synthetic and control soils. One set was lightly fertilized and a duplicate set left unfertilized. Light fertilization (macro and trace elements) had minimal effect on survival, growth, or yields, suggesting that nutrient availability was not a limiting factor, so the data were combined for analysis and comparing controls to synthetic blends.

The vegetables were pulled out by the roots and the pots of synthetic and native soils placed outdoors to weather for 3 autumn months, to destroy any alleopathic compounds present. The soils were then replanted with robar oak acorns. Germination rates were highly variable, some acorns sprouting within a few weeks, while others were sprouting or dormant when the experiment was terminated 7 months later. Good oak seedlings were produced by some synthetic soils and most of the controls.

The most significant results of this first research phase relate to effects of the number of ingredients in the blends. Some of the mono-wastes and simple blends of only 2 or 3 wastes, had either no survival or produced stunted, deformed, and/or discolored plants, whereas the more complex blends generally produced at least average growth. The two best synthetic soils, with vegetable and oak growth and yields mostly exceeding that in native control soils, were #35 - containing 10% fly ash, 10% bottom ash, 10% lime sludge, 10% sewage sludge incinerator ash and 60% landfill compost; and #36 - containing 10% lime sludge, 10% sewage sludge incinerator ash, 10% fly ash, 10% compost and 60% bottom ash. The results suggest that functions of natural soils can be duplicated by blending selected wastes to create synthetic soils. Much more research will be necessary to demonstrate the validity of the concept. However, our preliminary results are sufficiently promising

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that we encourage others to begin experiments with the bulk wastes available in their area.

Key Words: synthetic soil, land application, final cover, waste management, fly ash, coal combustion residue, sludge, sludge management

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Introduction

The use of soil amendments is as old as agriculture and even pre-agricultural people probably noticed improved plant growth around former camp sites, butchering sites, middens, and latrine areas. In recent centuries, industrial and municipal wastes have been incorporated into soils with the intent of improving the soil for agriculture. In the last half-century, with improved knowledge of plant nutrition and readily available concentrated "chemical" fertilizers, the purpose of utilizing wastes as soil amendments has shifted more toward emphasis on disposal of the wastes. Present-day constraints on this practice include the large acreages required, inability to incorporate during the growing season, concerns over heavy metals, the regulatory framework, potential liability, and NIMBY (not-in-my-back-yard). Every year some municipality or industry "discovers" that fly ash, lime sludge, kiln dust, sewage sludge, waste gypsum, etc. can be thinly land-applied with some benefit or little detriment to soils; but the bulk of these materials are still landfilled. Numerous agricultural and scientific papers have been published documenting various degrees of success with applications of individual waste types.

This research project addresses a different perspective: Is it possible to create synthetic soils entirely from blended bulk wastes? If so, these soils could be used to reclaim abandoned surface mines, mitigate or ameliorate derelict lands, improve sterile or badly eroded areas and perhaps also serve as final cover on landfills. Synthetic soils could provide adequate rooting depth for vegetation, use large volumes of waste, and be beneficial to the environment.

Methods

Synthetic Soil Properties

Synthetic soils must duplicate all of the functions of natural soil. Many wastes are dominently silt-sized particles and many of the Midwest's better upland soils are derived from geologically-produced silts (loess), so these types of natural soils were used as a general model to determine which soil properties are important. The major natural soil properties important for growing plants include:

Silt - This soil component is dominant in the control soils. Silts have moderate drainage, moderate water holding capacity; mineral weathering for nutrients.

Clay - This soil component comprises a minor portion of the control soils. Clay is important for ion exchange and water retention; also clay skins coat peds maintaining soil structure.

Sand - This soil component comprises a minor portion of the control soils. Sand is important for improved drainage and structure; also, larger grains weather slowly releasing nutrients.

Organics - Organic substances enhance ion exchange, increase water retention, and reduce bulk density; also, organic skins coat peds for maintaining a fine structure; roots penetrate peds improving structure.

Calcium Carbonate ($CaCO_3$) - Weathering and migration of calcite provides strong carbonate/bicarbonate buffering within a near-neutral pH range.

Micro-flora & fauna - Composting converts the raw organics to more useful humates, resins, waxes and fibrils; also provides mycorrhizal assistance to living roots.

Wastes Utilized

Wastes

Synthetic soils were blended from the following five wastes available in the vicinity of Iowa City, Iowa:

Lime Sludge (L) was obtained from the University of Iowa water treatment facility which treats Iowa River water. The sludge is a damp gray cake from the settling basin. Potentially useful components include $CaCO_3$, silt, and plant nutrients.

Fly Ash (F) was obtained from electrostatic stack scrubbers at the University of Iowa power plant (no limestone additives to the coal in these older boilers). The fly ash is a black sooty dust, probably dominated by glassy silt-sized microspheres. Potentially useful properties are silt, organics (unburned coal), and plant nutrients.

Bottom Ash (B) was obtained from an elderly chain grate stoker boiler at the University of Iowa power plant. The material is a coarse clinkery gray "gravel" with a high content of glassy slag. Bottom ash is potentially useful as a substitute for sand in improving structure and drainage, plus providing plant nutrients.

Sewage Sludge Incinerator Ash (I) was obtained from the Cedar Rapids Pollution Control Facility (CRPCF) where sewage sludge is incinerated. The material is a brown lightweight granular aggregate, mineralogically dominated by amorphous iron carbonates. Sewage Sludge Incinerator Ash is potentially useful for providing "instant" soil structure, good drainage and plant nutrients. New ash piles at the CRWPCF are promptly colonized by weeds, and older piles support a healthy stand of pioneer tree species.

Compost (C) was obtained from the Scott Co. Landfill, produced by composting yard wastes with some sewage sludge. The compost is a dark brown to black well-finished granular mix containing about 20% undigested twigs, and minor bits of plastic. The slightly warm pile released a trace of ammonia indicating decomposition was nearly completed. The compost is useful as a source of aged organics, micro-flora and fauna, and plant nutrients.

Synthetic Soil Blends

Thirty-seven blends were prepared, containing from 1 to 5 waste components. For each waste component there was at least one blend with 10%, 20%, 25%, 33%, 40%, 50%, 60% or 100% of that component (see Table 1 for details). Proportions were measured by volume, because this will probably be the method utilized in large scale applications, where the unit of measure will logically be the truckload. Four of the five wastes were dry powders or granules, so these components were measured by the scoopful. The pasty lime sludge was also measured by the scoopful, then slurried with water to the consistency of a milkshake before being blended with the dry ingredients.

Native Control Soils

The following three native soils were used for controls:

Colo Silt Loam Topsoil (code #38) - A sample was collected from the high quality 14 inch thick silt loam "A" horizon developed from mid-terrace fine sands and silt on the Iowa River floodplain.

Tama Silt Loam Topsoil (code #39) - A sample was collected from the 16 inch thick silt loam high quality "A" horizon developed on upland loess, formerly under prairie.

Clinton Silt Loam (code #40) - This soil has a degraded plowzone produced after agricultural erosion has removed much of the natural "A" horizon from an upland loess-derived forest soil. A sample was collected from the 9 inch thick silt loam Ap horizon which contains "A" and "B" horizon materials. This sample is deficient in aged organics and has little or no structure.

Plants & Planting

The plant varieties selected for the greenhouse growth tests were tomatoes, onion, green beans, lettuce, and oak. Lettuce and onions are early spring, cool season crops which were expected to be stressed in the hot summer greenhouse, while tomatoes and beans were expected to flourish. The 4 vegetables also represented a range of propagules, including large seeds (bean), small seeds (lettuce), seedling transplants (tomato) and bulbs (onion). The varieties selected were:

Tiny Tim Tomato - A dwarf determinant variety suitable for growing in pots (a "patio" tomato). This variety bears many small (1") fruits and is

Table 1. Waste Proportions In Blend.

Number of Components	Blend #	Proportions				
		100%				
	1	F (fly ash)				
	2	C (compost)				
1	3	B (bottom ash)				
	4	L (lime sludge)				
	5	I (incinerator ash)				
		50%	50%			
	6	F	C			
	7	F	B			
	8	F	L			
	9	C	B			
2	10	C	L			
	11	B	L			
	12	I	F			
	13	I	C			
	14	I	B			
	15	I	L			
		33%	33%	33%		
	16	F	C	B		
	17	F	B	L		
	18	F	C	L		
3	19	C	B	L		
	20	I	F	C		
	21	I	B	C		
	22	I	B	L		
		25%	25%	25%	25%	
	23	F	C	B	L	
	24	I	C	B	L	
4	25	I	F	B	L	
	26	I	F	C	L	
	27	I	F	C	B	
		10%	10%	20%	20%	40%
	28	F	C	B	L	I
	29	C	B	L	I	F
	30	B	L	I	F	C
	31	L	I	I	C	B
	32	I	F	C	B	L
5						
		10%	10%	10%	10%	60%
	33	F	C	B	L	I
	34	C	B	L	I	F
	35	B	L	I	F	C
	36	L	I	F	C	B
	37	I	F	C	B	L
		Native Soil Controls				
	38	(A,B,C,D) Colo Silt Loam Topsoil				
	39	(A,B,C,D) Tama Silt Loam Topsoil				
	40	(A,B,C,D) Clinton Silt Loam				

self-pollinating.

Oakleaf Lettuce - A bolt-resistant variety, selected so leaf growth could be compared without the complications of some plants ceasing leaf growth in order to put up a seed stalk.

Bluelake Bean - A green bush bean with a short maturity season (60 days).

White Onion - Small dormant "sets", about one half inch in diameter were selected.

Robar Oak - Large undamaged acorns were gathered under local trees in October and stored in a cool moist fruit cellar. Before planting in December, acorns were poured into a tub of cold water and only the "sinkers" were planted. The robar oak does not need cold stratification to germinate.

In June 1991, the vegetables were planted in the synthetic and control soils, in old 5" clay pots, with a shard shielding the drain hole. Planting rates were 5 bean seeds per pot, 4 onion bulbs per pot, 8 lettuce seeds per pot, and 3 sprouted tomato seedlings per pot. After 2 weeks, the tomatoes were thinned to 1 best plant per pot. Duplicate sets of all blend/planting combinations were prepared. One set was fertilized every second week with a dilute liquid macro/micro nutrient mix, while the other set was not fertilized. The plants were grown on raised, nearly full-sun greenhouse benches during summer 1991. Four sets of each control soil, half fertilized and half not, were planted to each vegetable and the pots spread out through the rows of synthetic soils. The plants were regularly watered as needed during the summer, to prevent wilting. Some minor whitefly and thrip damage occurred. Growth and yields were monitored (discussed next section).

In October 1991, the vegetable plants were pulled out by the roots and discarded. The contents of all pots containing the same waste blend were recombined into a single large plastic 2-gallon pot. The control pots were similarly recombined. These larger pots of synthetic and control soils were placed outdoors during autumn 1991, in order to weather and destroy any alleopathic compounds produced by the vegetable plants. They were then brought back into the greenhouse in December 1991 and planted with 12 robar oak acorns each, which were grown unthinned and with no additional fertilizer. This experiment continued until July 1992, when the roots of some of the control and a few of the synthetic soil oaks began to extend out of the pot drain holes and into the moist pebble layer on the greenhouse benches. Because they were beginning to obtain some water, and probably nutrients, from the pebbles, the oak experiment was terminated.

Growth & Yields

The major reason for conducting these preliminary experiments was to determine whether individual wastes can be preselected to mimic specific soil functions and when blended, whether wastes can collectively assume the necessary functions of a native soil, with regard to plant growth. If this is a valid concept, one would expect the multi-component blends to generally produce better growth and yields than those with fewer components. The growth and yield data for the vegetables is compiled on Tables 2 and 3, the oak data on Tables 4 and 5.

Table 2. Vegetables in Control Soils.

Native Soil		Plant Size At 8 Weeks: Bean	Onion	Tomato	Lettuce	Size Onion Bulbs 8 Weeks	Number Beans 8 Weeks	Number Tomatoes 13 Weeks
38A	U	+	+	+	+	++	1	12
	F	++	++	+	++	++	2	10
38B	U	+	-	+	++	-	6	10
	F	+	+	+	++	++	4	7
38C	U	++	++	+	++	++	5	10
	F	++	+	++	++	++	4	13
38D	U	++	+	++	++	+	2	11
	F	++	++	-	++	++	3	-
39A	U	++	++	-	++	+	2	2
	F	++	++	-	+	++	2	7
39B	U	+	+	-	++	+	2	9
	F	-	+	+	++	+	1	9
39C	U	++	++	++	++	+	4	10
	F	++	++	++	++	+	5	18
39D	U	-	-	+	++	-	1	9
	F	++	++	++	++	+	4	11
40A	U	+	+	+	+	+	2	2
	F	-	+	+	++	-	1	4
40B	U	+	+	+	+	+	0	7
	F	++	+	+	+	+	0	1
40C	U	++	+	++	++	+	7	23
	F	++	-	++	+	-	4	14
40D	U	++	+	++	++	-	3	5
	F	++	+	+	-	+	5	4
		-------Proportions of Robust (++)--------					----Fruits/Pot----	
		15/24 63%	8/24 33%	8/24 33%	17/24 71%	7/24 29%	71/24 3	208/24 9

Key: ++ = robust growth
+ = ordinary growth
- = dwarfed, stressed or dead
U = unfertilized
F = fertilized

Table 3. Vegetables in Synthetic Soils.

Number of Waste Components	Blend #	Plant Size At 8 Weeks: Bean	Onion	Tomato	Lettuce	Size Onion Bulbs 8 Weeks	Number Beans 8 Weeks	Number Tomatoes 13 Weeks
1	1 U	-	-	-	-	-	0	-
	F	-	-	-	-	-	0	-
	2 U	-	+	+	++	-	0	15
	F	++	-	+	++	-	0	1
	3 U	-	-	+	-	-	0	7
	F	+	+	+	++	-	0	5
	4 U	-	-	-	-	-	0	-
	F	-	-	-	-	-	0	-
	5 U	+	++	+	+	++	1	7
	F	++	+	+	++	++	1	12
2	6 U	-	+	-	+	-	0	0
	F	-	-	-	+	-	0	-
	7 U	-	-	-	-	-	0	-
	F	-	-	-	+	-	0	3
	8 U	-	-	-	-	-	0	-
	F	-	-	-	-	-	0	-
	9 U	+	++	-	-	+	0	7
	F	+	++	++	-	+	0	4
	10 U	-	+	-	-	-	0	-
	F	-	-	-	-	-	0	1
	11 U	-	-	-	+	-	0	1
	F	-	-	-	+	-	0	1
	12 U	-	+	-	-	+	0	5
	F	-	+	-	-	+	0	-
	13 U	++	++	++	++	++	1	14
	F	++	+	+	-	+	2	9
	14 U	-	++	+	+	++	0	16
	F	+	++	+	-	++	0	7
	15 U	+	++	+	+	+	0	5
	F	+	+	+	+	+	0	5
3	16 U	-	-	-	++	-	0	1
	F	-	-	-	+	-	0	7
	17 U	-	-	-	+	-	0	3
	F	-	+	-	+	-	0	4
	18 U	-	-	+	++	-	0	6
	F	-	+	-	++	+	0	0
	19 U	-	-	-	++	-	1	-
	F	++	++	+	++	++	2	9
	20 U	-	+	-	++	-	0	-
	F	+	-	-	+	-	0	-
	21 U	++	++	++	++	++	4	21
	F	+	++	++	++	++	1	14

(continued on next page)

Table 3. continued

Number of Waste Components	Blend #	Plant Size At 8 Weeks: Bean	Onion	Tomato	Lettuce	Size Onion Bulbs 8 Weeks	Number Beans 8 Weeks	Number Tomatoes 13 Weeks
3	22 U	+	+	+	++	+	2	10
	F	++	++	+	++	+	3	11
4	23 U	-	-	+	++	-	0	11
	F	-	-	-	++	-	0	-
	24 U	+	-	+	++	-	0	9
	F	++	+	+	++	+	1	7
	25 U	-	-	-	+	-	0	-
	F	-	+	-	++	+	0	-
	26 U	-	+	-	-	+	0	-
	F	+	+	-	+	+	0	-
	27 U	-	+	+	++	-	0	2
	F	-	+	+	++	+	1	1
5	28 U	++	+	+	+	+	3	12
	F	+	+	-	-	-	2	-
	29 U	-	-	-	-	-	0	-
	F	-	-	-	-	-	0	4
	30 U	+	+	++	++	+	2	3
	F	+	+	++	++	+	0	11
	31 U	+	+	++	+	+	0	6
	F	-	+	+	+	+	0	1
	32 U	+	+	++	++	++	0	9
	F	-	++	++	++	++	0	6
	33 U	++	++	++	++	+	3	12
	F	++	+	++	++	+	3	4
	34 U	-	+	-	+	+	1	0
	F	-	-	+	-	+	2	4
	35 U	+	++	++	++	+	2	21
	F	++	-	++	++	-	4	16
	36 U	++	++	++	++	++	1	8
	F	-	++	+	++	++	1	13
	37 U	-	+	+	++	+	2	7
	F	-	-	-	-	-	0	0
		--------Proportions of Robust--------					Fruits/Pot	
		13/74	16/74	14/74	33/74	12/74	44/74	384/74
		18%	22%	19%	45%	16%	0.6	5

Key: ++ = robust growth
+ = ordinary growth
- = dwarfed, stressed or dead
U = unfertilized
F = fertilized

Table 4. Oak in Control Soils - 7 Months.

	Native Soil	Number Seedlings	Average Height Inches	Dark Green Leaves	100% Undeformed Leaves	Germination and Growth
Colo	38A	5	9	80%	80%	
Silt	38B	1	27	100%	0%	+
Loam	38C	2	9	50%	100%	
	38D	5	10	60%	80%	
Tama	39A	3	10	100%	67%	++
Silt	39B	2	11	100%	100%	+
Loam	39C	0	-	-	-	
	39D	1	21	100%	100%	+
Clinton	40A	5	7	100%	100%	++
Silt	40B	2	6	0%	50%	
Loam	40C	1	3	100%	100%	+
	40D	4	6	100%	100%	++

Average Seedling Survival	Average Height
31/12 2.6/Pot	287/31 9.3 Inches

Key: ++ = good germination, tall, dark green & few deformities
+ = weak germination, tall, dark green & few deformities

(good germination $\geq$ 3 acorns/pot)
(tall $\geq$ 4 inches)

Table 5. Oak in Synthetic Soils - 7 Months.

Number of Waste Components	Blend #	Number Seedlings	Average Height Inches	Dark Green Leaves	100% Undeformed Leaves	Germination and Growth
	1	2	4	0%	0%	
	2	2	10	0%	0%	
1	3	3	7	100%	100%	++
	4	1	4	100%	100%	+
	5	5	6	100%	33%	+
	6	3	8	33%	33%	
	7	2	5	0%	100%	
	8	1	4	0%	100%	
	9	7	7	86%	71%	++
2	10	6	5	0%	100%	
	11	4	3	25%	50%	
	12	2	5	0%	100%	
	13	1	5	0%	0%	
	14	3	7	67%	67%	+
	15	2	6	0%	0%	
	16	1	3	0%	100%	
	17	3	4	100%	0%	
	18	1	12	0%	100%	+
3	19	4	6	0%	50%	
	20	1	4	0%	100%	+
	21	1	27	100%	0%	+
	22	4	4	40%	100%	
	23	5	5	0%	40%	
	24	2	5	0%	100%	
4	25	3	4	50%	100%	
	26	4	8	0%	75%	
	27	1	4	100%	100%	+
	28	2	5	0%	100%	
	29	5	3	40%	100%	
	30	1	5	100%	0%	
	31	3	6	0%	67%	
5	32	2	6	0%	100%	
	33	3	3	0%	67%	
	34	3	5	0%	100%	
	35	4	6	75%	100%	++
	36	2	13	100%	100%	+
	37	0	-	-	-	
		Average Seedling Survival	Average Height			
		99/37	568/99			
		2.7/Pot	5.7 Inches			

Key: ++ = good germination, tall, dark green & few deformities
+ = weak germination, tall, dark green & few deformities

(good germination $\geq$ 3 acorns/pot)
(tall $\geq$ 4 inches)

One obvious consideration is whether plant growth in the synthetic soils is being limited by availability of nutrients. One generalized test was to evaluate paired and matched fertilized versus unfertilized conditions, which are summarized on Table 6 (compiled from Tables 2, 3, 4, 5). In all cases, for both native and synthetic soils, at least one-half of the matched pairs showed the same response, and for synthetic soils only beans had more cases where the fertilized (F) outranked the unfertilized (U), rather than vice versa. Where the F versus U pair responses are compared between synthetic and native soils for the same vegetable; beans, onions and lettuce show the same trends and only portions of the tomato data show differences. The general conclusion is that nutrient availability was no more of a limiting factor for young vegetables in synthetic soils than it was for those in native soils. For oak, the average seedling count per pot was the same for synthetic blends as for native soils, although those in synthetic soils tended to be smaller. The acorns were so large they could have probably supplied adequate micro-nutrients even if their soils were deficient.

Because the fertilized plants had no demonstrated growth advantage over the unfertilized ones, the remainder of this evaluation combines data from both. Note that Table 3 (vegetables in synthetic soils) is organized with the simple blends listed first and grading down the page into increasingly complex blends, containing up to 5 components. In general the better plant growth and yields tend to be in synthetic soils with 4 or 5 blends, which helps support the proposal that different wastes serve different soil functions. Growth and yields comparable to or better than native soil indicate that collectively, all the necessary functions for plant growth are being met.

When all the vegetable data on Table 3 are combined, the 10 synthetic soils which produced good-to-excellent growth and yields in all categories are listed on Table 7. Incinerator ash is clearly the most versatile ingredient, and is present in all 10 of the best synthetic soils, in quantities ranging from 10-100%. Compost, bottom ash, and lime sludge are all present in 5 of the better blends, in some cases in proportions 40% or greater. Only fly ash remains a minor ingredient in all the better blends, never exceeding 20% and is absent from all of the blends containing 3 or less wastes. This suggests fly ash might be imparting some undesirable property to the synthetic soil. In the greenhouse, it was evident that blend #35 was the best synthetic soil, with #36 second best. This visual evidence included plant height, color, number of leaves and stem thicknesses as well as the parameters listed on Table 3. Collectively, the growth and yields in these 2 synthetic soils, in most cases, met or exceeded those from all the native control soils. Oak also did well in both these blends (Table 5). However, the oak data is less convincing due to the irregular and slow germination of the acorns. The oak data is most useful for evaluating whether there are any potential longer term concerns regarding growth in synthetic soils (7 months for oak growth vs. 2 months for vegetable growth). The oak control soils produced mostly dark green, undeformed leaves (Table 4). Of the 10 best synthetic soils, previously identified on Table 7, only blend numbers 21, 35 and 36 produced comparably dark and undeformed oak leaves (Table 5). The other 7 best blends produced a

Table 6. Fertilized Vs. Unfertilized Pairs

	Native Soils	Synthetic Soils
Bean (8 weeks growth)		
F better than U	3/12 = 25%	10/37 = 27%
F same as U	7/12 = 58%	22/37 = 59%
F poorer than U	2/12 = 17%	5/37 = 14%
Onion (8 weeks growth)		
F better than U	4/12 = 33%	8/37 = 22%
F same as U	6/12 = 50%	18/37 = 49%
F poorer than U	2/12 = 17%	11/37 = 30%
Tomato (8 weeks growth)		
F better than U	3/12 = 25%	3/37 = 8%
F same as U	7/12 = 58%	27/37 = 80%
F poorer than U	2/12 = 17%	7/37 = 19%
Lettuce (8 weeks growth)		
F better than U	4/12 = 33%	5/37 = 14%
F same as U	7/12 = 58%	25/37 = 68%
F poorer than U	1/12 = 8%	7/37 = 19%

Key: F = fertilized
U = unfertilized

TABLE 7. SYNTHETIC SOILS SUPPORTING GOOD GROWTH & YIELDS

BLEND NUMBER	PROPORTIONS	
#5	100% INCINERATOR ASH	
#13	50% INCINERATOR ASH 50% COMPOST	
#14	50% INCINERATOR ASH 50% BOTTOM ASH	
#21	33% INCINERATOR ASH 33% BOTTOM ASH 33% COMPOST	
#22	33% INCINERATOR ASH 33% BOTTOM ASH 33% LIME SLUDGE	
#30	10% BOTTOM ASH 10% LIME SLUDGE 20% INCINERATOR ASH 20% FLY ASH 40% COMPOST	
#32	10% INCINERATOR ASH 10% FLY ASH 20% COMPOST 20% BOTTOM ASH 40% LIME SLUDGE	
#33	10% FLY ASH 10% COMPOST 10% BOTTOM ASH 10% LIME SLUDGE 60% INCINERATOR ASH	
#35	10% BOTTOM ASH 10% LIME SLUDGE 10% INCINERATOR ASH 10% FLY ASH 60% COMPOST	Best Blend
#36	10% LIME SLUDGE 10% INCINERATOR ASH 10% FLY ASH 10% COMPOST 60% BOTTOM ASH	Second Best Blend

greater rate of pale or less perfect leaves, suggesting the presence of some deleterious growth factor which does not manifest itself in the shorter term vegetable trials.

Taste tests, comparing produce from the controls and the 10 best synthetic soils, were conducted by the senior author (LDD). The tomatoes were eaten raw, the lettuce on sandwiches, and the beans microwaved. The onions were too piquant raw to differentiate any subsequent flavor, so they were also microwaved. In all cases, flavor and texture could not be distinguished between produce from synthetic and control soils.

Discussion

Three weaknesses are conspicuous in the preceeding experiments:

1. The water supply was pumped from the Iowa River and treated by the University water treatment facility. This river is in the heart of the Corn Belt region and is excessively enriched with nutrients. During spring runoff, the treated water supply sometimes even exceeds the drinking water standard for nitrates, which is 10 mg/l NO_3-N. Hence, the unfertilized vegetables might have obtained some nutrients which would have not been available in a field situation dependent entirely upon rainwater.

2. Old clay pots were used, which could have supplied some micro-nutrients.

3. The sample size is small. All F vs. U pairs ideally should have been run in triplicate and evaluated for internal consistency, but greenhouse space was too limited.

These limitations are not serious in terms of the eventual practical field application of synthetic soils. If the waste blend being considered for a source region proves to be deficient in a particular macro- or micro-nutrient; either another waste can be incorporated to supply it or a commercial fertilizer source could be utilized. Coal combustion residues (CCR) are well-endowed with trace elements (Linton et al., 1976; Theis & Wirth, 1977) and would in most cases be readily available as a micro-nutrient source. Because of the pervasive use of coal in most regions and the limited market for CCR, this ingredient is likely to be candidate for most synthetic soils.

An interesting and potentially valuable aspect is that many of the more complex synthetic blends resembled real soils. The organics in the fly ash and compost made the synthetic blends black, while the bottom ash and silts gave them a granular texture, so the blends looked like, handled like, and felt like real soils. This appearance improved with age. When first blended, the soot from the fly ash would leave a person's hands filthy, requiring abrasive soap to get clean again. By the end of the oak experiments, a year later, a person's hands would be no more dirty from handling it than from a native black topsoil. We speculate that cross-polymerization and satisfaction of free chemical bonds has probably made the organics less reactive and incorporated them into more stable molecules, perhaps more similar to native soil organics. Appearances similar to native soils could prove useful, because one of the fears behind NIMBY is the notion someone might be dumping environmentally damaging substances. A demonstration of healthy plants growing in something that looks like soil, feels like soil and smells like soil may help to convey the message a proposed blend is no more risky than soil (assuming rigorous tasting has already demonstrated this to be factually correct).

These experiments are preliminary. Within any region, much more elaborate greenhouse experiments would be needed to outline the potential role of individual bulk wastes. The most promising blends will need to be tested in field plots, sampling not only growth but heavy metal redistributions in plants and soil drainage water. Finally, full scale permitted field trails, with appropriate monitoring, will be needed to design efficient means of spreading and blending the wastes on the landscape. Our preliminary short-term results are sufficiently promising that we encourage others to begin experiments with the bulk wastes in their area.

Here in Iowa, should these steps prove favorable, an obvious application would be the reclamation of abandoned coal surface-mines. During the past decade, much of the reclamation dollar was used for reshaping spoil piles, yet little cover soil is available and failures are all too common (Drake, 1991). Orphan surface-mine reclamation has essentially ceased within the state because of the expense and poor results. However, if synthetic soils can be blended from bulk wastes, reclamation might proceed as a less-costly alternative to landfilling. The ridge and valley configuration of shaley orphan spoils could form a leachate collection system, if needed, and be completely buried beneath a slightly domed cap of synthetic soil, almost eliminating the need for bulldozing the site (see Figure 1). Suitably blended synthetic soils will provide adequate rooting depth, an important criteria for establishing an effective permanent vegetative cover. A rising water table, produced by groundwater recharge beneath the new carbon-rich landscape, should cut off the oxygen supply to pyritic minerals in the shaley spoils and eliminate acid mine drainage and the solution of heavy metals which accompany it. This would help make a case for a thick synthetic soil cover, which would then improve the economics of reclamation as a waste utilization option.

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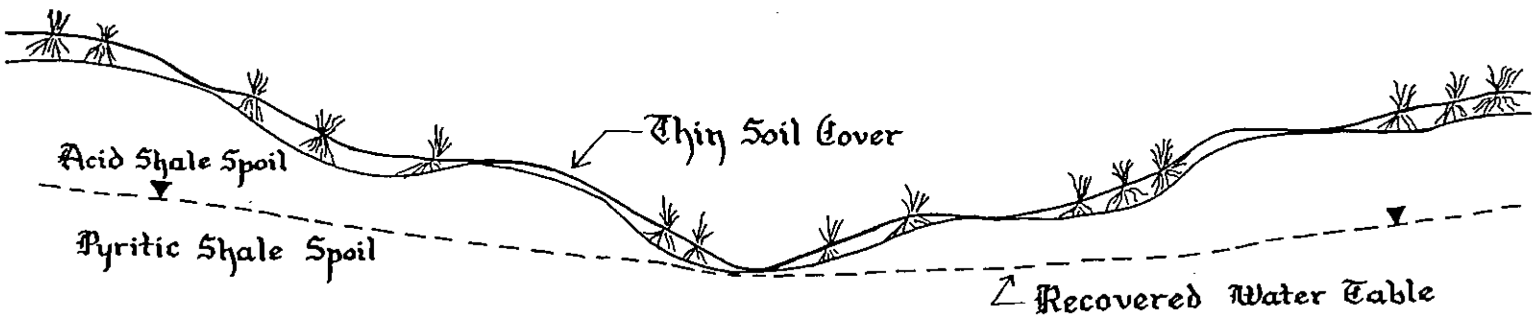
Typical Iowa Abandoned-Mine Reclamation



Proposed Synthetic Soil Reclamation

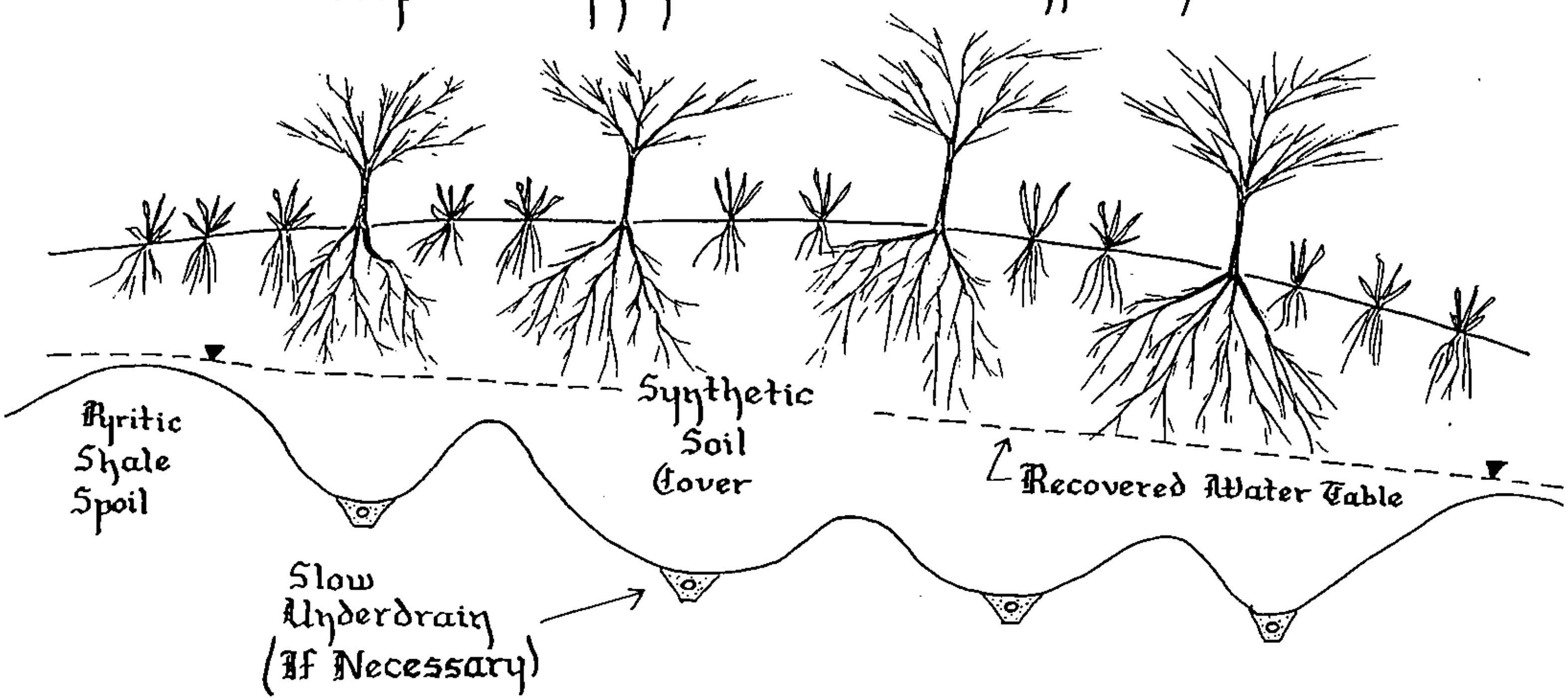


FIGURE 1