ESTABLISHING LONG-TERM VEGETATIONAL COVER ON ACIDIC MINING WASTE TIPS BY UTILISING CONSOLIDATED SEWAGE SLUDGES

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ABSTRACT

Many mining wastes in West Yorkshire contain a readily oxidisable form of iron pyrite. Pyritic oxidation generates sulphuric acid, which can rapidly destroy the vegetation established upon such restored sites, leading to problems of erosion. A joint project between Yorkshire Water and the Ecological Advisory Service commenced in 1981 to determine whether consolidated sewage sludge could provide an answer to these problems. Pot trials, growing various amenity and agricultural grass mixtures in substrates consisting of acidic mine wastes and sewage sludges, were undertaken, Substrate pH was found to be stabilised and the mixture proved to be highly fertile, sustaining good grass production over a period of nine years. The grasses were monitored for the uptake of the potentially toxic elements (PTE) Cr, Ni, Cu, Zn, Cd and Pb, which were found to be present in quantities significantly lower than both phyto- and zootoxic levels. These trials progressed, with the co-operation of Local Government Authorities to field scale reclamation. Sites reclaimed by the method developed, have been continualy monitored for substrate pH and PTE uptake into the sward at monthly intervals for five years in some cases, and the technique has been shown to be successful, providing a seed bed resistant to acid regression whilst sustaining high sward productivity and low PTE uptake. Approximately forty hectares of previously derelict colliery waste tips have now been reclaimed by this method which utilises 700 $tDSha^{-1}$ of consolidated sewage sludge.

Introduction

Successful reclamations of two extremely acidic minestone waste tips (pH < 3.0), which previously defeated all attempts to establish vegetation, have recently been achieved by treating the waste with up to 700 tDSha-1 of consolidated sewage sludge.

The treatment technique, developed jointly by Yorkshire Water and the Ecological Advisory Service, has been adopted and used by various local government authorities to restore over 40 ha of derelict minestone tips.

The cost of restoration is extremely important to local authorities operating under the financial constraints of government grant-aided budgets, savings in excess of £2000 per hectare can be achieved over soil-based techniques. The supplying water company also gains financial benefit in the reduction of sludge disposal costs.

Sewage Sludge

Sludges originate as a waste by-product of the processes involved in sewage treatment. They consist of the suspended organic matter which is removed by settlement. At this stage, they may have a dry solids (DS) content ranging from 2% to 12%.

At larger sewage treatment works they will often be thickened by processes such as centrifuging, pressing or lagooning in which the dry solids content will be raised to approximately 30%.

When further consolidated by stacking in windrows it is possible to achieve a material in excess of 50% DS which physically resembles, and can therefore be handled as, a rich loam soil. It possesses little or no odour and has an organic matter content in the order of 50%.

Sludges do however generally contain a higher proportion of potentially toxic elements (PTEs) than most soils, arising from the trade wastes discharged to the sewerage system. The degree and type of PTE contamination various from works to works dependent upon the nature of industry within the particular works catchment area. Careful selection of sludge and mineral waste can however, create 'soils' which are well within the E.E.C. limits for PTEs in agricultural soils.

The Reclamation Technique

The technique for establishing permanent vegetational cover is basically very simple. The constraints lie mainly in the physical limitations of machinery to spread and achieve incorporation of the sludge. Thus steep slopes of greater than 33-45% cannot be worked by tractor driven vehicles and trailers. Sites may therefore have to be contoured, both to avoid steep slopes and to achieve the desired landscape.

The site is then prepared by ploughing, ripping or re-grading the surface such that a layer into which the sludge may be cultivated is formed.

The sludge, chosen through pot trials, and having a DS content of 40-50%, is then tipped on site, bladed out to form a layer 7-10cm in depth, and cross-ripped or rotavated into the surface 7-10cm of mine waste. The prepared seed bed thus consists of a 1:1 volumetric mixture of mine waste and sludge. Because of the different bulk densities of the two materials, this will be approximately equivalent to a 2.4:1 mine waste:sludge mixture by dry weight. The seed bed created may then be rolled or left to settle prior to seeding with a selected grass mixture. [Metcalfe, 1984]

The technique works by accelerating natural soil forming processes, in which colonising vegetation slowly adds organic matter to weathered rock, allowing further colonisation. In this case, the sludge not only provides a rapid injection of organic material, it also supplies considerable quantities of major nutrients in slow release form, which promote, rapid establishment of the grass. Adequate nutrient remains available after six years to provide a satisfactory crop, and therefore no fertiliser applications or other amendments are needed, even if the grass is harvested or grazed.

A lush sward develops within two months of seeding and may be harvested or grazed depending upon the desired after-use of the area. In time, a natural humus layer is built up increasing the depth of the seed bed. Our observation, on sites restored some eight years ago, is that this humus layer is formed at the rate of approximately 1cm per year. [Metcalfe & Lavin, 1989]

Theory and Practice

Many of the historic mining waste tips in West/South Yorkshire, presently under local government control, contain a form of iron pyrites (FeS_2) which, when exposed to moist atmospheric oxygen, rapidly oxidises to form ferrous sulphate and suphuric acid.

$$4FeS_2 + 4H_2O + 14O_2 = 4FeSO_4 + 4H_2SO_4 \quad (1)$$

The ferrous sulphate may then be oxidised to generate a further and equal quantity of sulphuric acid.

$$4FeSO_4 + O_2 + 10H_2O = 4Fe(OH)_3 + 4H_2SO_4 \quad (2)$$

The net effect is that 1.0gm of sulphur in pyrite can produce 3.059gm of sulphuric acid. [Norton, 1988]

In minestone, some proportion of the acid will be neutralised by calcium carbonate ($CaCO_3$) contained in such minerals as ankerite, siderite, calcite, apatite, dolomite etc, this being determined by the solubility of calcium carbonate and bicarbonate in water. [Geidel, 1979]

Sufficient acid may, however, remain to attack the clay lattice of a soil cover liberating PTEs such as nickel and zinc, which are phytotoxic and cadmium, which is zootoxic, may accumulate in the herbage to a degree which is deleterious to the health of grazing livestock.

When such mining waste tips are contoured and regraded in a restoration scheme, fresh unweathered pyrite is inevitably brought to the surface to commence oxidation. [Chadwick et al, 1978]

The contrast in the behaviour of soils and consolidated sludges when mixed with such a waste was clearly demonstrated in laboratory/ greenhouse pot trials.

In the following experiment an acidic minestone, pH 2.5, was mixed volumetrically 1:1 with soil and limed to pH 6.5 before being sown with a grass/clover seed mixture at a rate equivalent to a field sowing of 20gm m^{-2}. The test was duplicated by mixing the minestone with a limed sewage sludge, consolidated by pressing and windrowing. In this case, pH adjustment proved to be unnecessary. Table 1 shows the analysis of the original materials.

Table 1 Analysis of Materials Used

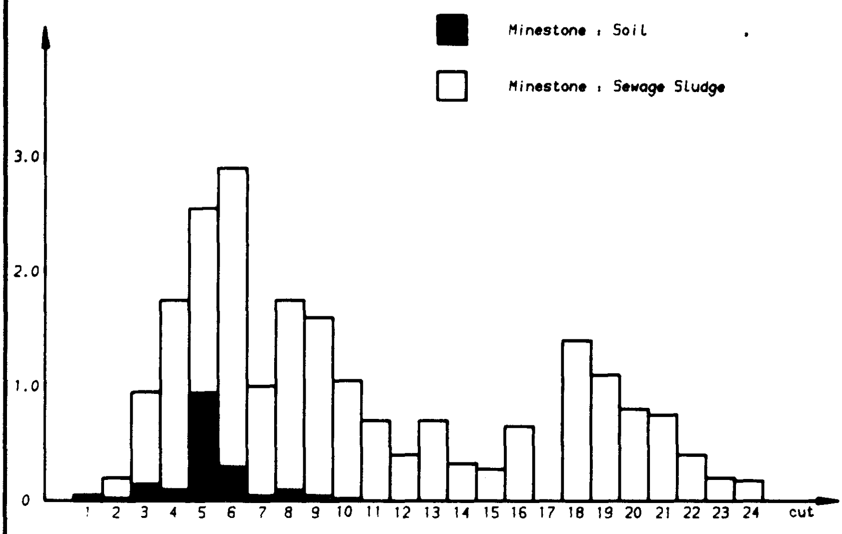
	pH	%N	%P	%K	Cr	Ni	Cu	Zn	Cd	Pb
							$mgkg^{-1}$DS			
Minestone	2.5	1.15	0.52	1.03	10	17	44	35	<1.0	41
Soil	5.9	0.26	0.18	0.24	22	14	27	77	1.0	77
Sewage Sludge	7.2	1.12	1.85	0.19	560	21	334	388	2.5	183

Ten replicates of each test were made and randomly arranged, in saucers to prevent leaching losses, in a cool greenhouse.

A 28 day growth period was allowed prior to each cutting. Pots were harvested at a standard 1.5cm above 'soil' level and the collected grass cuttings were dried in a moisture extraction oven at 100°C foor 24 hours and weighed to enable dry matter production to be determined. The dried grasses were then composited by test, milled to pass a 1mm mesh screen, and analysed for their PTE contents by atomic absorption spectrophotometry.

Figure 1 demonstrates the contrast in the productivity of the two mixtures.

Figure 1. Monthly dry matter production, tonnes DM $hectare^{-1}$



After six months, the grass in the minestone/soil mixture was dead due to the high acid production. The pH, when checked at this time, proved to have fallen to <3.0 from the original pH of 6.5 despite the inclusion of lime.

The minestone/sludge mixture had retained the original pH, and indeed continued to do so throughout the duration of testing. Some four years later these pots still retain a pH >6.0. In terms of total productivity, the minestone/sludge mixture yielded a crop equivalent to 21.64 $tDMha^{-1}$ in two years; the minestone/soil mixture produced only 1.12 $tDMha^{-1}$ before the grass cover was destroyed.

The productivity of the minestone sludge mixture can be compared to that of an agricultural sward. An irrigated grass/clover sward can yield approximately 15.8 tDMha-1 when supplied with 520 kg N ha^{-1} yr^{-1}. The yield is however influenced by harvesting, yield being inversely proportioned to the number of cuts. If the cutting frequency is raised from 3 to 8 cuts per year the yield is depressed by 36-65% depending upon the nitrogen availability. At a cutting frequency of 13 cuts/year, this experiment is not geared to producing high yields and yet the minestone/sludge mixture generated a yield of 14.84 and 6.8 $tDMha^{-1}$ in the first and second year respectively. [British Grassland Society, 1980]

When discussing PTE uptake it is important to define certain concentration criteria against which the trial results may be assessed. Table 2, drawn from various sources, summarises these criteria. [Allaway, 1968; Davis and Beckett, 1978; Underwood, 1977]

Table 2 Typical ranges, Background concentration To, Upper Critical concentrations Tc in plants - $mgkg^{-1}$ DT and Upper Critical levels TA - $mgkg^{-1}$ Total Diet, of PTEs for livestock.

Metal	Cr	(P) Nr	(P) Cu	(P) Zn	(Z) Cd	(Z) Pb
Typical Range		1-10	4-15	15-200	0.2-0.8	0.1-10.0
Natural Background To	1.0	2.0	11.0	50.0	0.5-<1.0	3.0
Upper Critical Tc	10.0	14.0	21.0	221.0	10.0	35.0
Livestock Ta,						
sheep	50.0				3.0	3.0
cattle	50.0	50.0	50.0	900.0		10.0

(P) = Phytotoxic (Z) = Zootoxic

The upper critical level Tc is defined as the level of PTE in the plant tissue at which the yield begins to reduce, not the level at which the grass dies. [Davis & Beckett, 1978]

Figure 2. Plant tissue concentrations of Nickel - Log_{10} mg Kg^{-1} DT

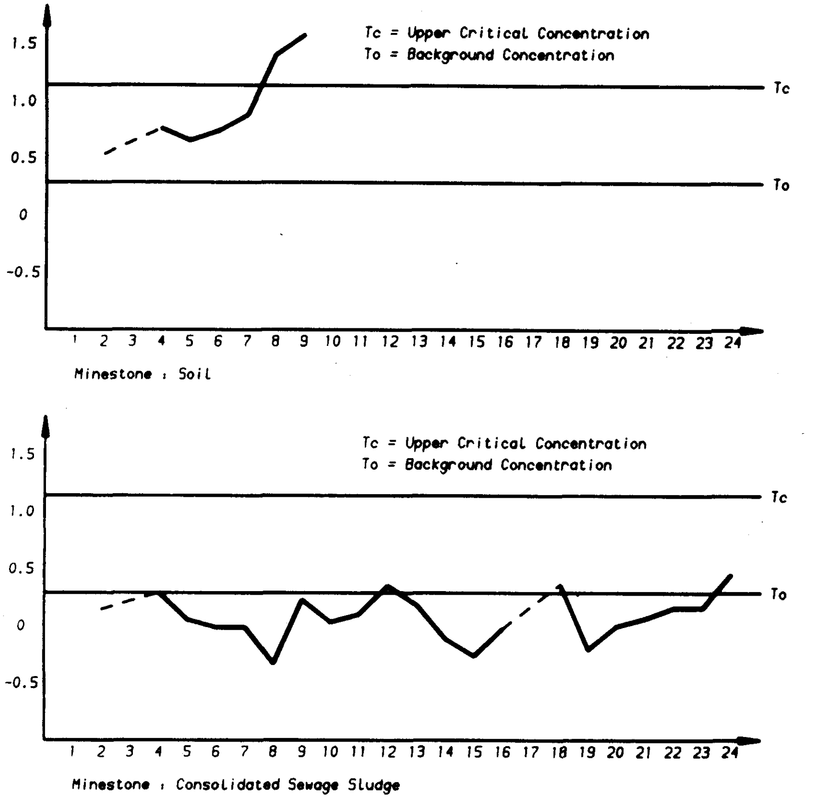


Figure 3. Plant tissue concentrations of Zinc - Log_{10} mg Kg^{-1} DT

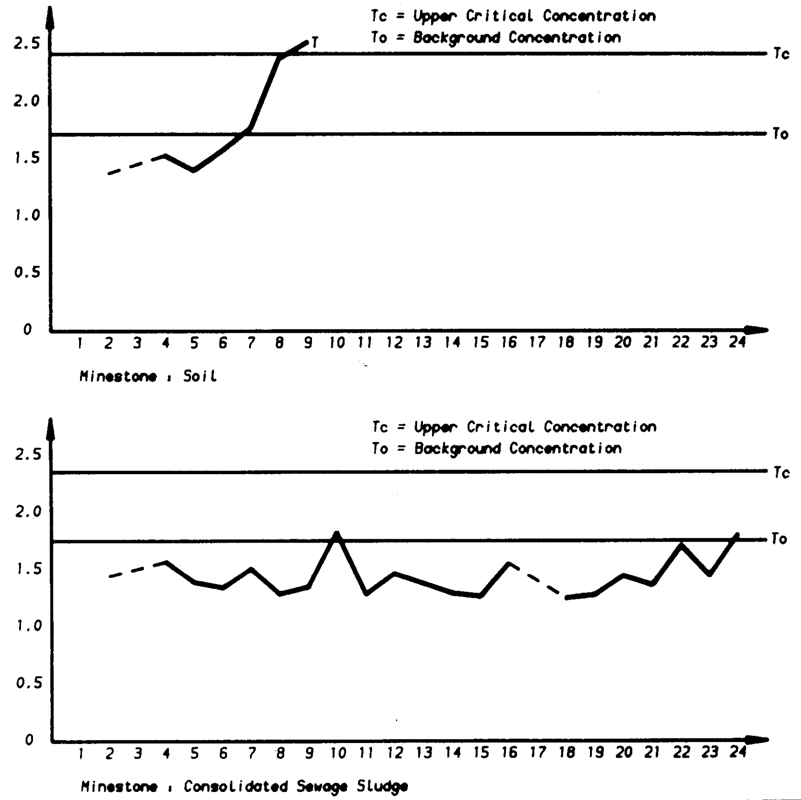
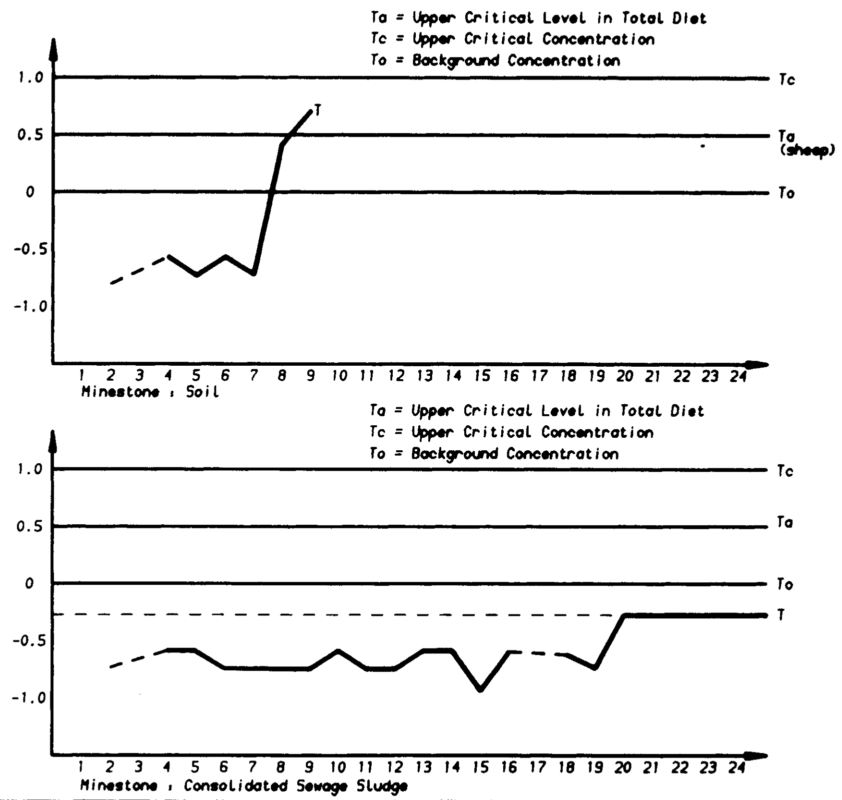


Figure 4. Plant tissue concentrations of Cadmium - Log_{10} mg Kg^{-1} DT



When the tissue concentrations of PTEs in the test crops are shown graphically as $\log_{10}$ equivalents against these criteria, the relationship between the criteria and the plant uptake becomes readily apparent.

Figures 2-4 demonstrate that the acid produced by the mine waste attacks the soil liberating the metals nickel zinc and cadmium, all of which accumulate in the grass tissue to an unacceptable degree before the grass cover is destroyed.

In contrast the minestone/consolidated sludge mixture, although it contains a greater reservoir of PTEs, consistently produces levels of these elements at, or below, the naturally occurring background levels.

It must however be remembered that both mining wastes and sewage sludges, originating from different localities, are variable materials. It is, therefore, important to select the right sludge for a particular mine waste. Typically, in an experiment of this nature, several sludges will be tested with the minestone and the most suitable will be used for site restoration.

Due to the accelerated growth rate and prevention of leaching, pot trials have a tendency to exaggerate factors such as PTE uptake. Sludges which prove acceptable in pot trials hence provide a wide safety margin for field use. Pot trials cannot however predict effects of local conditions pertaining to the geography of the site itself, eg. drainage patterns within the tip. We have therefore adopted the approach of treating sites as individuals and monitoring the restored site for substrate pH and metal uptake for up to 5 years in some cases. [Metcalfe & Lavin, 1989]

Conclusions

The consolidated sewage sludge reclamation technique for acidic minestone wastes has been demonstrated to work successfully at a number of sites over a period of some nine years in both West and, latterly, South Yorkshire.

Continuous monthly field monitoring for pH, PTE uptake and soil analyses have demonstrated that the method provides permanent and stable restoration of acidic minestone, on which conventional techniques have previously failed. [Metcalfe & Lavin, 1989]

The potential for the expansion of such a system nationally is encouraging. There are approximately 45,700ha of land officially designated as derelict in England, some 48% of which has resulted from the extraction of coal. [Dept of the Environment, 1982]. Further potential exists in that a mixture of suitable minestones and consolidated sewage sludges could be used to provide a soil substitute in the restoration of other derelict land.

The technique permits considerable cost savings to be made by both local government authories and water companies. It also allows the water companies to be seen to be safely disposing of large quantities of sewage sludges in an "environmentally friendly" manner. Some of the sites, restored in this way, have been grazed by both sheep and cattle for up to 8 years, ie. they have passed into normal agricultural use.

In these current times of environmental concern, to use the waste products of two large industries to create land of amenity or agricultural capacity must surely be considered to be of value.

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