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The effects on topsoil of long-term storage in stockpiles

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Summary During many quarrying, civil engineering and landscaping schemes topsoil is stripped from the site and stored in large heaps. These remain *in situ* for many years before the soil is reused and it is generally believed that there is a great reduction in the 'quality' of the soil during that period.

A study of stockpiles of different size, age and soil type has revealed that biological, chemical and physical changes do occur, mainly as a result of anaerobic conditions within the heaps, but also as a result of mechanized handling during the stripping and stockpiling. Visible changes occur within 0.3 m of the surface of stockpiles of clayey textured soils, but only below about 2 m depth for sandy textures. These visible changes are accompanied by chemical changes, particularly in the forms of nitrogen present but also in the content of available nutrients, pH and organic matter levels. Biological changes include reductions in potential for mycorrhizal infection, soil biomass and especially earthworm population. The soil atmosphere contains high levels of carbon dioxide, methane, ethane and ethylene. Physical changes include reduction in aggregate stability and resistance to compaction, increase in bulk density and changes in pore size distribution and micro-structure, as revealed by scanning electron microscopy.

Limited evidence suggests that many of the adverse effects quickly disappear when the soil is respread.

Introduction

Soil, especially topsoil is often saved from sites about to be disturbed, and placed in stockpiles for subsequent reuse in landscaping or restoration work. It is generally believed that in addition to the damage caused by mechanised handling and the compaction by heavy earth-moving machinery, there is a deterioration in the quality of the soil during storage. Hunter and Currie[5] considered that anaerobic conditions in topsoil heaps had affected organic compounds concerned in soil aggregation. O'Flanagan *et al.*[12], however, found relatively little structural deterioration and although rates of nitrification and counts of aerobic bacteria decreased with storage, there was a rapid recovery when the soil was respread. American workers, *e.g.* Miller and Cameron[10]; Singleton and Williams[16]; Reeves *et al.*[14]; Rives *et al.*[15] have concentrated attention on biological changes and have found, in particular, that long-term storage of topsoil causes substantial reductions in the population of viable vesicular-arbuscular mycorrhiza (VAM).

Eighteen topsoil storage heaps were examined representing a range of textures, ages and conditions of construction and storage. Samples removed from various depths within the heaps were compared with similar topsoils on adjacent, unworked land. A range of physical, chemical and biological determinations was carried out. The most significant of these are presented here for three characteristic heaps representative of soils of sandy texture (Charing Heath, Ashford, Kent), loamy texture (Bush Farm, Upminster, Essex) and clayey texture (Haywarden Farm, Tonbridge, Kent). Ages of these heaps was from 1½ years (Tonbridge) to over 7 years (Charing Heath), and heights of stacking varied from 3 to 7 m.

Methods

Soil atmospheres were collected by the method of Dowdell *et al.*[4] and analysed by gas chromatography. Aggregate stability was measured according to MAFF[9]. Standard chemical tests were carried out according to procedures described by MAFF[8]. pH was determined in a 1:2.5 soil:water suspension and organic matter by the Walkley–Black method. Phosphate was extracted by $1M$ $NaHCO_3$ solution at pH 8.5, potassium and magnesium by $1M$ NH_4NO_3 and manganese by $1M$ NH_4 acetate. The method of Jackson (1958) was used to extract iron with $1M$ NH_4 acetate. NH_4^+ and NO_3^-–N were extracted with $2M$ KCl. Earthworm populations were obtained by drenching soil with formaldehyde according to the procedure of Raw[13] and microbial biomass was obtained by the method of Jenkinson and Powlson[7]. The mycorrhizal population was investigated on the sandy soils of the Charing Heath site by the bioassay method of Moorman and Reeves[11] with samples from the surface of the undisturbed soil and from a depth between 1.8 and 2.0 m in the stockpile. A pot test growing lettuce was set up using undiluted soil and soil diluted with potting compost at $\frac{1}{4}$ and $\frac{1}{40}$ dilution. Each treatment was replicated five times. Plants were harvested 30 days after sowing and the percentage infection of the roots with vasco-arbuscular mycorrhiza (VAM) was calculated according to Daft and Nicholson[3].

Results and disucssion

Physical changes

The most obvious change in stockpiled topsoils was that the soils

Table 1. Soil atmospheres in stockpile heaps

Site	Depth m	Methane ppm	Ethane ppm	Ethylene ppm	O_2 %	N_2 %	CO_2 %
Charing Heath	0.5	.240	0.73	0.01	20.6	78.6	0.43
(CH)	2.0	2.45	1.01	0.17	19.1	78.9	1.96
Bush Farm	0.5	4.41	5.99	0.08	19.9	76.9	0.89
(BF)	1.5	4.65	3.72	0.18	18.6	78.7	2.31
Tonbridge	0.3	4.92	1.37	0.15	21.2	77.1	0.51
(T)	1.0	4.72	1.86	0.19	19.8	78.6	3.81

became dark grey in colour and gave off a characteristic anaerobic smell at depths from the surface which varied with soil texture. In the sandy Charing Heath soil the visual change occurred at about 2 m from the surface, whereas it was at about 1.3 m in the loamy Bush Farm soil and at only 0.3 m depth in the clayey Tonbridge heap.

The anaerobic nature of the heaps was also shown by analysis of soil atmospheres (Table 1). CO_2 and ethylene contents increased with depth and high levels of methane and ethane were found even relatively near the surface.

Compared with undisturbed soils, aggregate stability, measured on 1–2 mm aggregates, was greatly reduced by storage in the sandy and clayey heaps (Charing Heath and Tonbridge) but there was little effect on the loamy soil (Bush Farm) as shown in Table 2. Supplementary tests on the resistance of the soils to compaction under applied pressure at various moisture contents showed that stockpiled soils compacted slightly more at equivalent pressures and moisture contents than unworked soils. The corresponding reduction in the number of coarser pores, important for soil drainage, suggests that stockpiled soils are likely to be more susceptible to structural damage during subsequent respreading than they were before being stripped.

The microstructure of unworked and stockpiled soils was examined by scanning electron microscopy[1]. Loss of microstructure in stockpiled soils is particularly marked, even in the loamy Bush Farm soil. It is, however, uncertain how much of this damage is due to stockpiling *per se* or to the effects of compaction by heavy earth-moving machinery at the time the heaps were constructed. Bulk densities of surface soils showed an increase from unworked to stockpiled soils near the top of the heaps of the order of 1.5 to 1.8 for the loamy soil and 1.1 to 1.3 for the clayey soil. Bulk densities could not be determined accurately at depth in the heaps because of sampling difficulties.

Table 2. Aggregate stability (1–2 mm) of unworked and stockpiled soils

Charing Heath		Bush Farm		Tonbridge	
Soil depth m	Aggregate stability %	Soil depth m	Aggregate stability %	Soil depth m	Aggregate stability %
Unworked	34.4	Unworked	8.6	Unworked	95.7
0–0.2	2.6	0–0.2	8.1	0–0.2	77.9
0.4–0.5	1.1	0.2–0.3	5.4	0.2–0.3	82.3
0.7–0.8	0.6	0.3–0.4	8.1	0.3–0.4	61.9
0.8–0.9	1.7	0.4–0.5	9.2	0.4–0.5	49.4
0.9–1.0	2.0	0.5–0.6	6.2	0.5–0.6	60.8
1.0–1.25	0.7	0.6–0.7	6.3	0.6–0.7	50.6
1.25–1.5	1.0	0.7–0.8	13.0	0.7–0.8	45.7
1.5–1.7	6.3	0.8–0.9	18.4	0.8–0.9	43.0
1.7–1.8	6.3	0.9–1.0	2.8	0.9–1.0	39.5
1.8–2.0	15.9	1.0–2.0	3.7	1.0–1.5	33.9

Chemical changes

The chemical properties of samples from the three stockpiles and corresponding unworked land are given in Table 3.

The anaerobic nature of the heaps is most clearly shown by the contents of extractable manganese and ferrous iron. In the clayey Tonbridge heap, for example, ferrous iron rises from 72 to 5800 μ6/g at the point where the visible colour change in the soil occurs, and continues to rise with depth. In the sandy soil (Charing Heath) the sudden rise in iron content occurs at a much greater depth – around 1.5 m, just above where the colour change occurs. Results for the Bush Farm heap are much more variable and show no consistent trend with depth. Indeed, the results suggest the heap may be more heterogenous than was supposed. Corresponding trends are shown by manganese but in this case the results for the Bush Farm heap also show increased levels and hence probably increased anaerobism with depth. Tests on an adjacent heap at Bush Farm[2] showed that a high level of ferrous iron (1028 μg/g) in a composite sample taken from the core of the heap during respreading had dropped to only 124 μg/g in the respread soil two weeks later.

There is little variation in the amount of NO_3–N with depth in the stockpiles and levels are similar to those in unworked soils, analysed at the same sime. NH_4–N, absent or at a low level is unworked land, rises with depth in all stockpiles almost certainly because of the increasing anaerobism. The increase in pH in the stockpiles corresponds with the build-up of ammonium.

Extractable P, K and Mg tend to increase in the clayey Tonbridge stockpile, but to decrease slightly in the sandy (Charing Heath) and loamy (Bush Farm) stockpiles. In all cases, however, the levels are quite

Table 3. Some chemical properties of unworked (U) and stockpiled (S) soils – Charing Heath (CH), Bush Farm (BF) and Tonbridge (T)

Soil depth (m)	pH (1:2.5)	Organic matter %	Extractable elements μg/g						
			P	K	Mg	NH_4^+ N	NO_3^- N	Mn	Fe
CH(U)	5.3	1.9	34	162	100	0	3	5	228
(S)–0.2	6.5	0.7	19	61	24	3	1	7	534
0.4–0.5	7.0	0.3	21	30	23	2	2	7	371
0.7–0.8	6.6	0.5	19	30	23	2	2	7	323
0.8–0.9	6.5	0.6	24	30	22	3	2	20	133
0.9–1.0	6.2	0.7	30	30	28	4	1	32	157
1.0–1.25	6.5	0.4	24	30	26	4	2	55	155
1.25–1.5	6.4	0.7	29	30	28	13	1	139	697
1.5–1.7	6.5	0.8	32	30	36	19	2	164	4800
1.7–1.8	6.5	0.8	36	40	34	24	2	138	5280
1.8–2.0	6.4	1.1	34	70	41	50	2	169	6310
BF(U)	6.8	3.9	158	255	110	0	6	0	181
(S)0.02	6.8	3.1	140	193	88	1	3	0	43
0.2–0.3	6.9	2.9	156	193	89	10	8	5	132
0.3–0.4	7.1	2.7	153	183	95	17	10	5	23
0.4–0.5	7.0	2.9	161	214	107	26	9	12	90
0.5–0.6	7.1	2.9	145	183	102	30	30	15	136
0.6–0.7	7.0	2.8	132	214	105	25	26	7	91
0.7–0.8	7.0	3.7	171	246	97	105	8	12	233
0.8–0.9	6.9	3.8	163	285	88	117	6	15	301
0.9–1.0	7.1	3.2	130	173	79	77	9	7	164
1.0–2.0	7.1	2.8	130	194	97	50	9	7	197
T(U)	6.4	8.9	13	75	181	2	12	16	0
(S)0.02	6.2	7.9	36	169	271	3	11	16	117
0.2–0.3	6.5	8.1	48	158	265	9	21	42	76
0.3–0.4	6.5	8.3	51	189	281	177	17	52	72
0.4–0.5	6.3	7.2	40	168	254	364	18	52	5800
0.5–0.6	6.3	8.1	36	147	228	407	22	42	7035
0.6–0.7	6.4	7.1	35	137	229	422	25	42	13893
0.7–0.8	6.4	7.4	33	126	237	404	24	42	15860
0.8–0.9	6.5	6.1	31	116	245	307	20	74	17089
0.9–1.0	6.5	6.6	29	116	246	246	19	87	14000
1.0–1.5	6.5	6.6	28	126	260	259	22	92	18121

acceptable for agricultural purposes and so it could not be said that stockpiling had adversely affected chemical fertility, except in the case of nitrogen. On land restored with stockpiled soils nutrient defficiencies are rarely encountered but higher levels of nitrogenous fertilisers are usually recommended. Liming respread soils is required only when pH values are low.

Probably the most significant change due to stockpiling is a reduction in organic matter content: in the sandy heap (Charing Heath) up to 85% of the organic matter originally present has been lost and up to 32% in the other two soils.

Biological changes

Stockpiling has an adverse effect on the earthworm populations. The Results in Table 4 for earthworm number and biomass, both fresh and dry weights, are significantly lower ($p < 0.05$) for stockpiled soils than for adjacent unworked land.

Soil biomass, excluding earthworms, is given in Table 4 and similarly shows significant reductions in the stockpiles.

The mycorrhizal populations of the sandy soils of the Charing Heath site are given in Table 5. Storage has substantially reduced VAM infection, as found by the American workers quoted above. The $\frac{1}{4}$ dilution and $\frac{1}{40}$ dilution both showed that infection in unworked soil was approximately six to ten times greater than in the stored topsoil. Nevertheless the stored soil still retained sufficient mycorrhizal population to produce a 67% infection of the lettuce roots.

Table 4. Earthworm populations and biomass contents

Site	Soil	No. of earthworms	Earthworm biomass g/m^2		Microbial biomass mgC/100 g dry soil
			fresh weight	dry weight	
Charing Heath	Unworked	79	225.0	45.6	8
	Stockpile	17	52.3	8.7	6
Bush Farm	Unworked	64	276.4	44.3	365
	Stockpile	40	90.5	13.1	307
Tonbridge	Unworked	141	159.0	28.9	1435
	Stockpile	20	26.5	4.0	1254

Table 5. VAM infection of bioassay plants grown in unworked and stored topsoil (Charing Heath site)

Treatment	Per cent mycorrhiza infection, mean*
Unworked soil	
undiluted	79.3 a
$\frac{1}{4}$ dilution	50.0 c
$\frac{1}{40}$ dilution	19.1 e
Stored topsoil	
undilited	66.6 b
$\frac{1}{4}$ dilution	5.4 d
$\frac{1}{40}$ dilution	3.4 d

* Values followed by the same letter are not significantly different ($p < 0.05$)

Conclusion

It is well known that mechanised handling can seriously damage soils and it is difficult if not impossible to separate the effects of compaction by earthmoving machinery from those due to storage *per se*.

Unfortunately no heaps were available which were created by techniques such as the dump truck and back-acter method whereby soil is not compacted by machinery. Also it was very evident in some of the heaps that subsoil of totally different character had been incorporated, and there were pockets of extremely anaerobic soil associated with the burial of vegetation along with the soil.

Nevertheless, it is clear that while adverse effects due to storage can be demonstrated, the extent of deterioration of soil in stockpiles has been greatly overestimated. There is no reason why soils should not continue to be stockpiled and subsequently reused, though perhaps greater care should be taken to minimise compaction by earthmoving machinery, to avoid mixing topsoil and subsoil and to prevent loss of, or contamination of, soil while in store. Recommendations regarding the optimum size and shape of stockpiles are being prepared.

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