Editors
Ming H. Wong
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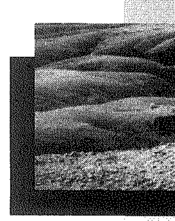

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Preface

It is an unfortunate but inescapable fact that we are unable to enjoy even a modest standard of living without damaging the surface of the earth. We occupy areas of it with our houses and buildings, and we cultivate large tracts of it in our agriculture. At the same time much of the materials we rely on for the things we make and use, and much of the fuel we use, come out of the ground, only after substantial disturbance.

We obviously accept the loss of land that we purposely occupy or cultivate. But the land that has been disturbed and degraded in our search for materials and then left, is quite another matter. This type of land inevitably accumulates if nothing is done to restore it. Some activities, such as surface mining can use and destroy over 100 ha per year on a single site. Others, such as deep mining for coal, may only use one or two ha a year, for the tipping of wastes, but in long established situations can accumulate hundreds of ha of destroyed land, as will be all too familiar in long established coal mining areas.

Such degradation is visually unattractive and casts a blight on surrounding areas sufficient to degrade them economically. But it can also be a serious threat to surrounding environments, by the transport of dust by the wind from the degraded areas, and by run-off of polluted water. Some dumps can constitute a major threat to local communities, exemplified by the appalling Aberfan disaster in S. Wales in 1967 where over 120 children and their teachers were killed when a colliery spoil heap slid into the local school killing a complete generation

In the last 40 years the serious nature of the problem has become appreciated, and a great deal of research has been carried out to find the best way of reclaiming such degraded land and restoring the plant and animal communities and soils – the ecosystems – that previously covered it. As a result a great deal of successful restoration has been achieved.

Nevertheless, on a world scale, there are still many areas where progress has been less than satisfactory. Often this is for economic reasons. Yet this is in turn often because the people concerned do not appreciate how the degradation can be treated simply and economically. They believe that restoration is difficult.

The trouble is that not all the information on restoration is readily available and brought into a coherent whole. This book is intended to answer this problem. It is the product of an Advanced Study Institute held in November 2000 at the Hong Kong Baptist University, attended by a selected number of specialists and practitioners, to review in simple terms what is known about the major problems involved in the restoration of degraded land, and how they can be treated economically, against a background of the situations in countries of Asia where restoration is a serious and immediate problem

It is all too common for the solutions known to be successful in one country to be considered as inappropriate for elsewhere, because of differences in climate and situation. Yet past experience shows that this is wrong – there is a body of general rules applicable to any degraded situation - of direct value to practitioners in all countries.

We hope that this small book – in effect a guidebook reviewing present problems and the modern approaches to their treatment – will be of value in stemming the tide of degradation and dereliction in many countries.

Acknowledgements

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The financial support from the Croucher Foundation is gratefully acknowledged. The Institute for Natural Resources and Environmental Management and the Biology Department would also like to express gratitude to Hong Kong Baptist University, and School of Life Science of Zhongshan University for co-sponsoring the event, all the authors for their contributions, and last, but not the least to Ms Doris Ng for her expert editorial assistance.

Editors

M.H. Wong and A.D. Bradshaw

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The Editors

Professor Ming H. Wong

After graduation from the Chinese University of Hong Kong with a BSc in Biology, Professor Wong obtained his MSc (Ecology), PhD (Soil Ecology) and DSc (Pollution Ecology) from the University of Durham. Professor Wong then served the Biology Department of The Chinese University of Hong Kong as Lecturer and Senior Lecturer from 1973 – 85, following which he became Head of the Biology Department of Hong Kong Baptist University (1986-) and was promoted to Chair Professor in 1990. He currently serves as Director of the Institute for Natural Resources and Environmental Management of the University.

Professor Wong's research work centers around restoration of derelict land and pollution ecology, especially heavy metals in earlier years, and persistent toxic substances more recently. He serves as regional co-ordinator of Central and North East Asia for the project "Regionally based assessment of persistent toxic substances" sponsored by the Global Environmental Facility (GEF) and implemented by the United Nations Environment Programme (UNEP).

Professor Wong has over 200 papers published in international scientific journals and edited several books. He serves on editorial boards of eight scientific journals related to environmental science, and is a Visiting Professor of several major institutes in Mainland China such as Nanjing Institute of Soil Science of The Chinese Academy of Science, Zheijian University, and Zhongshan University, and also Middlesex University in the UK.

Professor A.D. Bradshaw

Professor Bradshaw's first degree was in botany at Cambridge, followed by a PhD in plant evolution at Aberystwyth. He was lecturer in the Department of Agricultural Botany, University of Wales, Bangor from 1950 to 1968, and Holbrook Gaskell Professor of Botany of the University of Liverpool until his retirement in 1988, when he became a Research Fellow.

He has been a member of the UK Nature Conservancy Council, Natural Environmental Research Council, and Board of Management of the Sports Turf Research Institute. He was President of the British Ecological Society 1982 – 84, and first President of the Institute of Ecology and Environmental Management 1991 – 4. He was elected a Fellow of Royal Society in 1982 and has recently been given an honorary DSc by Hong Kong Baptist University.

His main research has been on evolution and on the reclamation of degraded land in urban and industrial environments. With his research group he has published many papers and books on these topics. He established the Environmental Advisory Unit of the University of Liverpool in 1974, until recently one of the largest environmental consultancy units of its kind in the UK. He has visited many overseas countries, particularly Hong Kong and China, to advise on land reclamation and environmental management.

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Chapter 1

Introduction – An Ecological Perspective

A.D. Bradshaw

The Problem

This book arises from a very successful Advanced Study Institute, about the restoration and rehabilitation of derelict land held in Hong Kong and Guangzhou in November 2000. The immediate reasons for paying attention to the problem, the visible degradation of many parts of the world are perhaps obvious. But the underlying causes are not necessarily so clear and are worth going over if we are fully to grasp the nature and seriousness of the problem we have to tackle.

The trouble is that impossible for us to live and have anything more than a minimal standard of existence, without disturbing the land surface of the Earth.

The land provides place for habitations, also materials from which those habitations are made, such as clay, stone, sand, cement. The land also provides materials needed for modern comfortable living, such as copper, iron, aluminium, kaolin and rare metals, on which many industries are based. The land also provides our major energy source, coal. Some of the materials are accessible by surface mining, others by deep mining. In the first case many hundreds of ha may be disturbed in large excavations; in the second case access is by small shafts, but it is nearly always necessary to bring up quantities of waste material which have to be deposited on the surface.

So living = disturbance = damage, because either the land surface itself is used, or has to be disturbed to get at what is underneath. The surface is used in material-winning processes, or in the simple process of living. In the past populations and expectations were small, so that damage was limited, although not insignificant. Now larger populations with larger expectations mean that the damage can be immense. A single mine for bauxite, the raw material for aluminium, can destroy over 100 ha of land a year.

Populations develop in association with mining and other industries, well shown in the coalfields of Europe and the USA and the metal mines of Australia (Blainey 1970). Many people, therefore, have damaged land where they live. At the same time the wastes from living – domestic garbage and waste building materials – are nearly always deposited as close as possible to where they originated and therefore on city outskirts, in what are now called landfill sites.

All this would not matter very much if the damaged land was inert. But is not. The damage entails 1. Loss of protective vegetation cover, 2. Loss of original soils, 3. Steep sided heaps.

The result is land which is

a) unstable	)
b) liable to erosion by wind and water	)
c) unable to support vegetation	) immediate
d) often a source of pollution	) problems
e) often a risk to human health	)

At the same time there is loss of

a) productivity (agriculture or forestry)	)
b) biodiversity (both plant and animal species)	) secondary
c) amenity	) problems
d) social attractiveness	)

In the worst cases this can lead to an almost complete collapse of the associated human societies, dragged down by the misery and health problems posed by their environments (Chapter 2). There is an inevitable tendency for fit and productive people to move away from these areas, leaving only the weaker people behind, and for new industries to go elsewhere.

Yet all this is unnecessary, because the damage can either be prevented from occurring in the first place or be repaired. Because we have an inheritance of degraded land which, although not large in overall terms, has major effects on human populations, this book is about the repair process – what can be achieved and by what means. Of course, in the future, prevention is essential and much better than repair, and could very profitably be the subject of another Advanced Study Institute.

The Solution

Is the repair a difficult job? There appear to be many problems to deal with. However, the simple solution – the establishment or re-establishment of a vegetation cover – will very economically provide an answer to most of the above problems. Once established, a vegetation cover can stabilise the surface, and be visually attractive, and be self sustaining. Except in special cases there is no need to employ costly engineered solutions (Schiechtl 1980).

In this consideration it is important to remember that nature left to itself will, given time, provide this cover without any artificial intervention, by the process known at natural succession. There are examples in many places; the best studied are where new land has been left by the progressive retreat of glaciers (e.g. Crocker and Major 1955). But there are many examples of what can happen where land degraded by man has been left to itself (e.g. Leisman 1957). It is important to realise that all natural ecosystems have developed by this process. However it can be a slow process, taking 100 years or more to achieve a mature vegetation cover. There can also be specific problems preventing successful natural succession. We have therefore to examine how these can be overcome and the whole establishment process speeded up.

An Ecological Perspective

But before we can do this, it is important to put what we are trying to do into an ecological perspective.

What has been lost is the original ecosystem. An ecosystem is the complex of plants, animals and soil that occur and interact together in one place. Some people think of an ecosystem as a sort of living organism, which is a possible analogy as long as it is not pressed too far.

Any ecosystem does have two major organism-like characteristics, a structure and a function (or a series of functions). Both of these are lost when the ecosystem is damaged. This loss and the restoration process can be represented by a simple graph with structure and function as the two axes (Fig. 1).

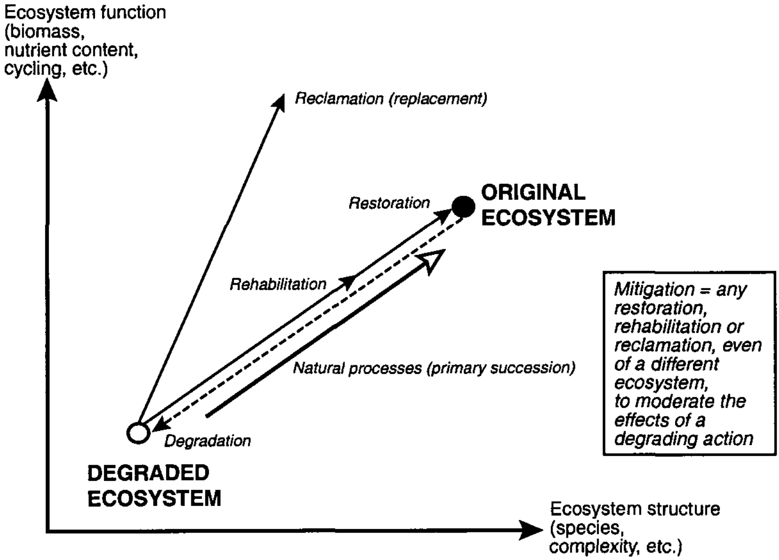

Fig. 1. A diagrammatic representation of the degradation of ecosystems and the different processes of restoration that are possible, expressed in terms of the two major attributes of all ecosystems – structure and function.

Although degraded, the ecosystem can begin to restore itself by natural succession processes. As we have already considered, this process is usually rather slow, taking 50 – 100 years, at least a human life time. It may also be held up by special characteristics of individual sites. So usually, work has to be carried out which will enable restoration to be achieved quickly.

This work can have different aims: *restoration* to put back exactly what was there before, *rehabilitation* to put back something that approaches what was there before but does not achieve it, and *replacement* where an alternative ecosystem is substituted. All these can be termed *reclamation*, because they are ensuring the re-use, the recycling, of the damaged land (Bradshaw 1996).

In the history of reclamation, because of the importance of meeting the immediate serious problems that derelict and damaged land causes, it has been usual to try to establish any sort of vegetation cover quickly. This could involve the establishment merely of a quickly produced grass cover. This will answer all the immediate problems, but probably not the secondary problems.

The quick establishment of a grass cover could involve no more than the sowing of a suitable grass species together with some fertiliser (for examples see Schaller and Sutton 1978). To overcome the secondary problems and to achieve a solution that is self-sustaining may require:-

1. the careful rebuilding of the soil to something approaching what was there before, at least in its biological properties, and
2. the complete replacement of the species of the original ecosystem.

Because of increasing concern to maintain the world's biodiversity and to find solutions which are self-sustaining,, the second approach is becoming required more often. This means that we have got to be more clever, whether as engineers, soil scientists or ecologists. We have to understand more precisely how the ecosystem works that we are hoping to create. We need to understand not only the critical aspects of its structure, but also of its function.

In this respect, restoration is a critical test of our abilities. It may seem easy to take an ecosystem to pieces scientifically on paper. But the acid test is whether we can put the pieces we recognise together in practice and make them work (Bradshaw 1987).

So reclamation in all its forms has two important attributes: it is a critical way in which we can *stem the accumulating damage* we are inflicting on this planet; but it is also a *supreme test of our knowledge.*

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Chapter 2

Degradation of Land and Its Relation to Public Health

J.C. Ng

Introduction

Degradation and contamination of land can be caused by both natural and anthropogenic forces. The latter is usually related to economic development as a result of increase in population. Population growth is a key driving force for more land development and increased intensity of land use. Urbanisation and industrialisation certainly exacerbate the degradation and contamination of land. This inevitably leads to loss of valuable natural and agricultural land. Land clearance coupled with bad agricultural practices create another set of pressure inducing environmental damage. Hazardous waste materials resulting from industrial activities that may impact on the environment and public health require proper management strategies so that the health risk can be minimised or eliminated if possible. The environmental threats can be categorised as "traditional hazards" and "modern hazards". The former is associated with lack of development whilst the latter is associated with unsustainable development. This Chapter therefore discusses a simplified abstraction of the complex cause-effect relationships operating between driving forces, environmental pressure, environmental states, human exposures and health effects, and considers the actions needed to minimize these hazards.

Events of both human and natural origins such flood, drought, wind and fire can have a major impact on land resources. In parallel, increases in population inevitably lead to intensified agricultural land use and urban development. Once urbanized, land is usually not able to be used for other purposes such as conservation or agriculture. Pressures on prime natural and agricultural land are often most intense in coastal areas. Economic pressures certainly exacerbate land degradation problems. All this leads to loss of biodiversity.

Much of the world woody ecosystems have been cleared since civilization. Although it has slowed in some parts of the world, clearing followed by grazing remains a major pressure on land and soil resources. In area of natural grassland, overgrazing is becoming a serious cause of degradation. In total, natural forests and rangeland pastures are declining in favour of exotic pastures, cropping, forest plantations, mining and urban development, all which can lead to further degradation.

In many countries, climates and soil types allow a wide range of crop types to be grown successfully. However, some cropping practices such as bare-surface production, maximum tillage and stubble clearing contribute to soil erosion and soil structure decline. Overuse of fertilisers has caused soil acidification, while irrigation can increase soil salinity. Salinity is a very significant problem in Australia (QEPA 1999). Acceleration of soil acidification occurs through the removal of harvested products, reduced levels of soil organic matter and excessive use of ammonium-based nitrogen fertilisers. Water erosion is a serious problem on sloping grazing land when overgrazing or drought are followed by heavy rain. Soil fertility decline is most severe in intensively cropped soils due to tillage, loss of natural soil organisms and organic matter.

But land may be degraded by contamination. The Environmental Protection Act 1994 (Australia) lists "notifiable activities" likely to cause land contamination. These include service stations, fuel storage, landfills, refuse tips, cattle dips, tanneries, wood treatment and various manufacturing and waste handling activities. There is also a range of industrial or domestic activities which cause contamination as well as simple physical damage. For examples, activities related to mining and chemical industries sometime result in environmental damage or undesirable adverse health implications. Unexploded ordnance on disused practice firing and bombing ranges is also considered land contamination. It is a particular problem in Queensland (and other parts of the world) because of the large training effort in numerous areas during World War II.

The complex relationship of sustainable economic development and public health issues therefore requires careful planning and management.

Health and Environment

The complex nature of health and environment cause-effect is inter-related to a number of factors including the driving force, environmental pressure and state of the environment, that impact on health. The health risk is a result of exposure and its potential adverse effects. A simplified scheme to illustrate this inter-relationship framework (WHO 1997) is shown in Fig. 1.

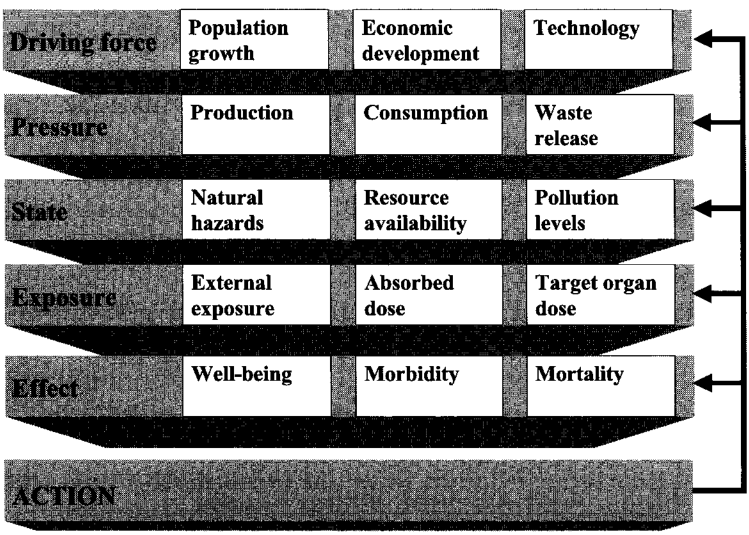


Fig. 1. A simplified scheme of health and environmental cause-effect framework (modified after Kjellistrom and Corvalan 1995).

The key driving forces in this framework include population growth, economic development and technology. These three factors are inter-related and in turn lead to demand for increase of production. Subsequently, the consumption of raw and finished products by the community and waste release into the environment, will increase. The increase of "driving force" and "pressure" will then impact on the "state" of the environment which the population relies upon.

The following are examples of land degradation due to human activities:

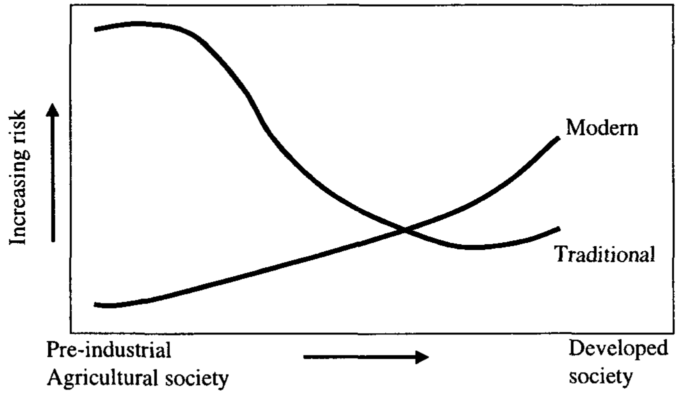
- land clearing – deforestation, soil erosion, salinity, loss of animal habitats, loss of valuable natural and agricultural land, deteriorated air quality
- mining – deforestation, soil erosion, acid mine drainage, waste rock and tailing dumps, release of metals harmful to plants, animals and humans
- pesticide spray – residues impacting on animal and human health
- oil refineries – emission of greenhouse gases, harmful gases, dispersion and deposition of hazardous wastes
- power stations – emission of greenhouse gases, harmful gases, fly ash, radiation hazards (from nuclear power plants), dispersion and deposition of hazardous wastes
- industrial waste dumps – chemical and physical hazards, deteriorated air quality
- urbanization – loss of agricultural land, generation of waste materials, pressure on sanitation services
- residential development – loss of natural environment, loss of coastal and estuary habitats
- traffic – emission of harmful gases, lead particulates from leaded-petrol

Any public health policy must have as its aim the protection of the well being of its people. Achieving this goal will ensure the reduction of morbidity and mortality due to many different adverse environmental factors. This means it will require a multidisciplinary approach.

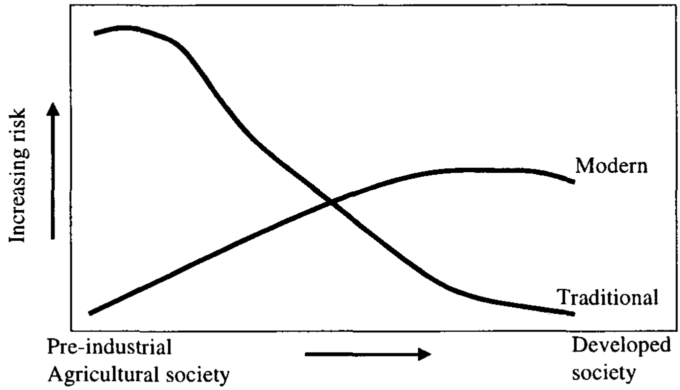
Environmental Hazards

The different environmental threats can be divided into "traditional hazards" associated with lack of development, and "modern hazards" associated with unsustainable development. The changing pattern of environmental health hazards and associated health risks – moving from "traditional" to "modern" with time and economic development – is called the "risk transition". The risk transition is depending on whether the environment health risks are badly managed or well managed, as shown in Fig. 2.

One of the differences between traditional and modern environmental health hazards is that the former are often rather quickly



Badly Managed



Well Managed

Fig. 2. The trends of traditional hazards and modern hazards when environmental health risks are badly or well managed (adapted from Smith 1997).

expressed as disease. For example, a villager drinks polluted ground/surface water today and tomorrow has severe diarrhoea. Diarrhoreal incidence can accordingly be a relatively useful measure of the relevant risk and of our effort to control it. For many modern health hazards, however, a long period of time may pass before the health effect manifests itself. A cancer-causing chemical released into the environment today may not reach a person some years later and then many more years elapse before the manifestation of the disease. The contamination of soil by pathogens as well as chemicals is a major contributor to human exposure to environmental health hazards. Contamination due to poor sanitation, application of agricultural chemicals, improper disposal of hazardous chemicals, and deposition of air pollutant particles, such as lead, is of particular concern. Mining activities and metal smelting have resulted many contaminated sites around the world. Fig. 3 shows the production and emission trend for some toxic metals (Nriagu 1996). It is worthy to note that global emissions are correlated to the increase of production up until about 1980 when a steady decline of emission is observed. But this is correlated with a fall of production, which does not suggest any real improvements in emission control.

Soil contamination can lead to groundwater pollution and uptake of contaminants by crops. For example, ground water was contaminated by arsenic leaching from tin mine tailings stockpile in a village of southwestern Thailand. Villagers developed arsenicosis including skin

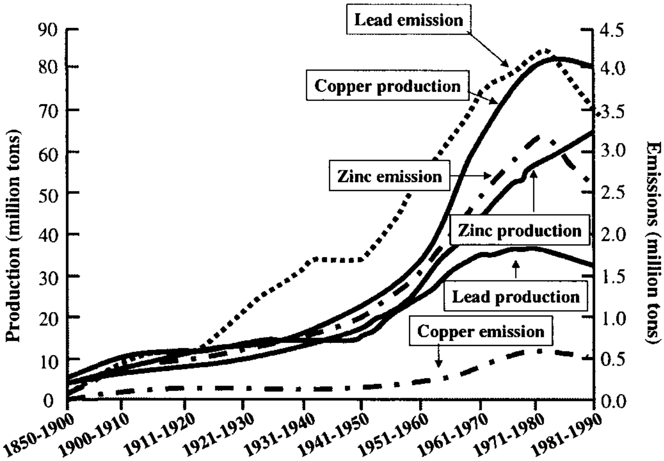


Fig. 3. Global production and emission trends of toxic metals from 1850 to 1990 (adapted from Nriagu 1996).

cancers some 15-20 years later from drinking the contaminated water (Division of Environmental Health 1992). In southwestern Guiyang, China, chronic thallium poisonings of villagers who ingested cabbages grown in thallium contaminated land have been reported (Zheng 2000).

Sustainability and Public Health

A new perspective on health has emerged whereby health is seen as an essential component of sustainable development, which in turn depends on concerted action by different sectors of society.

Major challenges to sustainable development are posed by mismanagement of natural resources, excessive waste production and production of environmental conditions that affect health. Poor environmental quality is directly responsible for around 25% of all preventable ill-health in the world today (WHO 1997).

Today's rapidly developing and changing technologies, industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. It is fair to say that contamination of the environment is inevitable with development of civilisation. There are numerous instances around the world where uncontrolled dumping or industrial spills have contaminated properties with hazardous materials. Since many of these properties are in prime urban locations, issues surrounding the reclamation and redevelopment of contaminated sites have become important international topics.

The cleanup of contaminated sites generally involves excavation followed by treatment and /or disposal at licensed off-site facilities for the most highly contaminated waste and soil (USEPA 1992). Some treatment methods, for examples, include high temperature incineration, base catalytic degradation (BCD) (e.g. for PCB's), extraction and/or concrete encapsulation, burial in isolated cell and etc. Less severely contaminated material (a notably subjective description) is usually disposed of in a semi-isolated cell on-site.

Whilst it is impractical to list all potential hazards which can be presented by contaminated land, it is useful to categorise the major hazards which may occur alone or in combination.

1. Toxic material may be ingested by the eating of plants and animals which become contaminated through uptake of substances from contaminated soil or surface contamination. E.g. the uptake of dioxins by zucchini, uptake of metals by certain plants, uptake of pesticides by cattle.
2. Inhalation and absorption can occur via gaseous or particulate material, and fluids present or emanating from a site.
3. Land contamination can pollute soils, ground water, surface water and air. In some cases, pollution can occur many kilometres away from the site.
4. Gases, volatile materials or potentially combustible substances such as methane, oil, tar and rubber can cause fire and explosion. Buildings on site can be rendered unsafe by structural corrosion or soil subsidence.

A multi-disciplinary approach is essential for the rehabilitation of contaminated land, as no single discipline or profession is likely to be able to deal effectively with the range and complexity of technical, toxicology, health, environmental, social and other issues that may arise. The public health implications need to be explicitly addressed for all contaminated sites. On-going monitoring is essential for environmental sustainability.

In Australia, and elsewhere, closure of a mine normally involves establishment of a plant cover. The subsequent land use is likely to be pastoral livestock. To determine whether this is a justifiable land use, cattle grazing trials are being conducted by a consortium of research teams investigating the interrelationship of bioavailability and potential metal accumulation in mine tailings-cattle, tailings-plants, and tailings-plants-cattle combination.

Greener (cleaner) production is a key step towards sustainable economic development. One of the approaches is to use cleaner resources including raw materials and better technologies to reduce production of waste materials that impact on the environment. For example, the removal of lead in petrol has contributed significant reduction in concentrations of lead in the blood of individuals particularly in young children who are the most sensitive sub-population.

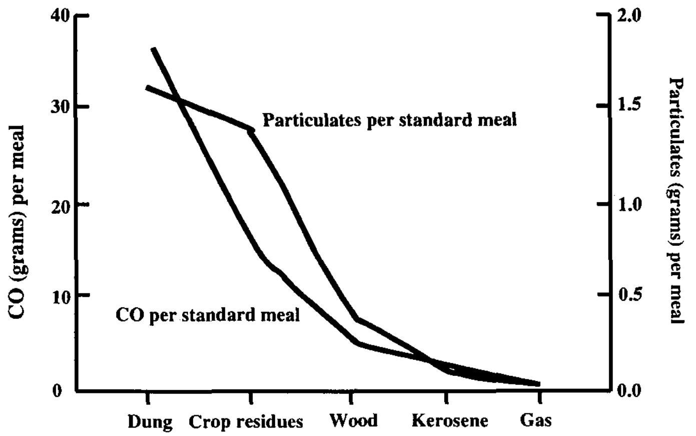


Fig. 4. Emissions per meal of household cooking fuels (adapted from Smith 1991).

The burning of wood for cooking places pressure on our forestry system. It is also not as environmental friendly as the use of gas (Fig. 4). Unfortunately, for developing countries, animal dung, crop residues and wood are often used as fuels. These will produce higher amount of harmful carbon monoxide and particulate matters compared to other fuel sources or electrical power.

In order to reduce the "modern hazards", the use of greener technologies that have positive impact on health and the environment is necessary. Examples of the benefits of new technologies are shown in Table 1. New technologies are just important in industries having direct impact on the land, shown in Table 2.

Table 1. Examples of the benefits of new technologies and their positive impact on health and the environment.

Technology	Benefits
Improved biomass stoves/burners	Reduced indoor/outdoor air pollution, more efficient fuel wood use
Heat pump technology for space heating	Negligible indoor/outdoor air pollution, no greenhouse gas emission
Photovoltaic energy conversion systems	No indoor/outdoor air pollution, no greenhouse gas emission, reduced dependence on power supplies
Genetically improved crops	Increased yield, reduced dependence on pesticides
Catalytic converters and Pb free petrol	Reduced air pollution from cars, reduced Pb particulates fallen on soil
Electric vehicles	Reduced emission of air pollutants along roads
HCFCs & HFCs as CFC alternatives	Reduced stratospheric ozone depletion
Low water-use irrigation systems	Reduced water use and water logging, reduced salinity
New alloys & plastics industry	Reduced waste
Biological pest control	Reduced use of toxic chemicals

Table 2. Examples of new technologies in mining reducing impacts on public health.

Technology	Impact
Improved mineral extraction technologies	Reduces generation of wastes
Re-extraction of old tailings using new technologies	Reduces environmental impact
Recycling of chemical reagents in mineral extraction processes – e.g. solvent for nickel and uranium extraction, cyanide for gold, sodium hydroxide for bauxite/aliminium	Minimises effects on stock, aquatic life, animal and human health
Improved construction of tailings dams	Minimises run-off and reduces toxic leachate, minimise downstream effects
Improved containment and better surface cover of waste rock and other mining wastes	Minimises acid leachate and reduces off-site ecological impact
Improved environmental monitoring systems	Reduces adverse environmental incidents
Re-vegetation of tailings and waste rock areas	Minimises waste dispersion and maintains biodiversity
Improved wetland design	Reduces downstream effects

Conclusion

The relationship between human health and degraded environments is evidently highly complex. Each of the traditional and modern hazards is associated with a variety of aspects of economic and social development. Moreover, there is no single best way of organising and viewing the development-environment-health relationship that reveals all the important interactions and possible entry points for public health interventions. This paper illustrates a simplified abstraction of the complex cause-effect relationships operating between driving forces, environmental pressure, environmental states, human exposures, health effects, and actions aimed at minimizing these effects.

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Chapter 3

Health Risk Assessment

J. C. Ng

Introduction

There are numerous organisations and government departments involved in risk assessment. The perception of risk by industries, governmental regulators and the communities may differ in certain circumstances. Often different approaches and methodologies for the evaluation of risk are adapted by different agencies and countries.

The calculated risks of contracting fatal cancers and selected non-fatal ailments are associated with different levels of exposure to radiation. These risk factors are, however, based on epidemiological data from high exposure groups, extrapolated to lower exposure levels. The extrapolation of risks from high exposure to low exposure groups is also carried out for the risk evaluation of other hazardous chemicals in the environment when epidemiological evidence for low doses is absent or not as strong. It is relatively easier to evaluate risks at high doses. There are many different ways for the extrapolation of risks. Some require complicated mathematical modeling. This chapter describes the framework for health risk assessment and highlights the need for harmonisation of the methodology.

A contaminated site is a site where toxic chemicals, that have the potential to be harmful to the environment and ultimately to humans, are present in higher concentrations than those found normally in the area. Contaminations can occur as a result of industrial, agricultural or commercial activities. It may also occur following waste disposal, spills or movement of contaminants from adjacent properties. Chemicals that could be found at a contaminated site include metals and metalloids (like lead, cadmium, mercury or arsenic from mining tailings or landfill sites), oil, tar, harmful gases, solvents, pesticides or other hazardous wastes.

Humans can be exposed to these contaminants from a contaminated site via various routes. The actual degree of risk to a hazardous chemical often requires a site-specific risk assessment.

Risk is the probability that a specified harmful effect will occur, or, in the case of a graded effect, the relationship between the magnitude of the effect and its probability of occurrence. Health risk assessment is a systematic process of assigning magnitude and probabilities to the adverse effects of human (anthropogenic) and natural activities. It encompasses well-defined end points for examples incidence of deaths, cancers and diseases. This is in contrast to other approaches to ecological assessment which have unstated or ambiguous endpoints such as "ecosystem integrity". Ecological risk assessment is the process of defining and quantifying risks to nonhuman biota and determining the acceptability of those risks (Suter 1993). Ecological risk assessment is much harder to defined. Should the emphasis of ecological assessment be on: i) ecosystem-level properties such as production and diversity?, ii) be limited to species of aesthetic or commercial value?, or iii) be focused on "representative species"? Health risk assessment has to deal with only one species – humans. This chapter will only focus on health risk assessment of humans.

Rather than seeking to determine the level of risk that would result from a particular level of exposure to a particular substance, agencies dealing with chemicals, or other substances which may cause adverse health effects to humans seek to determine the level of exposure that would result in no appreciable risk. Criteria for health risk assessment that need to be considered when defining an endpoint are i) societal relevance, ii) biological (effects) relevance, iii) unambiguous operational definition, iv) accessibility to prediction and measurement, and v) susceptibility to the hazardous agent.

In many instances situation-specific health risk assessments will not be necessary as the nature and magnitude of the risks will be obvious, so that the resources required for an adequate site-specific risk assessment or the generation of site-specific soil criteria should be directed to the management of the site. Health risk assessment may also be unnecessary as "there may be no population at risk, or decision may be made on other grounds" (ANZECC/NHMRC 1992).

The level of risk can be described either qualitatively ("high", "medium" or "low") or quantitatively (with a numerical estimate). Numerical estimates of risk may not be feasible because of limited toxicological and exposure data which will be reflected in the uncertainty assessment. Clearly defined qualitative categories can enable realistic and effective risk management decisions.

There are several methodologies developed by various countries for health risk assessment. Methods used in the past can be categorised broadly into two groups based on two different assumptions. These have been applied in particular to carcinogenic substances with and without genotoxic properties. In both cases, mathematical models have been used to assess the risk of particular chemicals, depending on their toxicological properties and mechanisms of action. These methods have traditionally been based on various conservative (default) assumptions in the absence of scientific information. For example, bioavailability of contaminants in soil is assumed to be 100% when risk assessment is based on worse case scenario. This would often over-estimate the risk. Expensive remediation is sometimes not necessary if bioavailability data can provide a more realistic estimation of the risk (Ng and Moore 1996, Ng *et al.* 1998). In Australia, a paradigm for the frame work of health risk assessment has been proposed which uses all relevant scientific data in the decision-making process and the clear recognition and justification of the major components of the process: public health policy, professional judgement and scientific principles (NHMRC 1999, Environmental Health Council 2000). This approach provides a positive step towards harmonizing chemical risk assessment for all toxic end-points.

The definitions of some commonly used terms in risk assessment, for examples ADI (acceptable daily intake), BMD (bench mark dose), RfD (reference dose), LOAEL (lowest observed adverse effect level), NOAEL (no observed adverse effect level), LED_{10} (lowest effect dose) and Guidline Dose, can be found in the references (IRIS 1996, JECFA 1991, NHMRC 1999, USEPA 1996).

Different Approaches

Environmental risk analysis (assessment) considers the risks to human health, welfare and ecosystems that are the result of adverse developmental impacts on the natural environment. The meanings of the words risk analysis and risk assessment are reversed in American and Australian English. In the United States, risk assessment refers to the component of the overall process that is devoted to the calculations, whereas risk analysis is the overall process which includes risk assessment, risk management, risk perception and risk communication. In Australia, risk analysis is widely used to describe the component that is devoted to calculations, whereas risk assessment is understood to be the overall process. The most frequently cited risk assessment framework (US meaning) is that of the National Research Council (1983). This framework is used by the USEPA for the health effects of chemicals, which they refer to as human-health risk assessment. This framework is based on a belief that most risk assessment problems are similar to those concerning food additives. The framework includes hazard analysis (i.e. i) hazard identification, ii) dose-response assessment and, iii) exposure assessment) and risk assessment (i.e. risk characterization). It considers risk management to be separate from risk assessment.

The Asian Development Bank (Office of the Environment 1991) considers that the National Research Council framework essentially represents the results of such a determination only for a particular set of condition and management questions. It therefore suggests that the framework of Smith *et al.*, (1988) is more appropriate. This framework consists of five steps; integrating risk management into the risk assessment paradigm: i) hazard identification, ii) hazard accounting, iii) environmental pathway evaluation, iv) risk characterization, and v) risk management. It is noteworthy that the National Research Council (1983) approach considers risk management to be separate from risk assessment.

Canada uses a three-step process of health risk assessment and risk management (Health Canada 1999): i) hazard identification, ii) risk estimation, and iii) option evaluation. The first two refer to risk assessment whereas the third deals with risk management.

Risk management is the process of deciding what actions to take in response to a risk. For the risk assessment of a toxic chemical at a contaminated site, a degree of conservatism is warranted where there are significant uncertainties about exposure or toxicological data or if the variability in populations has not been taken into account. The variability can arise from heterogenicity in factors such as:

1. uptake e.g. due to variations in diet and inhalation rates;
2. pharmacokinetic heterogenicity resulting in differences in metabolism or excretion;

3. response, where there are differences at the site of action (Hattis and Silver 1994 p. 422).

The degree of conservativeness should be made quite clear in the risk assessment so that risk managers are fully aware of the precautions inherent in the risk assessment and do not unnecessarily add further levels of conservatism for the risk management step. Environmental Health Council (2000) has proposed a framework for environmental health risk assessment for public consultation (Fig. 1).

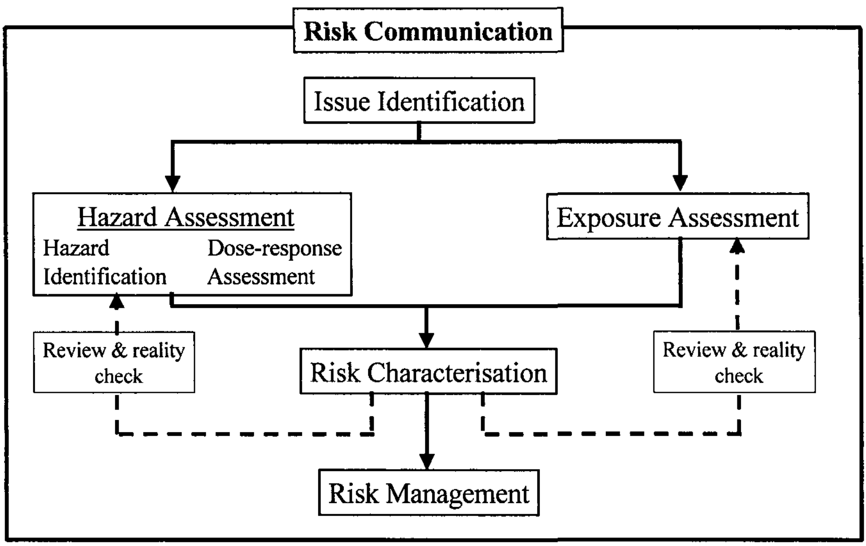

Fig. 1. Framework for environmental health risk assessment (Environmental Health Council 2000).

The framework considers both qualitative and quantitative toxicity data. Both human and animal evidence will be assessed as part of this process. It is preferable to use human data if sufficient data are available. The risk assessment cannot be done without good dose-response information. Different agencies may adopt different assumption to derive the dose-response relationship at concentrations lower than available experimental data for carcinogens or non-carcinogens (see later discussion).

Risk assessment and management is an iterative process that needs to be monitored and reviewed. There is a need to review the situation from time-to-time as new information becomes available or circumstances change to ensure that the risk assessment is still relevant and protective.

Risk communication should involve stakeholders and community consultation. There is a growing awareness among risk assessors and the community that risk assessment should be conducted in partnership. It is generally better to involve the community at an earlier rather than later stage of the process. The process may not always lead to consensus, but it is likely to smooth the path for the risk management process. It is also important that both parties should employ an unbiased approach and always based on sound scientific evidence to derive what might be a realistic risk.

Uncertainty Factors

Risk is the probability that a specified harmful effect will occur, or, in the case of a graded effect, the relationship between the magnitude of the effect and its probability of occurrence. Any risk assessment is associated with a degree of uncertainty. A scientifically sound risk assessment is one that has the least uncertainty.

Bioavailability data and dose response curve are examples of significant relevance in risk assessment. As mentioned above, the default assumption of 100% bioavailability is over-conservative. Bioavailability data can in fact reduce the uncertainty factor in risk assessment. The other concern for risk assessors is the lack of data at the environmental levels of exposure. Fig. 2 shows a hypothetical scenario in which only a limited data set is available. In this case, a number of dose-response curves can be speculated.

Historically, the risk estimate has been selected from a position on the 95 percent lower confidence limit on the dose-response curve (Fig. 3). The preference for choosing the 95 percent lower statistical limit as the starting point in the risk assessment is thought to account for the uncertainty and variability in the experimental data (a conservative approach which is protective of public health). The use of central estimates compared to the lower statistic limit has been debated during the development of the revised US EPA cancer guidelines and cogent arguments have been put forward for each position (Barnes *et al.* 1995, USEPA 1996).

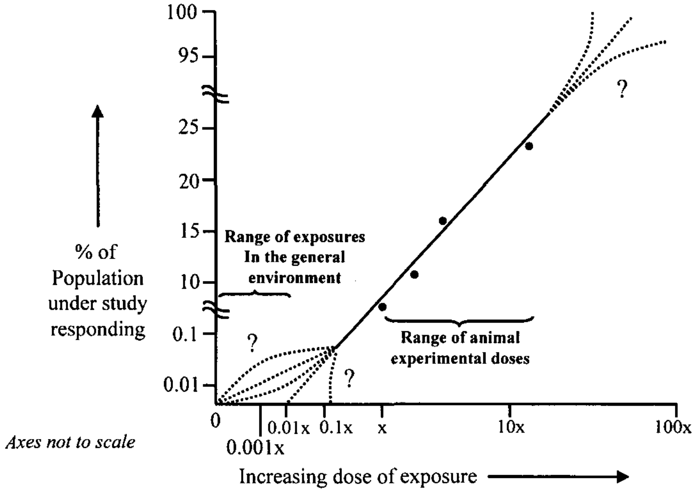

Fig. 2. Hypothetical curve for an animal carcinogenicity study (adapted from Levy and Wegman 1988). Where circles represent actual experimental observations; dotted-lines are mathematically modelled extrapolations; question marks represent areas of uncertainty.

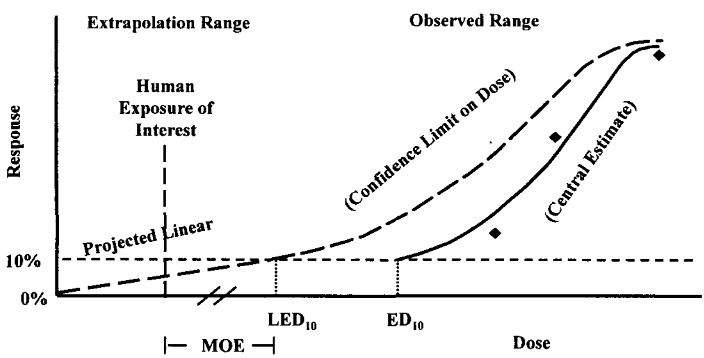

Fig. 3. Quantitative risk assessment approach by USEPA (1995), MOE is margin of exposure.

In the Australian approach, the central estimates (i.e. modified-BMD) of the dose-response models are used to calculate the dose to which factors are applied rather than the 95% lower confidence limit on the dose-response curve (see Fig. 4.). The main reason for this choice relates to the limitations of confidence intervals in describing the variability in given data when the number of data points is small (Murrell *et al.* 1998). Further, because any estimate of a confidence interval involves some assumptions errors, the lower confidence limit (except for extremely low doses when it essentially zero) is more model-dependent than the central estimate. The lower confidence limit tends to be conservative and thus may lead to substantial overstatement of the actual level of risk (NHMRC 1999). Significantly, as Wilson (1995) puts it: ".... Choosing a statistical lower bound to represent a fitted model value introduces a policy decision into a technical procedure."

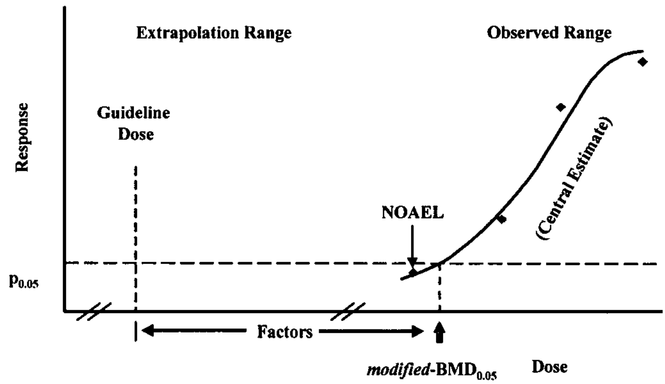

Fig. 4. Quantitative risk assessment – an Australian approach.

In order to derive a Guideline Dose, the modified-BMD is reduced by several factors. The factors encompass both uncertainty factors (reflecting scientific uncertainty, measured or inferred) and safety factors (reflecting the status of knowledge on the development of end-point). The steps to derive the modifying factors are shown in Fig. 5. The upper limits of each factor are based on internationally used assessment methods (e.g. inter- and intraspecies factor adapted from IPCS 1994) and scientific judgement on what values will achieve the definition of the guideline dose. It is believed that the value of these factors will attain a degree of concordance with other international assessment methods (NHMRC 1999). It is obvious that the higher the quantity and quality of the data available, the smaller the factor is likely to be. The overall factor is less than or equal to 50,000, i.e., the guideline dose is reduced to 1/50,000 of that of the BMD.

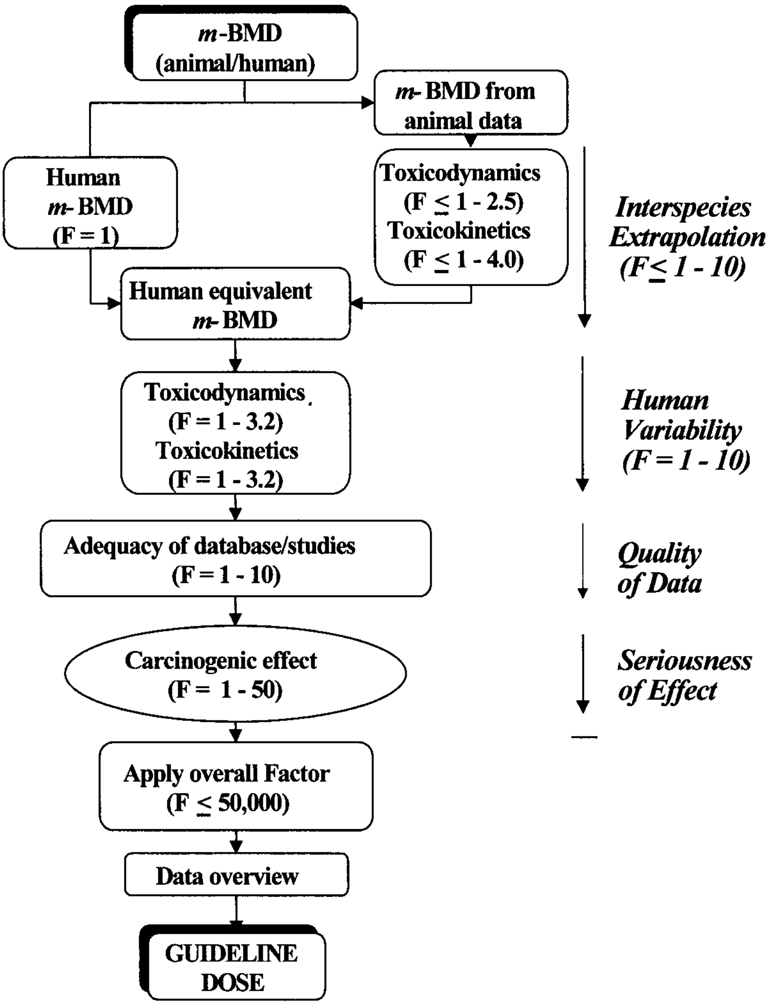

Fig. 5. Application of factors to modified-benchmark dose (The steps for deriving the factors are outlined in the reference (NHMRC 1999). In each case, where a range is expressed, the high value will be the default value. The use of a lower value must be a scientifically based judgement. In all cases, whether a default value or some other value is used, the reason for this choice must be clearly stated.

Advantages of the Australian approach include:

- Optimises use of relevant data
- Clear separation and justification of public health policy, professional judgement and scientific principles
- Weight of evidence based on expert judgement
- Transparent and accountable
- Quantitative and qualitative aspects separated
- Outcome is an estimate of guideline dose, which is protective of human health

This approach is conceptually similar to that used to derive the ADI or RfD from the NOAEL. It differs from other current risk assessment methods in three important ways:

1. Maximum likelihood estimate of the dose is used rather than the 95% lower statistical limit on dose (referred to as BMD);
2. Methodology is applied in the same way to all carcinogen hazards to humans, whether or not they are also genotoxic; and
3. Factors are derived according to a decision tree which takes into account all available data, and scientific judgement addresses a number of the uncertainties in the risk assessment process.

Conclusion

In order to achieve harmonisation of various methods of risk assessment, it is important for a understanding of the methods and practices used by various countries and organisations so as to develop confidence in the acceptance of assessments that use different approaches.

A harmonised framework would provide a uniform approach in the setting of guideline limits for chemicals at contaminated sites in various countries. It further involves a willingness to work towards convergence of these approaches or methods. In the longer term it may be appropriate to standardise some aspects of risk assessment. Harmonisation provides framework for: comparing information, sharing information, understanding basis for exposure standards, common classification systems and common labeling schemes.

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Chapter 4

The Importance of Soil

A.D. Bradshaw

Introduction

When derelict land is created the most crucial part of the environment which is destroyed or degraded is the soil. This can arise when vegetation is being exploited in agriculture or forestry, by loss of the protective vegetation cover, leading to erosion, or where soil is directly disturbed or destroyed, especially to exploit another resource, as in quarrying or mining.

The crucial point is that such soil degradation has major effects on plant growth. Without the support of a fully functioning soil, plant growth is limited or even totally inhibited. As a result the redevelopment of a fully functioning ecosystem, which would normally happen on cleared land, does not occur, and there can be a downward spiral of further degradation. At the same time, it must be remembered that, in soils that are functioning normally, soil controls the nature of the final ecosystem by favouring or disfavouring the growth of different species.

This should be very familiar. However both the extent of the major effects and the subtleties are often not realised. Nutrition experiments, both in the laboratory and in the field, are very valuable, for example the remarkable 140 year old Park Grass Experiment at Rothamsted Experimental Station (Brenchley and Warrington 1969), in which different simple fertiliser treatments have caused radical and remarkable differences to appear a once uniform area of grass meadow.

The Development of Soil Fertility

If soil degradation is to be repaired, a fundamental understanding of the processes leading to soil development is required. However it is the development of biological soil fertility in which we are interested, rather than in long-term pedogenesis which concerns the overall soil structure.

In fact, the components of biological soil fertility are simple. They are best defined and understood by a consideration of plant needs (Table 1). Fertility is made up of a capacity to provide adequate supplies of water, plant nutrients, physical support, in a medium which is not hostile. This will enable plant growth, and therefore ecosystem growth, to occur.

Table 1 What a plant needs from the soil - the components of biological soil fertility

Water	preferably but not necessarily a continuous supply
Nutrients	preferably but not necessarily a continuous supply
Physical support	at least so that it is anchored upright
Lack of hostility	no substances inhibiting root growth

The raw mineral material which is the starting point of all soils achieves fertility by the slow breakdown of soil minerals, the invasion and growth of plants, leading to the accumulation of organic matter able to hold nutrients and water. The raw, skeletal, materials of derelict land do not have time to be subject to these processes and are therefore very different.

Nevertheless some spontaneous vegetation growth does occur on most skeletal materials showing that vegetation and soil development is brought about by a series of processes that do occur, even if they sometimes be rather slow (Table 2). In the restoration of derelict land, where there is often an urgency, or where there may be special problems, these natural processes need assistance.

Soil Repair - What Is Involved - What Are the Solutions?

It is commonly believed that every situation is special and that expensive interventions are necessary, especially the importation of fully formed soil from elsewhere. It is sometimes convenient to use such topsoil, but it is usually expensive and difficult to obtain (see later Chapters).

Table 2 Processes involved in the development of soil fertility (Bradshaw 1997)

Biological processes		Pedological processes	
Time (yrs)	**Process**	**Time (yrs)**	**Process**
1-50	1 Immigration of appropriate plant species	1-1,000	1 Accumulation of fine material by rock weathering
1-50	2 Establishment of appropriate plant species		
1-10	3 Accumulation of fine mineral materials captured by plants	1-1,000	2 Decomposition of soil minerals by weathering
1-100	4 Accumulation of nutrients by plants from soil minerals	1-100	3 Improvements of soil available water capacity
1-100	5 Accumulation of nitrogen by biological fixation and from atmospheric inputs	1-1,000	4 Release of mineral nutrients from soil minerals
1-20	6 Immigration of soil flora and fauna supported by accumulating organic matter		
1-20	7 Changes in soil structure and organic matter turnover due to plant and soil organism activities		
1-20	8 Improvements in soil water holding capacity due to changes in soil structure		
10-1,000	9 Reduction in toxicities due accumulation of organic matter	10-10,000	5 Leaching of mobile materials from surface to lower layers
		100-10,000	6 Formation of distinctive horizons in the soil profile

The more economical approach is to think of using and helping the individual natural processes, outlined in Table 2. The key is to use plants as the driving force, to get them to grow and accumulate organic matter.

But it is not enough to know of the existence of these processes. The need is to determine what is wrong and how it can be put right (Table 3). Since they will be dealt with in detail in later chapters, they will only here be put into perspective. But this will illustrate that soil repair is not difficult if tackled in a systematic manner. The short term treatments are, from experience, effective over a short period of time, the long-term treatments, however, are closest to natural ecological processes and are most likely to be self-sustaining.

Table 3. The physical and chemical problems that can be found in the soils of degraded terrestrial ecosystems and their short and long term treatments (from Bradshaw 1983)

Category	Problem	Immediate treatment	Long-term treatment
Physical			
Texture	coarse	organic matter or fines	vegetation
	fine	organic matter	vegetation
Structure	compact	rip or scarify	vegetation
	loose	compact	vegetation
Stability	unstable	stabiliser or nurse	re-grade or vegetation
Moisture	wet	drain	drain
	dry	irrigate or mulch	tolerant vegetation
Nutrition			
Macronutrients	nitrogen	fertiliser	N-fixing species
	others	fertiliser and lime	fertiliser and lime
Micronutrients	deficient	fertiliser	-
Toxicity			
pH	low	lime	lime or tolerant species
	high	pyritic waste or organic matter	weathering
Heavy metals	high	organic matter or tolerant plants	inert covering
Salinity	high	weathering or irrigate	weathering or tolerant species

Physical Problems

The manner in which plants can grow in physically very extreme materials, from coarse rock wastes to fine clays, is remarkable. However, although the starting conditions may be adequate for some species, there may be serious problems for others. A key improvement is the incorporation of organic matter, which will lower soil bulk density and improve porosity and water holding capacity. Once plants have been established this will occur progressively.

However a common starting problem is compaction, usually due to the effects of heavy machinery. This can be relieved rapidly by ripping and cultivation, but this must be followed by plant establishment. The plants themselves may also need protection from wind and sun and other exposure, particularly immediately after they have germinated. A coarse mulch of straw spread over the surface is commonly used; but a quick growing short-lived species such as a cereal can act as a living protective nurse, and continue to provide protection even when it is dead. But it must not be sown at too high a density.

Nutrient Problems

Plants will scavenge for, and accumulate, nutrients by their normal growth. These will be deposited back on the surface layers of the soil in the organic matter that the plants produce, and so will accumulate over the passage of time. But gross deficiencies may require relieving, usually by the use of fertilisers. Innumerable experiments show this is an economic and important treatment (see later Chapters).

Nitrogen is the nutrient most needed by plants. Because it is stored in the soil in organic matter and only released slowly by its breakdown by micro-organisms, a large capital is required - in temperate ecosystems about 1,000 kg N ha^{-1}. To provide this amount, fertiliser is not at all effective, because nitrogen compounds are very soluble and much will be leached away after application, and the large amounts needed are costly. A better method is by the use of nitrogen-fixing plant species (see later Chapters).

Other nutrients may also be in short supply - commonly phosphorus, but also potassium. These can easily be provided by fertiliser application. The amounts needed are relatively small, and leaching is not usually a problem.

In a normal ecosystem a large proportion of the nutrients are recycled annually. This will only occur, however, by breakdown of organic matter by soil organisms. Most of these will enter the developing soil by themselves, but larger organisms such as earthworms may require assistance because they are less mobile. This can be done by bringing in and scattering small quantities of local top soil. Some specialised micro-organisms associated with plants, such as the rhizobia which fix atmospheric nitrogen and the mycorrhizal fungi that assist nutrient uptake on poor soils, may require to be inoculated onto the plants concerned (see later Chapters).

In the long term, the activities of the soil organisms, in combination with the input of organic matter will lead to major improvements in soil structure and available water capacity. In particular soil particles will become aggregated by fungal mycelium and bacterial decomposition products, and form crumbs with substantial pores in between.

Toxicity Problems

In some situation toxicity due to acidity or toxic metals can be very serious, and prevent plant growth entirely. However if their origins and effects are understood, they can be treated.

Acidity is a common problem in colliery and some metal mine wastes, due to the oxidation of sulphide compounds releasing sulphuric acid. This can readily be neutralised by the addition of lime. In some materials, after the available acidity has been neutralised, more will appear due to the oxidation of previously unoxidised sulphide. This can mean that large amounts of lime (about 300 t ha^{-1}) have to be applied to treat both the present and potential acidity.

Toxicity due to high concentrations of toxic metals such as lead, zinc and copper can inhibit plant growth for many years. There is no simple ameliorating additive that can be used, although the availability of the metals can be reduced by lime and organic matter. But this tends to be a temporary effect. As a result, special engineering treatments may be necessary in which the toxic material is covered by a deep layer of normal soil, or subsoil itself covered with topsoil (Williamson *et al.*

1982). However there are a number of new biological treatments which appear promising (see later Chapters).

Conclusion

Effective restoration commonly depends on establishing a new, functioning, ecosystem rapidly so that the degraded surface is fully covered and cannot erode further and has a satisfactory appearance. This requires rapid plant growth. This can only occur if a biologically satisfactory soil can be developed. This depends on identifying and, if necessary treating, any soil factors that are limiting. A simple guide for this are the items already given in Table 3, and the methods by which they can be treated.

All this means that to be effective, the restoration ecologist must have both the theoretical understanding of the factors that are likely to cause problems and the practical knowledge of how they can be treated effectively and economically.

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Chapter 5

Physical Limitations

L.C. Bell

Introduction

The use of land for agriculture, mining and mineral processing, and urban and industrial development is important for human survival, but, in many cases, poor environmental management has led to these pursuits resulting in severe land degradation and the resultant need for rehabilitation. Most post-mining land uses involve the establishment of vegetation whether it be in the form of native ecosystems, pastures for cattle, or food or tree crops. Similarly the rehabilitation of land degraded by industrial activities often involves plant establishment.

Limitations to vegetative establishment on degraded land may include the nature of the climate and the physical, chemical and microbiological properties of the surface of the degraded site. This Chapter focuses on the physical limitations of sites and briefly addresses means of overcoming these limitations. Factors considered include mass movement, water and wind erosion, root anchorage, water availability, aeration, mechanical impedance and temperature.

Mass Movement

The terms mass movement, mass wasting and hillslope failure have been used to describe the movement of soil, rock or waste downslope under the influence of gravity. On some drastically disturbed sites, this process may occur and be a limitation to rehabilitation in the absence of any restructuring of the landform.

There can be a range of causes of hillslope failure. Various geomorphic processes driven by gravity produce shear stress in hillslope or dump materials. When the shear stress exceeds the shear strength of the materials, dislocation and movement of the materials will occur. In many cases, the slope failure is triggered by (1) removal of lateral support by either natural or human agencies or (2) addition of water to the slope contributing to both an increase in stress and a decrease in strength. In those cases where mass movement may pose a limitation to rehabilitation, recontouring to reduce the degree of slopes is required (Toy and Hadley 1987).

Erosion

Soil erosion is a normal process in landscape development, but when land is degraded through a marked change in topography, or loss of vegetation through clearing or soil contamination, the forces of water and wind can cause accelerated erosion leading to further degradation of the site and environmental insult off-site by deterioration of water quality (water erosion) or air quality (wind erosion).

Active erosion is a major limiting factor in the establishment of vegetation on degraded land. Applied seed and fertilizer are removed from the site (or buried in down-slope areas) with water erosion, whereas loss of emerging seedlings by sand blasting or coverage occurs with wind erosion which is generally limited to semi-arid and arid regions.

Water Erosion

The average annual water erosion at a site can be expressed by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) –

$$A = R \times K \times L \times S \times C \times P \qquad (1)$$

Where A = computed spatial average soil loss and temporal average soil loss per unit of area (t $ha^{-1}yr^{-1}$)

R = rainfall-runoff erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = support practice (cultivation) factor

Soil loss is that material actually removed from the particular site or site segment. The soil loss may be less than erosion due to on-site deposition in micro-topographic depressions on slopes. The sediment yield from a surface is the sum of the soil losses minus deposition in macro-topographic depressions, at the toe of the hillslope, or in terraces and channels sculpted into the hillslope.

As the name implies, the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.* 1997) is a revised equation which can be used to estimate soil loss from most undisturbed lands experiencing overland flow, from lands undergoing disturbance, and from newly or established rehabilitated land. The equation estimates soil loss from a hillslope caused by raindrop impact and overland flow (collectively referred to as interrill erosion), plus rill erosion. It does not estimate gully or stream-channel erosion. Guidelines for the equation's use on mined lands, construction sites and other disturbed lands have been produced by Toy and Foster (1998).

Another useful model for predicting erosion is the Water Erosion Prediction Program (WEPP) (Flanagan and Livingston 1995) which runs on a daily time step and can consider soil water balances, plant growth, and management impacts such as grazing and burning.

Prediction of the long-term evolution (up to 1,000 years) of channels and hillslopes in a catchment on the basis of runoff and erosion has been attempted (Willgoose and Riley 1998), and such approaches are useful in the design of waste rock dumps and tailings disposal facilities on mine sites.

Erosion models can be used to ascertain what alternative management practices are required to achieve tolerable erosion values. Although one cannot change the climate at a site (i.e. rainfall erosivity R), one can reduce erosion by changing the length and degree of slope, extent of vegetative cover and conservation practice (ripping versus not ripping etc.). At some sites, one cannot change the nature of the surface materials (i.e. erodibility factor K is fixed), but in other cases, materials handling during rehabilitation may enable highly erodible materials to be buried.

A comprehensive discussion of post-mining landscape design considerations to control erosion is given by Toy and Black (2000).

Wind Erosion

Wind erosion is possible when the velocity of the wind at the soil or waste surface exceeds the threshold velocity required to move the least stable particle. Wind-eroded particles are transported in one of three modes, viz. (1) surface creep (particles 1.0 - 2.0 mm in diameter), (2) saltation (0.1 – 1.0 mm), and (3) suspension (0.001 – 0.1 mm). The net result of wind erosion is that the finer (and nutrient-rich) particles are transported away from the site leaving a less fertile soil. Establishment of vegetation on sites susceptible to wind erosion can be hindered by sand blasting of seedlings.

The factors influencing wind erosion are the wind speed, soil erodibility (function of texture, structural stability and water content), soil roughness and degree of vegetative cover. Various models have been used to predict wind erosion (Fryrear 2000). One of the most widely used has been the Wind Erosion Equation (WEQ) –

$$E = f(IKCLV) \tag{2}$$

Where E = annual soil erosion (t $ha^{-1}yr^{-1}$)
f = functional relationship
I = soil erodibility (t $ha^{-1}yr^{-1}$)
K = soil roughness factor
C = climatic factor
L = unprotected field length (m)
V = vegetation factor

The major practices used to control wind erosion include surface residues, soil roughening, wind barriers and shelter belts, cover crops and soil amendments.

Root Anchorage

Plant roots anchored in the soil or waste enable growing plants to remain upright. Whereas grasses require a minimal depth for root anchorage (e.g. 30 cm), trees and large shrubs require a deeper rooting depth to ensure resistance to being blown down in strong winds. For sites located in areas subjected to violent storms and cyclones (typhoons), wind throw of shallow-rooted trees can occur with potentially detrimental effects on the integrity of specially designed barrier covers overlying toxic materials.

Root depth restriction can occur through poor aeration or excessive mechanical impedance but can also be caused by chemical toxicities or lack of nutrients. Where covers are used to contain sulfidic and other potentially toxic wastes through construction of a non-toxic root zone over a compacted clay layer barrier, it is important that the depth of the root zone is sufficient not only to meet the water requirements of the vegetation but also to provide adequate anchorage.

Available Water Supply

To produce one kilogram of dry plant matter, plants must take up from several hundred to several thousand kilograms of water. Most of this water passes through plants (transpiration) and is responsible for providing a continuous supply of nutrient elements from the soil solution. Thus the ability of a plant to grow in a given material is very much dependent on the material's capacity to provide a non-limiting supply of water to the plant roots.

Only a proportion of the water which falls on a soil or waste as rainfall or irrigation is held by the material; some is lost as surface runoff, and a portion of that which infiltrates the soil surface moves through the profile under gravity and passes beyond the root zone. Not all the water which is held by the material against gravity is available to plant roots. Productive substrates have a high "available" water capacity which is the difference between field capacity and permanent wilting point, these values representing the approximate upper and lower limit of water that is held in soils and which is available for plants. The magnitude of these limits depends on the total porosity and the pore size distribution which is in turn influenced by the particle size distribution and the degree of aggregation.

The supply of water to plants is determined by the water storage capacity of the soil, its ability to be replenished from surface applied water, its internal drainage, and the depth and distribution of the root system.

The total porosity (f) of a soil is the proportion of the total size volume (V_t) that is available to be filled with air (V_a) and water (V_w), viz.

$$f = \frac{V_a + V_w}{V_t} \quad (3)$$

$$= 1 - \frac{BD}{AD} \quad (4)$$

where BD = bulk density of the soil
and AD = absolute density of soil particles

The fractional air-filled void space (ξ) corresponding to a given volumetric water content (θ_v) is given by

$$\xi = f - \theta_v \ \text{cm}^3 \ \text{cm}^{-3} \quad (5)$$

As a rule of thumb, an air-filled void space of 0.10 $\text{cm}^3 \ \text{cm}^{-3}$ is considered as the minimum necessary for adequate aeration for plant roots.

Immediately after substantial rainfall or irrigation, the pore space will be filled with water (saturation), but the macropores in soils drain readily. The drainage often slows after 24 hours, and the water content at this time is arbitrarily considered to be the field capacity. In practice, intermediate-sized pores continue to drain under the influence of gravity. An approximation to the field capacity value obtained in the field after 24 hours is to measure the water content of an undisturbed soil core on a pressure plate at 0.1 bar suction.

As the water content of a soil decreases through drainage, evaporation and plant extraction, a point is reached where the remaining water is held in films and small capillary pores with such energy that roots have difficulty extracting it. This water content is the permanent wilting point and can be determined by measurement of the water content of soil exposed to a 15 bar suction on a pressure plate. The difference between this value and the field capacity represents the available water capacity. The available water capacity tends to be highest for intermediate textured soils, although the degree of aggregation of the soil is also important (Brady 1990) (Fig. 1).

For establishment of a sustainable vegetative cover on a disturbed site, it is important to ensure that there is adequate available water capacity in the root zone to enable the vegetation to survive the annual dry season and periods of extended drought. The desired capacity can be achieved by (1) selection of root zone materials which have an adequate available water capacity per unit volume, and (2) ensuring a sufficient depth of the root zone. Water balance models are particularly useful for calculating the water capacity required, but these require a knowledge of the transpiration characteristics of the vegetation as well as the temporal precipitation and evaporation for the site (Flanagan and Livingston 1995).

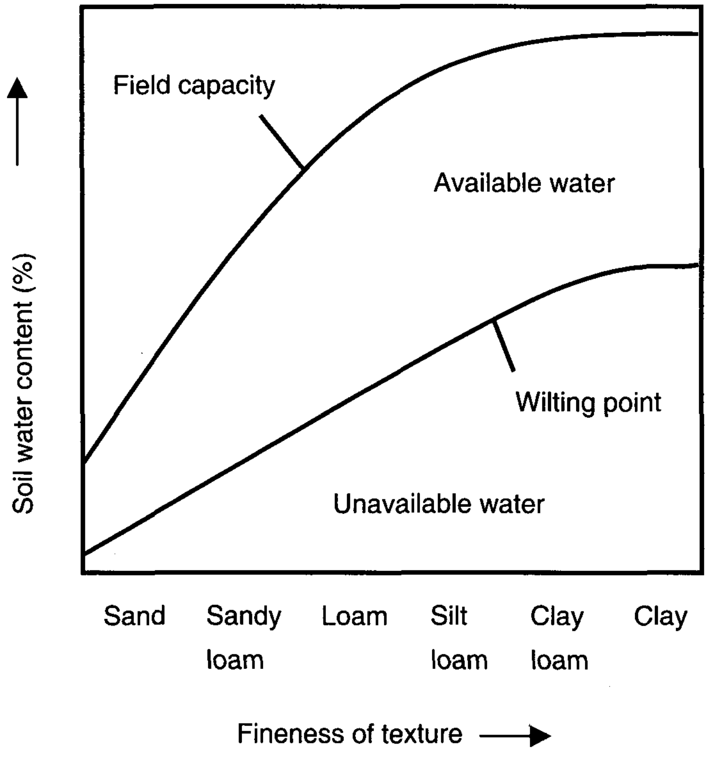

Fig. 1. General relationship between soil moisture characteristics and soil texture (adapted from Brady 1990).

For sites which have a low available water capacity (e.g. sands) and for which no other site materials are available, there is the potential to increase the water holding capacity by the incorporation of organic wastes (e.g. sewage sludge) or fine-textured wastes such as fly ash.

In mining situations, proper characterisation of materials should enable selective handling of materials to ensure that the root zone material has an adequate available water capacity for sustainable vegetative growth.

Aeration

The composition of air is approximately 79% N_2, 20% O_2 and less than 1% CO_2. Because plant roots and organisms living in the soil remove O_2 from the soil and release CO_2 through the process of respiration, the soil air is richer in CO_2 and poorer in O_2 than the atmosphere.

Plants roots require an adequate supply of O_2 and non-toxic levels of CO_2 for growth (Glinski and Stepniewski 1985). The processes that govern the concentration of these gases in the root zone are (1) the rate at which plant roots and soil organisms are converting O_2 into CO_2 and (2) the rate of gaseous exchange between the soil and free atmosphere.

Aeration limitation can occur in water-logged situations arising from excessive supply of surface water or the reduction in the volume of non-capillary pores (>50 μm), which are particularly important for gas exchange, as a result of compaction of materials by earth moving machinery. Amelioration of compacted sites is discussed by Barnhisel (1988).

Surface Crusting

Effect on Water Infiltration

Although a potential root zone may have an adequate inherent available water capacity for the support of vegetation, the voids in the zone must be recharged by infiltration from precipitation. A common limitation in degraded sites is the tendency of the surface materials to form surface crusts of low permeability which reduce infiltration, and increase runoff with resultant increase in water erosion.

Materials with an elevated exchangeable sodium percentage (greater than about 10%) have a tendency to disperse, with the clay-sized material blocking larger pores important in water transmission. These so-called sodic materials can be ameliorated by the application of gypsum. The text edited by Summer and Naidu (1998) provides a comprehensive coverage of the properties and management of sodic materials.

Effect on Seedling Emergence

The crust strength in dispersive soils increases with decreasing water content, and the crust strength may become sufficiently high in some soils and waste materials to prevent emergence of seedlings. Application of gypsum to promote reduction in the exchangeable sodium percentage can aid in amelioration. Additionally any technique that can maintain the water content high (and crust strength low), such as the use of basin listing or application of mulches, will be beneficial. In central Queensland coal mines, which have very dispersive, sodic spoil, the use of basins to retain water on a micro- (1 m diameter) and macro- (2 – 3 ha) scale have proved successful in reducing the crusting problem.

Mechanical Impedance

Mechanical impedance refers to the resistance offered by the soil or waste matrix against deformation by a growing root. Root elongation occurs only so long as the root pressure exceeds mechanical impedance which can be measured using a penetrometer. Soil strength and thus mechanical impedance to roots increases with bulk density and decreases with the water content of the medium (Bennie 1991)

The general relationship between these parameters is shown in Fig. 2. The soil strength at a given water potential and bulk density varies with soil texture. Thus it has been found that the critical bulk density values for root impedance may range from 1.3 g cm^{-3} in clays to 1.8 g cm^{-3} in sands. The amelioration of materials with high mechanical impedance is discussed by Barnhisel (1988).

Temperature Extremes

The surface temperature of waste materials can have a direct influence on the establishment of vegetation, particularly that which is direct seeded. The factors which affect the temperature of a given soil or waste material are the amounts of radiation received, the amount reflected or scattered (albedo), the moisture and air contents, and any factor which affects the rate of evaporation from the material (Payne and Gregory 1988).

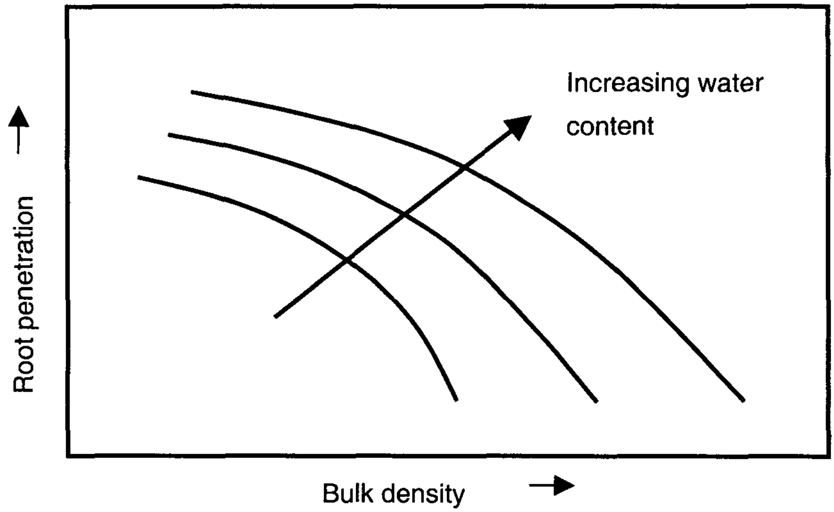

Fig. 2. General relationship between the extent of root penetration and bulk density at different water contents for a soil of given texture. Each curve gives the general relationship between penetration and bulk density at a given water content with the topmost curve representing the highest water content.

The amount of radiation received will be influenced by aspect. In the northern hemisphere, a south-facing slope will tend to be warmer than a horizontal slope, and this is warmer than a north-facing slope. This difference can influence the rate of germination of seed. The reflectivity of soils varies from about 10-15% when moist, and the value increases with drying. Light coloured materials have higher reflectivities than dark coloured materials. For wastes such as some coal mine spoil which can be dark, extreme surface temperatures in summer (e.g. 60°C) can have a detrimental effect on seedling establishment. Mulches can be used to reduce surface temperatures.

Conclusion

The physical properties of a medium are often the most difficult to ameliorate, and thus these often dictate the yield potential for plants after

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the more easily altered chemical or microbiological properties are changed. Tests which can be used to assess physical limitations to plant growth of degraded sites are described by Klute (1986), Williams and Schuman (1987), Hossner (1988) and Sobek *et al.* (2000).

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Chapter 6

Soil Degradation and Nutrients

N.M. Dickinson

Introduction

In recent years, the emphasis has tended to change from simply establishing a vegetation cover towards (i) an awareness of the importance of sustainability and (ii) restoration of more naturalistic ecosystems. To achieve this requires an understanding, firstly, of the contrasting adaptations of different species to soil conditions and secondly, how we can redress the balance of nutrients in degraded soils. This Chapter explains how soil nutrients influence both the establishment of vegetation following reclamation, and the maintenance of the species assemblage of its flora and fauna.

Mining and other use of the land, as well as landscape engineering, frequently mean that soils are substantially modified from their natural state or can be completely artificial. Commonly we are dealing with various materials which may be soil forming but are initially skeletal, such as the crushed overburden strata following mineral extraction. Clearly, this creates a number and variety of constraints to plant growth (see Table 3 in Chapter 4). Soil development and nutrition is a fundamental aspect of the problems of reclamation, but cannot be viewed in isolation. Several factors can combine together to cause problems (Table 1)

An example to illustrate this can be taken from the growth of *Larix leptolepis* (Japanese larch), a tree that is widely used in reclamation of colliery mine spoils in South Wales. A recent study found growth success was correlated with nitrogen and phosphorus availability. However, application of fertilisers was found to be of limited value unless associated problems were also treated; namely high bulk density, anaerobic conditions caused by waterlogging, low soil pH and high concentrations of extractable magnesium (derived from clay mineral groups in overburden strata) (Bending and Moffatt 1999). Soils that are adequate for sustainable vegetation require suitable both physical properties and the ability to supply elements appropriate for plant growth, without extremes of deficiency or excess.

Table 1. Constraints to plant growth associated with derelict and degraded land

Soil constraint	Associated problems
Compaction	Impeded root establishment and colonization by macrofauna Unsatisfactory water percolation Drainage
Particulate structure	Excessive drainage and lack of water-holding capacity Lack of organic matter
Aeration	Lack of O_2 Excessive CH_4 or CO_2
Nutrition	Deficiency Excess
Biological integrity	Lack of soil development Absence of fundamental soil processes
Toxicity	Extreme pH High levels of heavy metals Salinity Organic contamination

Nutrient Problems

At least 13 elements are essential for the growth of higher plants, major nutrients (N, P, K), secondary nutrients (Ca, Mg, S) and micronutrients (B, Cl, Cu, Fe, Mn, Mo, Zn), with other elements also sometimes required by some plants (e.g. Ni, Co, Na, Si) and animals (e.g. I, F, Se, Sn).

Nitrogen is the nutrient required in the greatest amounts by plants from soil, from which it is taken up as ammonium (NH_4^+) and nitrate (NO_3^-). However, NH_4^+ tends to bind to clays and organic fractions in the soil, from which it is slowly released, whereas NO_3^- can be rapidly leached from soil. The main sources of nitrogen are from the decomposition of organic materials and from nitrogen fixation by legumes. Phosphates are particularly important for plant growth and health in the early stages of vegetation development, but this element has low availability in both very acid and very alkaline soils. In established vegetation, symbiotic associations with root mycorrhiza play a particularly significant role in plant acquisition of phosphorus. Potassium and secondary elements are required in lesser amounts by most plants but may be deficient in the early stages of site reclamation. Nutritional issues vary considerably between different types of degraded land, despite some common features (Table 2).

While the soil solution acts as the main source of nutrients, plants are also able to modify the chemistry of the rhizosphere, the root environment. Through nutrient uptake, roots deplete the immediate soil solution causing diffusion gradients of some elements (such as K and P), convective flow and desorption of elements from the surfaces of clays and organic matter. Additional nutrients enter the soil solution through organic matter decomposition, from the atmosphere and from the soil minerals. Symbiotic mycorrhizal associations usually also play a significant role in these processes.

This means that a complex set of factors determine nutrient status, involving more than just concentration in the soil solution. The usual estimate is an index of availability, measured as the amount of nutrients released into one of several chemical extractants. This has been useful where the index can be correlated with crop responses. Accurately identifying the most limiting factor for plant growth on degraded land is not, however, necessarily straightforward. We are usually interested in rapid establishment of a closed vegetation cover, but less concerned with high yields. Adding nutrients, even when they are limiting, may not produce a growth response if other constraints such as pH or salinity, are of overriding importance.

Crop species are usually selected for high yield in monoculture and in conditions of high soil fertility. Their nutritional requirements may therefore be different from those of natural vegetation, particularly vegetation adapted to soils with low fertility. Such vegetation more commonly consists of species with low growth rate and high root/shoot ratios, that are more reliant on mycorrhizal associations to enhance nutrient acquisition. Responses to fertilisers and efficiency of fertiliser usage may therefore vary from agricultural situations. Careful choice of adapted native species (or if they do not exist, exotic species) may be a more efffective approach than adding large quantities of nutrients.

Table 2. Soil nutritional factors on different types of degraded land

Degraded land type	Factors associated with nutrients
Overburdens	General lack of major nutrients, especially nitrogen
Colliery spoil	Commonly pyrite (FeS_2) oxidation creates acidity and toxicity problems. Low pH likely to require treatment with lime as crushed limestone Low nitrogen and phosphorus Sometimes high salinity
Former industrial sites	Land may consist of building materials and debris Soil varying considerably in fertility. Possible hotspots of heavy metals and / or organic contaminants
Landfill	Poor physical structure and low organic matter of soil cover Low nitrogen, phosphorus and potassiumMinor elevation and hotspots of heavy metals and As pH often in upper range.
Urban derelict land	Low levels of heavy metals from urban fallout. Soil may be fertile.
Metalliferous mine waste	Extremely high concentrations of mined metals and companion metals (e.g. Pb, Zn, Cu, Cd, Ni). Inadequate soil structure and major nutrient deficiency. Extremes of pH often influence availability of metals to plants.
Saline soils (particularly in semi-arid climates)	Excessive alkalinity requiring displacement of Na, Mg or Ca, by leaching or by balancing with calcium sulphate

Prior to reclamation, a substrate may require amendments that provide appropriate particle size distribution, aeration,water holding capacity and percolation (see Chapter 5). But the substrate will also require an appropriate pH, and sources of macronutrients, secondary elements and micronutrients. While potentially complex, we shall see that all these problems can sometimes be resolved through the addition of one or a few simple soil treatments. As a basis for determining whether there is deficiency or toxicity of chemical elements, we need to have good knowledge of the normal concentrations in most soils (Table 3).

Table 3. Normal concentration ranges of chemical elements in soils

Major and Secondary Elements	Concentration (%)	Trace Element	Concentration ($mg\ kg^{-1}$)
Total N	0.1 – 1.0	Fe	5 – 200
		Cu	2 – 250
NH_4-N	0.02 – 0.3	Zn	1 – 90
NO_3-N	0.01 – 0.2	Ni	7 – 70
P	0.02 – 0.15	B	0.4 – 3.1
K	0.3 – 2.0	Cd	0.01 – 2
Ca	0.5 – 2.0	Cr	10 – 121
Mg	0.2 – 2.0	Hg	0.01 – 0.3
S	0.03 – 0.3	Pb	2 – 300
		As	0.1 – 50
		Co	2.3 – 53
		Mo	< 1 – 10
		Se	0.1 – 5

Summary of values from Allen (1989); Alloway (1995); Archer and Hodgson (1987); Dickinson *et al.* (2000); McGrath and Loveland (1992) and Reimann and Caritat (1998).

The Role of Organic Matter

Many degraded soils and mine wastes have initially no organic matter at all. In normal soils the organic matter they contain is very important. It firstly forms part of the physical structure, especially lowering bulk density and increasing water holding capacity. It does this both directly by its presence, and indirectly by supporting the growth and activities of myriads of microorganisms and soil fauna which break up the organic matter and incorporate it into the soil. In this way the soil mineral materials become aggregated into a retentive crumb structure. Of equal importance the organic matter has a key role in the retention and supply of nutrients. Being derived from plants, it contains nutrients which were once part of the plants. When the plants die and the organic matter begins to breakdown under the influence of microorganisms, these nutrients are released into the soil solution ready to be taken up again by plants. The organic matter therefore constitutes a critical storehouse for plant nutrients, especially for nitrogen which does not exist in an insoluble mineral form, but also for phosphate which does exist in an insoluble mineral form but one that is so insoluble that the organic store of phosphate becomes particular important especially in skeletal soils.

The organic matter normal breaks down at a rate dependant on soil temperature and moisture, usually between 1% - 10% per annum. If decomposition does not occur then it accumulates and the nutrients it contains are locked up. This occurs particularly at low pH and high levels of heavy metals, common in some degraded land. In skeletal substrates, such as mine spoils, it is therefore important to get rid of any limiting conditions so that nutrient storage and cycling, can begin. It will initially be difficult because of a lack of organic matter. But once a vegetation cover is established, supported artificially by inputs of nutrients as fertilisers, reclaimed substrates or those colonised naturally by invading plants start to accumulate substantial amounts of organic matter in their surface layers. This has been estimated in reclaimed coal mining spoils in Ohio, for instance, to amount to 36.7 t ha^{-1} for pasture and 37.1 t ha^{-1} for forest over a period of 25 years. This is a rate of approximately 1.5 t ha^{-1} $annum^{-1}$. Without initial help the rate of accumulation of organic matter can be extremely slow and the growth of vegetation very poor, even over decades, brought about by a vicious circle of lack of nutrients, lack of plant growth, lack of accumulating organic matter and lack of nutrient cycling.

Organic amendments can enhance this process through their own contribution and by improving the retention and supply of water and nutrients, until enough organic matter accumulates from vegetation to provide a sustainable soil. Sewage sludge and a range of other readily available sources of organic amendments, such as farm manures and slurries, and even paper waste, can serve this purpose. Many of these are surplus wastes otherwise requiring alternative forms of disposal, such as incineration or landfilling. Amounts of these wastes in the order of 100 t ha^{-1} or more of dried solids, usually applied in a wet state, can be used in land reclamation. Quite typically, for example, simple addition of paper de-inking sludge to mine spoils produces revegetation in two growing seasons that is equivalent to the effects of a vegetation cover after 15 years.

The Particular Problems of Nitrogen

In degraded soils since organic matter is deficient, nitrogen is particularly likely to be in short supply. Nitrogen can be supplied in fertiliser in readily soluble forms as nitrate or ammonium ions. Whilst giving a rapid vegetation response, these forms are susceptible to leaching and can be lost as nitrogen gas (in acid conditions) or ammonia (in alkaline conditions). Slow-release forms of nitrogen such as urea-formaldehyde and coated fertilisers are two alternatives, but they tend to be expensive and may be dependent on microbial activity to release nitrogen.

Temperate plants require about 100 kg N ha $annum^{-1}$ (Table 4) and is likely that soil must contain about 1,000 kg N ha^{-1} to supply this amount from decomposing organic matter (Bradshaw 1999). Obviously this varies according to the rate of breakdown of organic matter, but sustainable vegetation requires a capital of nitrogen in soil that decomposes to provide nitrogen for uptake by plants each year. Repeated application of fertilisers during restoration is one way to maintain vegetation until soil reserves of organic matter develop, but this is expensive and there are likely to be significant losses through leaching. A single fertiliser applications of 100 kg N ha^{-1} is likely to provide little more than is sufficient for the first year's growth. This is discussed further in Chapter 11.

The importance of organic matter is demonstrated by the application of organic wastes such as sewage sludge, farm manures and slurries already mentioned. They can be shown to provide a cheaper, longer-term and more sustainable solution. Much larger amounts of nitrogen can be applied by a single application of sewage sludge than by inorganic fertilisers, with less concern about leaching losses. Sewage sludge provides a source or organic matter and nutrients, available as liquid and cake, in both digested and undigested forms. Total nitrogen content of sewage sludge is generally in the range of 0.2-3%, with the bonus of additional total phosphorus in the range of 0.1-2%. The release of nitrogen from sewage sludge can typically take place over a period of 5 years or more, thus providing a significant reservoir of nutrients.

Table 4. The total amounts (kg) of nutrients required annually for plant growth (from Bradshaw, 1997)

Nutrient content of plants (%)	**Annual productivity of vegetation**		
	5 t ha^{-1}	**10 t ha^{-1}**	**20 t ha^{-1}**
Nitrogen (2%)	100	200	400
Potassium (1.1%)	55	110	220
Magnesium (0.51%)	26	51	102
Calcium (0.26%)	13	26	52
Phosphorus (0.18%)	9	18	36

Nitrogen fixation by symbiotic microorganisms contained in root nodules is an alternative, more economical, approach of particular relevance to reclamation of degraded land. Many species of the Leguminosae can form this type of symbiosis with N-fixing bacteria (such as species of *Rhizobium).* Other woody species include species of *Alnus* (in association with the actinomycete *Frankia*), *Acacia*, *Prosopis*, *Robinia pseudoacacia*, *Leucaena leucocephala*, *Sesbania grandiflora*. Numerous species of herbaceous plants, such as *Trifolium, Lotus* and *Medicago,* also possess this ability. *Alnus* can fix up to 90% of its own nitrogen requirement when grown on nutrient poor substrates. In addition to this, nitrogen-fixing species also improve the nitrogen status of the soil. Within a small number of years (about 5 years for temperate species such as *Alnus*), they also benefit companion species planted alongside. Recent UK Forestry Commission studies, however, have shown that the beneficial effects of planting nodulated *Alnus* as a nurse crop for conifers (*Larix kaempferi*, Japanese larch) on reclaimed coal spoils does not always compare favourably with other methods of improving soil nutrition such as adding sewage sludge or other organic materials. The time factor to achieve a beneficial effect may not be appropriate. However, despite these findings, other studies have provided evidence that *Alnus* may contribute 60-320 kg N ha^{-1} annum^{-1} to the soil in natural forest stands and 50-100 kg N ha^{-1} $annum^{-1}$ on degraded soils. Nitrogen fixing plants certainly do have a role to play in land reclamation.

Management of Nutrients During Land Reclamation

Soil is, of course, much more than an inert substrate with *ad hoc* physical and chemical properties that provide appropriate conditions for plant growth. Biological activity from microbial, animal and plant processes provides the the catalyst from which soil derives its integrity. To maintain this, some considerable care is required handling soil in reclamation projects. This is illustrated by the example of soil stockpiling that often takes place during open-cast mining, road construction, pipeline installation and many other development projects. Topsoil is removed and temporarily stored, to be replaced on completion of the work. Unfortunately this does not necessarily restore the same conditions, and low soil nitrogen is commonly found in re-instated soils. Within stockpiled soils, anaerobic conditions replace aerobic condition at depths greater than 1 m, generating high levels of ammonium which in turn provide high amounts of readily leachable nitrate. This leached nitrogen depletes the soils and may be a pollution hazard to adjacent water resources. One study showed that, after 12 years of stockpiling, total nitrogen was similar to adjacent undisturbed soils with concentrations of about 5%. However, in the first 18 months after replacement, total-N concentrations fell to below 1% and the soil had lost 2,800 kg N ha^{-1} (30% of the original amount). Nearly half of the loss was within the first 6 months (Davies *et al.* 1998). Attention to removal and replacement is clearly required.

An almost reverse effect has been found in other situations. In reclaimed bauxite mine sites in north Queensland, highly weathered soils have an inherently poor phosphorus status. Natural plant communities are open grassy forests dominated by *Eucalyptus tetradonta*. Soil stripping in which the top 20-30 cm A horizon is separately stripped and then immediately returned to the surface during replacement results in 50% more extractable-P in soil and 50% more phosphorus uptake by plants after 5 years. This can cause the development of the new ecosystem to deviate considerably from what was intended (Grigg *et al.* 1998).

Contamination of soil may exert a direct toxic effect on plants, but it can also have an indirect effect by causing shortages of available nutrients. In soils with high concentrations of heavy metals, microbial activity is inhibited which in turn inhibits decomposition and leads to a shortage of available nitrogen and other nutrient elements. Heavy metals and soil acidification can displace Ca and Mg from organic layers in the soil, leading to shortages of these cations for plant uptake, as well as other nutrient imbalances. However these deficiencies can often be corrected using fertilisers or other soil amendments to indirectly remove the effects of the heavy metal. In *Pinus sylvestris* (Scots Pine) stands in Finland, liming with Mg-rich granulated limestone has been found to be a better way to increase the availability of Ca and Mg than is the application of slow-release mineral fertilisers containing these elements (Derome 2000).

Interactions between soil nutrients also occur. For example, phosphorus is commonly rendered unavailable by high levels of iron or calcium by forming insoluble phosphates. In colliery spoils high in iron released by oxidation of sulphide materials, successful restoration to grassland requires very high additions of phosphorus (Fitter 1974). Soils adjacent to Cu-Ni smelters in Sudbury in Canada have been treated with lime and phosphorus fertilisers which has allowed grasses, shrubs and trees to establish on otherwise barren land. However, in acid conditions, excessive use of lime giving free lime in the substrate can lead to the formation of phosphorus compounds that are less soluble, so several months gap may be required after liming a site before phosphate is applied.

Mobility of Trace Elements

Trace elements are usually not deficient in degraded soils. However there are chemical processes that affect their mobility (or bioavailability), and subsequently their deficiency or excess. The concentration of trace elements in the soil solution depends on the rate of transfer from solid to liquid phases, which is affected by factors such as acidity, redox status and the presence of organic complexing ligands. There are essentially three major groups of influential soil chemical variables: soil organics (including organic matter, N, P), soil bases (including Ca, Mg, base saturation, CEC) and soil acids (Al^{3+}, H^+, pH).

Soil acidity may have a number of associated effects in any particular soil beside that caused by high H^+.One major effect is toxicity due to high available Al or Mn and deficiency of other elements. Most trace elements are more mobile in acid conditions (Table 5). In cases where the elements are essential nutrients (e.g. Cu, Zn, Mg) and are present in the soil in low concentrations, more acid conditions may be beneficial to uptake. In contrast, when the same or other elements occur at high soil concentrations (e.g. Fe) this also means that pH may increase their toxicity. Thus a combination of acidity and deficiencies or excesses may affect plant growth and performance e.g. by altering root growth, and the plant's ability to withstand other stresses or disturbances such as drought, competition or grazing.

Table 5. Effects of pH on the relative availability of chemical elements in soil

	Highest mobility and availability
Low pH (<5.5)	Al Fe Mn Zn Cu Cd Pb
Intermediate pH	NO_3 PO_4 K Mg S B Cu
High pH (>7.0)	Ca Mo As Se

In acidified nutrient poor soils (pH < 4.2) reactive Al^{3+} is a key ion which strongly affects the soil nutrient balance and supply, as well as itself being seriously toxic to fine roots. Exchangeable aluminium increases with acidity. But there are also other crucial factors such as elevated concentrations of organic and inorganic compounds that may form complexes with aluminium. Increased mobility of trace elements may be caused by sulphide mineral oxidation, fertilizer $NH4^+$, organic matter decomposition, or leaching. Soluble low molecular weight dissolved organic compounds (from root exudates or decomposing organic matter) can act as ligands and complex and mobilise metal species. Increased mobility may even be caused by application of organic wastes; microorganisms can convert As, Hg, Sb, Se and Sn to methyl forms in the presence of high concentrations of dissolved organic compounds, markedly increasing the toxicity of these elements.

Whilst mobility of trace elements is influenced by so many interacting variables, trace element deficiency is generally relatively easily to identify and then to amend using fertilisers. Low pH can be raised by liming. In reclamation projects at any site where trace elements are found to occur in excesive and potentially toxic concentrations, fortunately the problem is usually restricted to a single or small number of heavy metals or metalloids.

Manipulation of Metal Contamination

If highly adsorptive minerals such as zeolites are added to soil, metal toxicities can be reduced. Combinations of zeolites and fertilisers have been shown to be very effective in promoting establishment, increasing plant growth and limiting uptake of heavy metals from toxic Pb/Zn mine spoils. A combination of beringite and compost has been used to stabilise contaminated soil containing 20,000 mg Zn kg^{-1} in Lommel-Maatheid in Belgium, at a site which was then sown with metal-tolerant grasses; seven years after treatment, phytotoxicity was still low, plant species richness was markedly improved, mycorrhizal infection was high and bacterial and nematode diversity was improved. Inactivation of Pb-contaminated soils has been achieved using amendments of liming agents, phosphates, Fe and Mn oxides, organic materials and aluminosilicates, with extensive field trials being carried out at Pb/Zn mine and smelter sites in the U.S.A. at Joplin, Missouri, and at Palmerton, Pennsylvania, and also in Poland at Katowice (Vangronsveld and Cunningham 1998).

The toxicity of heavy metals in soil can also be reduced by promoting the formation of metal phosphates by adding a source of phosphorus. Metal phosphates have low solubility over a wide pH range and therefore, in theory, any metal ions in solution are mopped up, rendering them immobile and not available to plants. Lead, zinc, copper and cadmium phosphates are significantly less soluble than other metal phases such as sulphates and carbonates. Metal phosphates become more soluble in the presence of organic compounds, by forming organo-metal complexes, although there is good evidence that metal phosphates are relatively insoluble and stable in soils, even in the presence of organic matter.

However it is important that the phosphate itself is available. Fertiliser phosphorus as calcium superphosphate is relatively soluble, whilst rock phosphate is slowly-soluble. The natural rock apatite may not release phosphate fast enough to be particularly effective in land reclamation, although synthetic apatites are more soluble. Highly soluble triple super phosphate and Na_2HPO_4 have been shown to be very effective at mopping up metals but may dissolve too rapidly and leach through soils into water bodies. The phosphorus in bone meal has intermediate solubility and costs only about 20% of synthetic apatites. It has shown to be very effective at reducing availability of Zn, Cu, Pb and Cd in contaminated soils (Hodson and Valsami-Jones 2000). In alkaline soils, however, it is possible that bone meal will have the effect of forming organo-metallic complexes and increasing solubility. It is also possible that added phosphate may increase the solubility of some toxic elements such as the metalloid arsenic.

A search of the literature will reveal numerous case studies in which imaginative solutions have been found to reduce the toxicity of high concentrations of heavy metals (e.g. Vangronsveld and Cunningham 1998, Wong *et al.* 1998).

Low Nutrient Status Plant Communities

Scientific and technical knowledge exists to allow us to establish a vegetation cover on most types of derelict land (Bradshaw and Chadwick 1980). A substantial knowledge base should provide us with a realistic expectation of being able to create sustainable plant communities as components of valuable ecosystems. Demands are now being made to pay attention to the creation and maintenance of biodiversity. This requirement presents a challenge to our knowledge of the functional ecology of natural plant communities, extending beyond the simple growth requirement of agricultural, forestry and amenity species.

Ecologists are aware that many of our most diverse and interesting plant communities exists on nutrient poor soils. It seems that when the most productive and competitive species lack the appropriate conditions to become dominant, species with a broader range of adaptations are provided with ecological niches that allow them to co-exist. We value mosaics in many types of vegetation that exist through some combination of environmental variability, competition, grazing and disturbance within the framework of normal successional processes. This requires an overview of a large body of ecological literature and furthermore to relate this to our interest in land reclamation. Suffice it here to use a single example of heathland management in lowland Britain to show what is involved since it is an excellent model for similar approaches using analogous species in other countries.

Heathlands in lowland Britain are high-profile ecosystems for conservation action, because of the rate they have been lost and as a result have become rare and fragmented. They are plagioclimax ecosystems (dependant on human influences) with a relatively small assemblage of species usually dominated by *Calluna vulgaris* (heath) a low nutrient demanding species. Many areas have been invaded by *Betula* spp., *Pinus sylvestris*, *Pteridium aquilinum* and *Rhododendron ponticum*, or else have been replaced by grasslands. Heathlands are typically found on sandy, acidic, nutrient-poor and welldrained soils. The problems is that their soils have tended to accumulate nutrients in recent years through changed management practices and industrial pollution. Mitchell *et al.* (1999) have recently demonstrated that changes in heathland communities appear to be very closely related to soil chemistry and management (consisting of clearing dominant species) (Table 6).

Table 6. Soil factors associated with dominant plant species in lowland heathland vegetation in Britain

Major invaders	**Associated soil factor(s)**
Calluna vulgaris	Low pH, low N, P and Ca
Pteridium aquilinum	Raised mineral-N
Betula spp. at successional sites	Raised pH, extractable-Mg, extractable-Ca
Betula spp. at managed sites	Raised NH_3-N and NO_3-N, organic matter
Grasses	managed sites, raised extractable-P
*Rhododendron ponticum**	low pH

*exotic species

Perhaps the most interesting feature of these results is that differences were related to extractable rather than total concentrations of nutrients. They demonstrate that subtle changes in soil chemistry lead to quite dramatic changes in ecosystem structure. These results can be used to provide an imaginative approach to the problem of reclaiming acid mine wastes. Establishing a *Calluna*-dominated vegetation provides a naturalistic vegetation without resort to heavy application of lime and fertiliser.

Clearly there are large advances in knowledge of this type still waiting to be made for most natural plant communities. This is a single particularly intensively studied example, based on a plant community with relatively low diversity. There are rather few natural temperate ecosystems described as well, in terms of the way nutrition plays such a determinate role in shaping community and ecosystem structure of benefit to reclamation. In the tropics there is a considerably more diverse range of soils and vegetation than in temperate regions and considerably less is known about management of nutrients required to sustain healthy soils and a self-sustaining vegetation. Land reclamation will provide a focus and rationale for this type of research in the future.

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Chapter 7

Problems of Toxicities

Z.H. Ye, A.J.M. Baker and M.H. Wong

Introduction

Human society is facing many problems related to the environment. A significant number of these problems are the consequence of current modes of processing materials and energy leading to pollution problems (van der Voet *et al.* 2000). Environmental problems related to heavy metals are a particular case, having a long history. Heavy metals have toxic properties, leading to adverse effects on human and ecosystem health even in small doses, which are exacerbated by the fact they are not degradable: once they enter the environment they will remain there for a long time. A range of environmental factors are known to affect the toxicity of heavy metals. One very important aspect of the environmental toxicity of heavy metals is their speciation. The particular state of the metal is dependent on the chemical properties of the metal itself and on the properties of the medium. Numerous studies have demonstrated that biotoxicity and other responses are determined by free ion concentration of the metal. Other factors affecting metal toxicity include pH, presence of other elements and ions such as Ca, Mg, P, or other heavy metals, sulphur compounds, salinity etc.

This Chapter examines the problems of toxicities in metal-contaminated land, including toxicity problems of heavy metals, pH, and salinity. It shows that despite their many problems, restorative treatments are possible.

Problems of Heavy Metals

All heavy metals (e.g. Pb, Zn, Cd, Cu, Co, Cr, Ni, Hg) and metalloid elements (e.g. As, Se, Sb) are toxic to plants and animals when exceeding critical concentrations (Table 1). Their bioavailability – and toxic potential – however, is greatly influenced by other soil constituents such as calcium level, pH, organic matter and nutrient status. Consequently, soils or waste materials which have become contaminated with heavy metals may or may not be potentially toxic and hazardous to plants, animals and ultimately man.

Heavy metals and metalloid elements in soil derive from natural mineral weathering and anthropogenic sources. They can accumulate locally in soils due to *in situ* weathering of rock minerals. There are generally higher quantities of metals in igneous than in sedimentary rocks, with Mn, Cr, Co, Ni, Cu and Zn being present in the highest concentrations in most rock types. Apart from metals entering the soil through weathering of rock minerals, there are many anthropogenic sources (Alloway 1990, Ross 1994):

Table 1. Concentrations (mg kg^{-1}) of heavy metals in soils and plants and their critical concentrations in plant and fishes

Element	'Normal' range in soil[1]	Critical soil total concs[2]	Normal range in plants[1]	Critical concs in plants[3]	Toxicity in solution to plants[4]	Toxicity in solution to fishes[5]
As	0.1-40	20-50	0.02-7	5-20	---	---
Cd	0.01-2.0	3-8	0.1-2.4	5-30	2.1	2.1
Co	0.5-65	25-50	0.02-1	15-50	---	---
Cr	5-1500	75-100	0.03-14	5-30	3.8	120
Cu	2-250	60-125	5-20	20-100	0.02	0.02
Hg	0.01-0.5	0.3-5	0.005-0.17	1-3	6.6	0.02
Mn	20-10000	1500-3000	20-1000	300-500	0.05	100
Ni	2-750	100	0.02-5	10-100	0.18	30
Pb	2-300	100-400	0.2-20	30-300	1.7	1.7
Sb	0.2-10	5-10	0.0001-0.2	—	---	---
Se	0.1-5	5-10	0.001-2	5-30	---	---
Zn	1-900	70-400	1-400	100-400	1.3	1.3

Notes and Sources:

[1]Data mainly from Bowen (1979).

[2]The critical soil total concentration is the range of values above which toxicity is considered to be possible. Data from Kabata-Pendias and Pendias (1984).

[3]The critical concentrations in plants is the level above which toxicity effects are likely. Data from Kabata-Pendias and Pendias (1984).

[4]Concentration reducing growth (of roots of *Lolium perenne*) to 50%: this will vary with species. Data from Bradshaw and Chadwick (1980).

[5]Concentration reducing survival of rainbow trout (*Salmo gairdneri*) to 50% after 48 hrs (concentrations permitting long term survival and reproduction may be 10% of these values). Data from Bradshaw and Chadwick (1980).

1. Metalliferous mining and smelting: spoil heaps and tailings, transported ore separates, smelting, iron and steel industry, and metal finishing. The data in Table 2 summarises the element concentrations in different mine tailings and waste rocks. The properties of tailings and waste rocks range widely and even tailings of the same type may be ofdifferent mineralogy and therefore have different physico-chemical characteristics.

Table 2. Element concentrations in tailings (from Ritcey 1989)

Elements	Tailings Mean	Tailings Range	Tailings No.	Waste rock Mean	Waste rock No.
Fe%	15.5	0.4-56.81	202*	7	24
Al%	2.8	0.1-8.1	61	6.2	26
Mn%	0.2	0.01-4.0	167	0.12	26
Cd (mg kg^{-1})	38	2-280	115	175	27
Cr (mg kg^{-1})	1000	70-7000	31	---	---
Co (mg kg^{-1})	1140	100-9999	39	150	10
Ni (mg kg^{-1})	96	10-546	132	85	13
Pb (mg kg^{-1})	340	0.3-2810	139	---	---
Zn (mg kg^{-1})	510	1-5000	149	15	18
Cu (mg kg^{-1})	130	1-750	164	---	---

*Number of sites examined.

2. Industry: environmental contamination by heavy metals was previously mostly associated withindustrial emissions. Today, many industrial activities still cause environmental contamination by heavy metals, such as in the plastics (Co, Cr, Cd, Hg), textiles (Zn, Al, Z, Ti, Sn), microeletronics (Cu, Ni, Cd, Zn, Sb), wood preserving (Cu, Cr, As) and refinery (Pb, Ni, Cr) industries (Ross 1994).

3. Atmospheric deposition: urban/industrial sources, pyrometallurgical industries, automobile exhausts, and fossil fuel combustion. A high proportion (22.1%) of the Cd entering soil through atmospheric deposition is derived from mining activities (Nriagu and Pacyna 1988). The Hg entering soils from atmospheric sources (28.6%) is mainly of natural origin such as volcanism and through microbial processes which occur in water and soil. Lead is the only other metal added to soils in significant quantities from the atmosphere (6.6% of all

Pb additions). Fifteen times more Cd, 100 times more Pb, 13 times more Cu, and 21 times more Zn are emitted by man's activities than natural processes.

4. Agriculture: fertilizers, manures, lime, pesticides, irrigation water, and corrosion of metals. Table 3 summarises the typical ranges of trace elements in agricultural amendments.

Table 3 Ranges of trace elements in agricultural amendments and waste disposal on land (mg kg^{-1}) (from Alloway 1990 and Fergusson 1990)

Element	Composted refuse	Farmyard manure	Phosphate fertilizers	Nitrate fertilizer	Lime	Pesticides	Irrigation	Sewage sludge	Fly ash
Cd	0.01-100	0.1-0.8	0.1-190	0.05-8.5	0.04-0.1	---	<0.05	<1-3410	0.2-14
Co	---	0.3-24	1-12	5.4-12	0.4-3	---	---	1-260	---
Cr	1.8-410	1.1-55	66-245	3.2-19	10-15	---	---	8-40600	22-259
Cu	13-3580	2-172	1-300	---	2-125	---	---	50-8000	45-616
Hg	0.09-21	0.01-0.36	0.01-2.0	0.3-2.9	0.05	0.6-6	---	0.1-55	---
Mn	---	30-969	40-2000	---	40-1200	---	---	60-3900	145-950
Ni	0.9-279	2.1-30	7-38	7-34	10-20	---	---	6-5300	1.8-420
Pb	1.3-2240	0.4-27	4-1000	2-120	20-1250	11-26	<20	2-7000	3.1-241
Zn	82-5894	15-566	50-1450	1-42	10-450	---	---	91-49000	14-406

5. Waste disposal on land: sewage sludge, coal ash (see Table 3), leachate from landfill, scrap heaps, and bonfires, etc.

Cultivated land, as opposed to land being used specifically for waste disposal, receives continuous, appreciable, deposits of toxic metals. If these inputs were to be dispersed uniformly over the cultivated land area of 16 x 10^{12} m^2, the annual rates of metal application would range from 1.0 g ha^{-1} for Cd to about 50 g ha^{-1} for Pb, Cu and Cr, to over 65 g ha^{-1} for Zn and Mn (Nriagu and Pacyna 1988). The two main anthropogenic sources of soil trace metals are: (i) fly ash residues from coal combustion, providing 34.2%, 33.3%, 62.9% and 51.3% of the annual inputs of Cd, Hg, Mn and Ni respectively; and (ii) corrosion of commercial products, which provides 47%, 55.8%, 42% and 36.2% of all Cr, Cu, Pb and Zn inputs respectively. Other sources are individually important, such as agricultural and animal manures which provide 22.9% of Zn inputs, and urban refuse which provides 20.5% of Cd input (Ross 1994).

Metal bioavailability in soil is complex, due to the many soil factors which contribute to it. These include pH, organic materials and cation exchange capacity. Total heavy metal concentrations in a soil are, in fact, poor predictors of heavy metal bioavailability. The bioavailable fraction is the fraction of the total heavy metals that best predicts plant uptake and transfer to the food chain. Metal additions to soils, which will increase total metal concentrations, are likely to increase metal bioavailability but not in a precise manner (Pierzynski *et al.* 1994).

Problems of pH

The pH of a soil is a function of the H^+ ion concentration in the solution present in soil pores. This is in dynamic equilibrium with predominantly negatively-charged surfaces of the soil particles. The pH of most soils ranges from 3.0 to 8.0. However, the maximum range of pH conditions found in soil is 2-10.5 (Alloway 1990, Pierzynski *et al.* 1994). Extreme acidity usually results from the weathering of exposed sulphide minerals, producing sulphuric acid. Low pH soils result in the mobilization of Al^{3+}, Fe^{3+} and Mn^{2+} ions which can be directly phytotoxic. High pH (above 8) is a result of alkaline soil reaction usually from either sodic soils (in arid areas) or from the dumping of industrial materials such a Solvay Process or chromate wastes.

The effects of pH in soils are complex. It can cause nutrients to become unavailable. It can also cause elements which are micronutrients, and other elements which are not nutrients, to become available to plants in toxic amounts. In acid soils, quite apart from a deficiency of calcium, there is a serious excess of aluminium and manganese. These two elements are present in nearly all soils but usually in a form unavailable to plants. But when the pH drops below 4-5, they become more soluble and can exert direct toxic effects (Fig. 1). Aluminium also has an indirect effect. Together with iron, it combines with phosphate forming insoluble compounds in which the phosphate is not available to plants. In very acid soils microbial activity is reduced. As a result, release of nitrogen and other nutrients can be very low so that there is a considerable nutrient deficiency.

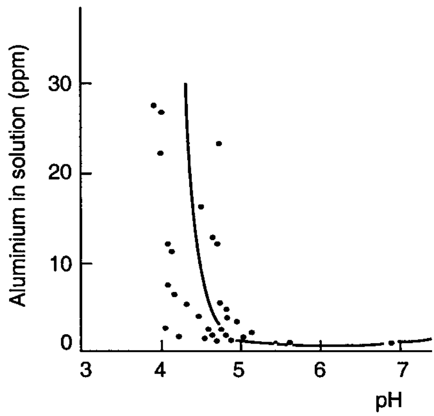

Fig. 1. High levels of aluminium at low pH exclude many plants from acid soils: a graph showing the effect of pH on the solubility of aluminium in water and the concentrations of aluminium found in soil solutions (Bradshaw and Chadwick 1980).

Problems of Colliery Spoil

In common with most other rock wastes, colliery spoil is totally deficient in N and almost equally deficient in plant-available P (Bradshaw and Chadwick 1980). Some acid spoils are also deficient in plant available K. Many of the problems encountered in revegetating colliery spoil are concerned with extreme acidity which is generated by the oxidation of iron pyrites (FeS_2). Colliery spoil commonly contains significant quantities of pyrite (more than 1%). The pyrites exposed on the surface of the tip oxidises spontaneously when in contact with the atmosphere. In many cases, the rate of acid production and the quantity of acid produced exceeds the buffering capacity of the spoil material and the pH of the spoil falls to extremely low levels, making aluminium and manganese available in toxic amounts to plants (Harris *et al.* 1996). It can give rise to acid mine drainage (AMD), not only of very low pH but also containing levels of aluminium and manganese causing damage to streams and river. This may occur after original available acidity has been treated with lime, as more pyrites become oxidised. It is important to quantify this potential for acidity generation by determination of residual pyrite (see Chapter 10). Values as low as pH 2.3 have been recorded and values of pH 3.0 or less are not uncommon. The same can occur in the wastes produced by mining for metals.

Some buffering capacity of colliery spoil is derived in part from free carbonate minerals, and also from the clay minerals which form the bulk of the rock debris in the spoil. Many spoils contain significant quantities (1% or greater) of free carbonate which is generally a variable mixture of Ca, Mg, Fe and Mn carbonates. Reaction between the carbonate minerals and the products of pyrites oxidation occasionally produces high levels of water -soluble sulphate salts and also soluble Mn, both of which are potentially hazardous to plant growth. Some spoils also contain Cl salts, generally of Na but also occasionally of Mg, in sufficient quantities to be regarded as a potential risk to plant growth.

Problems of plant toxicity due to acidity and/or salinity are not universal, but in some coalfields 50% of the spoils encountered may be considered to be potentially toxic. The most common characteristic of colliery spoil on reclamation sites which may subsequently give rise to problems is the extremely variable chemical nature of the material found.

As an extreme example, the pH values recorded from the surface 300 mm of spoil on a 10 ha site can vary from pH 9.0 to 2.6. The water-soluble salt content also varies in a similar manner. Estimated as the specific electrical conductivity of a 1:2 extract of spoil in saturated calcium sulphate, values may vary from 2,000 to 4,000 μmhos cm^{-1}. The source of variation may be in the range of materials as originally tipped on site, or because the process of re-contouring the site results in a mixture of weathered and unweathered material on the final surface of the reclaimed site.

Problems of Salinity

Salinity is quite a widespread problem. Many waste materials, particularly those produced by mining for heavy metals, but also some colliery spoils, contain sulphides such as pyrite and also carbonates particularly of calcium and magnesium. When the pyrite oxidises it can give calcium and magnesium sulphates. Neither of these is at all toxic at normal concentration. But they are soluble and in arid climates may accumulate and cause extreme salinity in the surface layers of the waste as the soil moisture evaporates (Bradshaw and Chadwick 1980). Salinity of tailings may therefore result from:

1. Interaction of products of pyrite weathering with native carbonates.
2. Concentration of naturally occurring salts due to recycling of water.
3. Additions made to tailings to adjust effluent pH.
4. Excessive evaporation from the surface.

Other Toxicities

Toxicities can also arise from non-metallic elements in their anionic forms, e.g. F^-, Cl^- (salinity), SO^{2-} (as above). These are generally associated with rather specialist wastes or exceptional environmental conditions.

Possible Approaches

The contamination of soil, sediment, and water resources with toxic metals and metalloids is an unfortunate by-product of industrialization. In the most seriously contaminated sites, native plants have declined or disappeared, leaving the sites biologically barren. As a result, the most contaminated sites can be a serious threat to human health and the environment, and require immediate action (see Chapter 2).

For the restoration of these metal-polluted sites, two different approaches can be adopted (Vangronsveld and Cunningham 1998). These depend upon the nature and degree of the pollution, the desired end use of the area, and the technical and financial means.

Engineering Approaches

Burying

Soil excavation and landfilling is perhaps the simplest method for removing metal contamination, but it is very expensive. It requires removal of the contaminated soil to a special landfill and subsequent site restoration which usually includes back-filling with clean soil and establishment of vegetation. This method is the most widely used technique for small, heavily contaminated sites. On a large scale, the method is not feasible due to high costs with excavation involved and restrictions in the availability of suitable landfill sites.

Combined Chemical and Engineering Approaches

Capping

A common method of remediating polluted sites is to leave the material *in situ* and place a physical barrier (cap) on the soil surface that prevents water infiltration and erosion of the polluted material. This solution is applicable at small or medium sized sites (see also Chapter 9).

Immobilization

Polluted soil can be stabilized by mixing with solidifying materials such as cement or other pozzolanic materials, or other suitable agents. This method may be conducted *in situ* or on an excavated soil and it is most effective on low to moderately contaminated soils, especially where contamination is near the surface where excavation or *in situ* mixing is easiest.

Biological Approaches

Phytoextraction

The use of plants to extract toxic compounds from soils (phytoextraction) is being developed as a method for remediation of metal-contaminated soils (Baker *et al.* 1994, Raskin *et al.* 1994). Phytoextraction is often attractive because of its potential low cost and low site input. However, the technique is still developing, and may not be a practical remediation technique in all sites (see Chapter 12).

Phytostablization

This technique involves direct seeding with metal-tolerant plants on metal-contaminated sites. The tolerant plants are used to cover the soil surface to prevent erosion, reduce water percolation, and serve as a barrier to prevent direct contact with the soil. Phytostablisation does not remove the contaminant from the soil, but reduces the hazards to human health and the environment by a different yet protective strategy. Direct seeding with tolerant plants has many distinct advantages on wastes too toxic to be seeded directly with non-tolerant plants. The tolerant plant approach is very economical, requiring only direct seeding of the substrate with the addition of standard NPK fertilizer. Tolerant plants also have a great advantage in that they tolerate nutrient limitation and drought. Despite the economic and practical benefits of this approach, however, the use of metal-tolerant cultivars in large-scale revegetation schemes has not become as widespread as predicted since the development of commercial varieties in the late 1970s (Tordoff *et al.* 2000) (see Chapter 12).

Inactivation and Phytorestoration

This type of solution is the *in situ* reduction of the pollution by amendments sufficient to allow revegetion of the area with normal or tolerant plant species. The amendments commonly include phosphates, liming agents, metals (Fe/Mn) oxyhydroxides, organic materials (e.g., sludges or composts), and other materials (e.g., synthetic zeolites, beringite, or steel shots). One of the most remarkable examples is the treatment of the large areas of grossly polluted land around the nickel smelters at Sudbury, Ontario with lime which reduced the metal toxicity sufficiently to allow natural colonisation to take place (Gunn 1995). In very toxic situations, alternatively the material can be covered with a simple soil cap which isolates the plant sufficiently to allow growth of a vegetation cover (Johnson *et al.* 1994).

The integration of soil amendments and establishing plant growth results in the installation of a normal functioning ecosystem. These are more natural approaches to remediation when compared to some current remediation practices, such as excavation and landfilling, and stabilization with cement. Through the selection of plants, cropping schemes, and soil amendments, this technique may be adapted to different metal contaminants and soil types (Table 4). It can be an economically more realistic and cost-effective approach than other alternatives, especially for vast industrial sites and dumping ground (Vangronsveld and Cunningham 1998) (see also Chapter 14).

Table 4. Approaches to revegetation (adapted from Johnson *et al.* 1994)

Waste characteristics	Reclamation technique	Problems encountered
Low toxicity Total metal content: <0.1%. No major acidity or alkalinity problems.	***Amelioration and direct seeding with agricultural or amenity grasses and legumes*** Apply lime if pH < 6. Add organic matter if physical and chemical amelioration required. Otherwise apply nutrients as granular compound fertilisers. Seed using traditional agricultural or specialised techniques	Probable commitment to a medium/ long-term maintenance programme. Grazing management must be strictly monitored and excluded in some situations.
Low toxicity and climatic limitations Toxic metal content: <0.1%. No major acidity or alkalinity problems. Extremes of temperature, rainfall, etc.	***Amelioration and direct seeding with native species*** Seed or transplant ecologically adapted native species using amelioration treatments where appropriate.	Irrigation often necessary at establishment. Expertise required on the characteristics of native flora.
High toxicity Toxic metal content: >0.1%. High salinity in some cases.	(1) ***Amelioration and direct seeding with tolerant ecotypes*** Sow metal- and/or salt-tolerant ecotypes. Apply lime, fertiliser and organic matter, as necessary, before seeding.	Possible commitment to regular fertiliser applications. Relatively few species have evolved tolerant populations, and of those that have very few are available commercially. Grazing management not possible.
	(2) ***Surface treatment and seeding with agricultural or amenity grasses and legumes*** Amelioration with 10-50 cm of innocuous mineral waste and/or organic material. Apply lime and fertiliser as necessary.	Regression will occur if depths of amendment are shallow or if upward movement of metals occurs. Availability and transport costs may be limiting.
Extreme toxicity Very high toxic metal content. Intense salinity or acidity.	***Isolation*** Surface treatment with 30-100 cm of innocuous barrier material and surface binding with 10-30 cm of a suitable rooting medium. Apply lime and fertiliser as necessary.	Susceptibility to drought according to the nature and depth of amendments. High cost and potential limitations of material availability.

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Chapter 8

The Significance of Microbes

A.G. Khan

Introduction

Many microbes have their origin in the soil or are closely associated with the soil environment and have had a substantial impact on mankind (Doyle and Lee 1986). The soil microorganisms play important role in recycling of mineral nutrients such as nitrogen, phosphorus, sulfur and many metallic cations such as copper, mercury, iron and aluminium, and thereby contributing to the sustainability of life. Solution to many environmental problems of today lies in the better understanding of the ecology of microbes in the soil.

The Soil Habitat

Physical (texture, bulk density, particle density, pore spaces), chemical (pH, cation and anion exchange capacity) and abiotic soil factors such as soil water, soil aeration, and soil temperature are integrated with biotic factors (flora, fauna and microbes). Soil, as a weathered rock, contains minerals and nutrients that can support plant growth. Most soils are mineral soils; only 0.9% of the world's soils are organic (Miller and Donahue 1995). Based on the particle (sand, silt and clay) distribution, all mineral soils are divided into 12 textural classes. The texture of a soil is important in the aeration and drainage of soil. Soil microorganisms reside in soil pores that play a major role in air and water movements. Groups of soil particles, soil aggregates, define soil structure. Both soil texture and soil aggregation (structure) influence soil productivity.

Biotic factors such as plant roots, organic matter, and microbes also influence soil aggregate formation. Soil microorganisms can physically bind soil particles and are fundamental to soil structure as well as soil formation. Soil chemical characteristics such as pH and positive and negative charged ions are also important because chemicals in their environment influence plants and microbes markedly. This means that, in contrast to physical binding, soil microbes can chemically bind (adsorb) to clay and organic matter soil particles. In other words, soils can attract or repel microbes.

Soil abiotic factors also influence soil microbes, both prokaryotic bacteria and eukaryotic fungi. *Soil water* is not only essential for microbial activity, it also affects gas exchange and many soil chemical reactions. *Soil texture* affects soil moisture, which, in turn, has a profound effect on soil microorganisms and soil microbial processes. *Soil aeration* is highly dependent on soil moisture, soil porosity, and soil air. It produces oxidizing or reducing environments, depending upon aerobic or anaerobic conditions, respectively. *Soil temperature*, which is inextricably linked to soil moisture, affects the rates of chemical, physical and biological processes in the soil.

All these soil physical, chemical and abiotic factors are integrated with soil microorganisms and illustrate how soil conditions can influence soil microorganisms. The soil microorganisms, in turn, influence soil properties positively or negatively. They are interdependent.

Eukaryotic fungal organisms are also common soil microorganisms and are important as pathogens, beneficial symbionts, and saprophytes to degrade organic matter, and as biotic agents to improve soil structure and aeration.

Most soil microorganisms are heterotrophs, using non-living organic matter in soils or forming symbiotic associations with plants and animals. Many other soil microbes are autotrophs, which use light energy (cyanobacteria) or energy obtained from the oxidation of inorganic substrates, e.g. S, to synthesize carbohydrates with carbon dioxide as their primary source of carbon. Many flagellates, amoebae, and ciliate protozoa, and nematodes also inhabit soil environments In short, soil microorganisms play central roles in soil formation, nutrient cycling, and organic matter decomposition.

Among other biological entities in the soil, viruses are also the most numerous but are the least understood.

Microbially Mediated Transformations in Soil

Soil contains an enormous diversity of microbial population. But we know very little about what control microbial population composition, even though the properties and behaviour of microorganisms in their soil environment affect the function of the soil ecosystems in many crucial ways.

Carbon Transformations

Soil microorganisms decompose plant residues and form soil organic matter. But the decomposition rates differ for different decomposable fractions, e.g. cellulose, hemicellulose, lignin, etc. During the process of decomposition, a portion of the carbon is incorporated into microbial biomass and an additional fraction is evolved as carbon dioxide. This process of decomposition (also called microbial respiration or mineralization) is one part of the carbon-cycle. From the atmospheric pool of carbon dioxide, photosynthetic and chemoautotrophic bacteria fix carbon into various organic compounds. The flow of carbon through the soil depends on the efficiency with which the microbes use the residues as substrate for growth. As a result of microbial decay of plant residue, humus (soil organic matter or SOM) is formed which enhances soil quality (Doran *et al.* 1996). The overall process of decomposition is influenced by seasons, i.e. slow in cold or dry climate and fast in warm spring. Temperature and soil moisture strongly affect residue decomposition by microbes. In addition to plant residues, the cells of dead microbes can also act as substrates for living microorganisms. Sewage sludge (biosolids) and animal manure also contain organic materials similar to those in plant residue and are subject to the same general pathway of decomposition.

The population of microbes involved in decomposition of plant residues is regulated by soil aeration, soil moisture, soil temperature, soil pH, and soil nutrient status. Soil conditions favourable for growth of microbes engaged in decomposition also favour rapid decomposition of plant residues. Over time, the decomposing microbial population undergo a microbial succession as the decay progresses in stages depending upon the variety of plant residue components.

The soil organic matter imparts some beneficial properties to the soil. It provides a carbon and energy source to support a variety of active microbial populations. It increases cation exchange capacity of soil, buffers pH change, provides a slow release of organically bound nutrients (N, P, and S) and enhances chelation and thus bioavailability of trace elements to plants, accelerating mineral weathering. Many physical properties of soil are also influenced by SOM, e.g. improving soil structure, decreasing soil density thus increasing pore spaces and total water holding capacity, etc.

Nitrogen Transformation

Nitrogen is an essential nutrient for all life on earth and is present in various forms, primarily as dinitrogen gas, organic nitrogen in plants, animals, microbes, and SOM, and ammonium and nitrate ions. Certain bacteria (diazotrophs) transform nitrogen gas to ammonia by a process called nitrogen fixation, which is carried out by many free living or symbiotic bacteria, cyanobacteria, and the actinomycete *Frankia*. Microbially mediated processes, such as ammonification and denitrification, transform nitrogen from one form to another by an exclusively prokaryotic enzyme complex nitrogenase. Biological nitrogen fixation offers an alternative to the use of expensive nitrogen fertilizers and it has an important place in sustainable agriculture as well in restoring derelict land.

Many typical bacteria (*Azobacter, Beijerinckia, Clostridium, Pseudomonas and Azospirillum*) and specialized bacteria (cyanobacteria, actinomycetes), which are micro aerophiles (that grow best at low oxygen tension), are widespread in nature as free-living microbes or in non-symbiotic association with plants and animals. They can provide fixed nitrogen for growth of non-fixing microbes and plants and are significant in areas where no other source of nitrogen is available. The ability of these diazotrophs to fix nitrogen and transfer nitrogen to plants have been demonstrated by many researchers using the isotopic N method (for references see Barea *et al.* (1992)) and Chapter 11. There are many species of aerobic photosynthesising cyanobacteria that fix nitrogen.

The free-living N-fixing bacteria make important contributions to the N-economy of areas such as grasslands and forests. Free-living cyanobacteria can fix significant amounts of nitrogen in deserts after rain and on the surface of arctic tundra soils. Rice paddies can accumulate heavy growth of such free-living N-fixing microbes.

Sulfur Transformation

Sulfur is an essential element for all living organisms. It is found in many oxidation states in soil and it undergoes many microbially mediated transformations. The soil microbes influence sulfur cycling through concurrently occurring biological mineralization and immobilization processes. Soil factors that influence the growth and activity of microbes also affect the S transformations. The S-using bacteria occurring in soil and aquatic habitats include genera such as *Desulfovibrio, Thiobacillus, Beggiatoa, Chlorobium, Chromatium,* etc. (Cook and Kelly 1992).

Transformation of P, Fe, Mn, Hg, Se

Soil microorganisms are also actively involved in the transformation of many other elements such as P, Fe, Mn, Hg, Se, etc. by a variety of mechanisms such as mineralization and mobilization, solubilization and methylation of elements.

Organic phosphorus compounds in the soil are acted upon by enzymes phosphatases released by soil microbes extracellularly into the soil solution to catalyse phosphorus mineralization. Many organic acids are produced by microorganisms and plant roots in the soil, which act as chelating agents to solubilize P into soil solutions (Stevenson 1967). Some bacteria, such as *Bacillus spp.,* are very effective in solubilizing P from rock phosphate.

Many metallic and metalloid elements, such as Fe, Mn, Hg and Se also undergo biotic transformations by soil microorganism such as *Bacillus, Thiobacillus, Pseudomonas, Streptomyces, Desulfovibrio, Clostridium and Micrococcus* (Ehrlich 1990). Oxidation and reduction of Fe and Mn can affect availability of these elements to plants. Many microorganisms produce iron-complexing compounds called siderophores (Leong 1986), which solubilize iron for uptake, by the organisms. The chelation of Fe^{3+} from iron phosphate minerals also results in soluble orthophosphate.

Methylation of mercury is caused by its reduction to volatile Hg^{o} by many microbes such as *Bacillus, Pseudomonas, Corynebacterium, Micrococcus,* and *Vibrio* (Nakamura *et al.* 1990). Selenium, an essential trace element for animals, is oxidized by many soil bacteria, including *Pseudomonas* and *Clostridium* (Doran 1982).

Microorganisms within the Rhizosphere and Their Significance

The microbial population in the root environment is affected not only by the physical and chemical parameters of the soil in general, but also by the abiotic rhizosphere (soil in the vicinity of a plant root) environment. Rhizosphere moisture, its soil structure, temperature, pH, and organic materials released from the roots, all alter the microbial diversity and activity (Lynch 1982). Many Gram negative bacteria, mostly Pseudomonades, actinomycetes, and some fungi (mainly zygomyceteous and asexual forms of many ascomycetes) are found in greater abundance in the rhizosphere rather than elsewhere in the soil.

Several microbes inhabiting the rhizosphere are pathogenic while others form symbiotic associations with the roots, e.g. root nodule-forming Rhizobia and mycorrhizal fungi.

Symbiotic Nitrogen-Fixing Bacteria

Roots of most legumes harbour symbiotic nodule forming and N-fixing bacteria (*Rhizobium* and *Bradyrhizobium*). Many non-leguminous plants also form N-fixing nodules by non-rhizobial microbes. *Frankia* spp. (actinomycete) are able to form N-fixing nodules in the roots of certain woody non-leguminous plants, e.g. *Alnus, Coriaria, Datisca, Elaeagnus, Hippophae, Myrica, Ceanothus, Discsria, Dryas,* and *Casuarina.* Many gymnosperms such as Cycadales can be nodulated by the cyanobacteria (*Nostoc, Anabaena*) (Jeffrey 1987). *Azolla/Anabaena* symbiosis is of great significance in some Asian countries, especially China (Lumpkin and Plucknett 1980; Peters and Meeks 1989). Some species of the genus *Sesbania* form N-fixing stem-nodules as well as root-nodules when infected with a specific *Rhizobium* spp. (Ndoye and Dreyfus 1988). The only non-leguminous genus able to form N-fixing root nodules by *Rhizobium* is *Parasponia* (Ulmaceae) (Trappe 1986). Many studies performed on plants growing on derelict lands have reported them to possess N-fixing nodules (Khan 2001). Such plants may be largely responsible for the successful colonization of these habitats. Implication of such findings needs to be considered in restoration strategies.

Symbiotic Mycorrhizal Fungi

Nearly all plants depend on symbiotic mycorrhizal fungi, which help their roots absorb minerals and water from soil (Smith and Read 1997). In the nutrient-poor or dry soils, the extramatrical hyphae of these fungi in the soil take up nutrients and transport them to the root, thereby leading to improved plant growth and reproduction. Mycorrhizal plants are often pioneers on derelict soils and better able to tolerate environmental stresses than are non-mycorrhizal plants. Hyphae of mycorrhizal fungi increase the absorbing surface of the root (Sylvia 1990). Mycorrhizal associations are caused by a wide variety of soil fungi. Ectomycorrhizal fungi are mostly basiodiomycetes that grow between root cortical cells of many tree species forming what is termed a Hartig net, whereas most endomycorrhizal fungi forming branched structures called arbuscules (hence the name arbuscular mycorrhizal, AM, fungi) within root cortical cells of most plants, are phycomycetes.

Although AM fungi are most common, they differ in their specificity, infectiveness, and effectiveness that affect their impact on nutrient uptake and plant growth. Hyphae of the mycorrhizal fungi can penetrate small soil pores inaccessible to roots or root hairs and have access to non-available nutrient pools. Plant roots and their associated microflora (including mycorrhizal fungi) produce organic acids and hydrolytic enzymes such as proteases and phosphatases, which results in hydrolysis of organic matter and release of inorganic P. Extramatrical hyphae of mycorrhizal fungi not only have an impact on organic matter mineralization and availability, but also bind soil particles together and thereby improve soil aggregation (Miller and Jastrow 1992). A unique microbial community develops around the rhizosphere of mycorrhizal plants (mycorrhizosphere) due to enhanced C-flow to the soil mediated by mycorrhizal fungal hyphae.

Plant Root Pathogens

Plant pathogenic bacterial species such as *Mycoplasma, Corynebacterium, Agrobacterium, Pseudomonas, Xanthomonas, Streptomyces* and *Erwinia*, are widely distributed in soil and cause a variety of diseases. Soil plant pathogens produce toxins or enzymes such as pectinases, cellulases and hemicellulases that result in degradation of the plant roots. Once plant roots are invaded by a primary plant pathogen, they are subject to additional invasion by opportunistic secondary pathogens. Some bacterial root pathogens, e.g. *Pseudomonas* species have a permanent soil phase, occur abundantly as saprophytes in the rhizosphere but infect plant through roots when available. Others, e.g. *Erwinia amylovora,* causing the fire blight disease of pears and apples, have a continuous association with plant tissue throughout its lifecycle and lack a free soil phase (Agrios 1978). Many plant bacteria such as *Pseudomonas phaseolicola* and *Xanthomonas malvacearum* are seed born, i.e. bacteria survive on seed as surface contaminant. They are subject to be influenced by soil parameters such as texture, moisture and temperature. Crown gall bacterial disease caused by *Agrobacterium tumefaciens* occur after bacteria enter either through the root or through wounded stem at the soil-plant stem interface (Kosuge and Nester 1984).

Many soil fungi also cause plant diseases. For example, *Rhizoctonia solani*, causing root rots of various plants, invade the plant through its roots. Some fungi such as *Venturia*, causing apple scab, pass part of their lives on the host as parasite and part on dead host tissue on ground as saprophyte. Survival and infectivity of most plant pathogenic fungi, like bacteria, depend on abiotic soil conditions, especially temperature and moisture. Changes in soil environmental conditions may affect the plant pathogen, the host plant, or both.

Microbial Interactions within Rhizosphere

The interaction of plant roots and rhizosphere microbial populations depends largely on physio-chemical changes in the soil environment caused by modification of the soil environment due to the release of chemicals to the soil by the roots and microbially mediated availability of mineral nutrients.

Free living dinitrogen fixing bacteria use root exudates as the energy source to support N-fixation and have a marked effect on the growth of plants. Other microbes in the rhizosphere produce auxins and gibberellins-like compounds which aid plant growth (Brown 1974). A synergistic relationship exists between a plant and its rhizosphere microbial population. Significant increase in Ca uptake by the roots, for example, may be due to high concentrations in the rhizosphere of carbon dioxide produced by soil microbes which increases the solubility and thus the availability of Ca. The majority of interactions in the rhizospheres are mutually beneficial to both plants and microbes in the soil. A further exploration and optimisation of these interactions may lead to significant improvement in soil fertility and revegetation of derelict land.

Soil microbes, including plant pathogens, have been adapted to a relatively stable habitat. Slight changes in soil environmental conditions brought about by various agricultural and industrial practices, may have profound effects on soil microbial populations. Some antagonistic relationship between soil microbial populations can be used to control plant pathogens. For example some *Bacillus* and *Streptomyces* produce antifungal substances, which have been shown to control wilt caused by soil fungus. *Rhizoctonia solani* A possibility of biological control of important plant diseases caused by soil microbes, exists. The mycelium of *Trichoderma*, for example, coils around the wider hyphae of the pathogenic fungus *Rhizoctonia solani* and cause their lyses (Bettiol 1996). Rapid lyses of *Pythium*, a common soil-born plant pathogen, by a basidiomycetous fungus *Laetisaria arvalis*, is another example of biological control (Schroth and Hancock 1981).

Bioremediation of Contaminated Soils

Microbes also have a potential in removing or detoxifying toxic or unwanted chemicals from derelict soils by biodegradation or mineralization. There are various strategies for bioremediation using microorganisms such as: (1) *Biostimulation* – adding P and N to stimulate indigenous microorganisms in soil; (2) *Bioventing* – adding gaseous oxygen and methane to stimulate microbial activity; (3) *Bioaugmentation* – inoculating contaminated soil with appropriate microbes either as a single species or a consortium of several species, to facilitate biodegradation; (4) *Landforming* - mixing contaminated soil with non-contaminated soil to reduce contaminant's concentration and coupled with biostimulation; (5) *Composting* – using aerobic and thermophilic microbes in constructed soil piles physically mixed and moistened periodically to enhance microbial activity, and (6) *Phytoremediation* – using plants to remove, contain or transform contaminants. This can be achieved directly by planting hyperaccumulating plants or indirectly by plants stimulating microorganisms in the rhizosphere or a combination of the two methods by using plants with bacterial (rhizobial nodules) and/or fungal (mycorrhizae) symbioses. Many recent reviews (Burns *et al.* 1996, Rao *et al.* 1996) have provided an overview of bioremediation strategies and presented many case studies to illustrate application of these technologies (see Chapter 7).

Much of the current debate and controversy surrounding inoculating contaminated derelict land with appropriate microbial consortia (whether indigenous or introduced (bioaugmentation) stems from the difficulties in establishing whether *in situ* biodegradation leads to contaminant detoxification and loss. Much research need to be conducted to understand better the advantages and disadvantages of this technology.

Conclusions

The soil microorganisms play a significant role in transformation of mineral nutrients and thereby contributing to the sustainability of life on the planet earth and it is important to better understand their ecology. We know very little about the enormous diversity of microbial populations in soil and their properties and behaviour in the soil environment. Soil microorgansms inhabiting the rhizosphere environment interact with plant roots and mediate nutrient availability, e.g. those forming useful symbiotic associations with the roots and enabling survival of plants under nutrient deficient conditions characteristic of derelict lands. Implications of occurrence of plants with mycorrhizae and/or N-fixing root nodule on derelict habitats need to be fully exploited and encouraged by inoculating such soils with appropriate microbes in restoration strategies.

Soil microbes also have a potential in removing or detoxifying toxic substances from derelict soils by biodegradation or mineralization but much research is needed to understand better the pluses and minuses of this technology of bioremediation before it is applied to a large scale

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Chapter 9

Handling of Soils and Cover Materials

L.C. Bell

Introduction

To rehabilitate land that has been contaminated by industrial or mining activities, it is often necessary to encapsulate toxic materials with a cover which (1) effectively reduces the potential environmental impacts of the waste, and (2) assists the establishment of a stabilizing vegetative cover.

In mining, major environmental impacts can arise from waste rock or tailings containing sulfides which oxidise to produce sulfuric acid on contact with oxygen and water. Water draining from these materials can have pH values as low as 2 to 3 and exceedingly high metal concentrations. In older mining operations, encapsulation of sulfidic wastes may be difficult and costly if appropriate materials are no longer available. With new operations, there is the potential to effectively cover and contain the wastes in a cost-effective manner. Covers may also be required to minimise the environmental impacts for a range of domestic and industrial wastes.

In this Chapter, the various issues that need to be addressed in the design of covers will be considered, viz. requirements for waste containment, requirements for plant growth, characterisation of materials, cover systems, selection handling of soils and other materials for cover construction.

Requirements for Waste Containment

Many solid wastes are not only sufficiently toxic to prevent plant growth which protects the surface against erosion but also result in contamination of surface and groundwaters. Rehabilitation of such sites may be achieved by removal of the toxic material and appropriate burial. However, the amount of waste is commonly large enough (e.g. in old mining operations) where this approach cannot be used, and a cover needs to be constructed. The objectives of this cover are (1) to reduce the transport of water through the toxic material to reduce the quantity of contaminated seepage, and (2) to allow the establishment of vegetation which will reduce water and wind erosion (and improve aesthetics). Vegetation can also assist in reducing the water flow through covers to underlying waste through transpiration, but may also have detrimental effects on cover performance.

When sulfidic wastes are involved, the objective is to reduce the movement of both water and oxygen into the sulfidic material to reduce oxidation of the sulfides.

Requirements for Vegetative Growth

There are a number of plant requirements for adequate growth (Wild 1988), viz. (1) sufficient anchorage to allow the root system to support the plant, (2) adequate available water capacity to enable the plant to survive periods of water stress, (3) sufficient drainage to preclude inhibition of root growth through lack of aeration, (4) non-limiting mechanical impedance to root penetration, (5) capacity to provide an adequate supply of essential plant nutrients, and (6) absence of excessive acidity, alkalinity, salinity and toxic elements.

Careful characterisation of materials available for the construction of the potential root zone is necessary to ensure that materials are selected which satisfy these criteria. The method of handling of the materials will also influence how well some of the criteria are satisfied.

Cover Systems

The nature of a cover required to achieve the objectives outlined above may be quite simple, as in the case where the waste to be covered is non-sulfidic, and there is not the requirement to exclude oxygen as well as water. In cases where the waste is potentially very toxic (e.g. containing sulfide, radioactive), the cover may be quite complex consisting of many layers (Hutchinson and Ellison 1992). The basic units of multi-layered covers are (USEPA 1989) –

- A top layer, consisting of either a vegetated soil layer or armouring to minimize water and wind erosion;
- A drainage layer, that minimizes water infiltration into the waste or the infiltration barrier located under it;
- A one- or two- component infiltration barrier layer, that limits water infiltration into the underlying wastes; and
- Special layers, such as biotic barriers to prevent damage to the infiltration barrier by burrowing animals and plant roots, and foundation layers needed to support a cover and/or provide the cover shape necessary for control of surface runoff and internal drainage.

Their characteristics are listed in Table 1.

The number of layers used in a cover will be determined by (1) climate which determines the potential amount of infiltration and the potential surface water erosion, (2) the mineralogical, chemical and physical properties of the waste, and (3) the underlying geology and distances to sensitive water bodies.

The requirements for each layer in a multi-component cover have been described by Hutchinson and Ellison (1992).

Table 1. Characteristics of different layers within covers (adapted from Hutchinson and Ellison 1992)

Layer	Purposes of layer	Layer alternatives	Typical thickness	General requirements
Surface layer	Minimize waste dispersion by surface water or wind transport	Granular in situ mine waste	Variable	• Slopes can vary from a minimum of 0.5-1.0 percent to the angle of repose of the material. • Slopes and material should be stable and provide durable protection against erosion. • Surface contouring to prevent surface runoff concentration in local areas or ponding of water
		Vegetation	Not applicable	• Slopes can vary from a minimum of 0.5-1.0 percent to 50 percent • Slopes and vegetation should be stable and provide durable protection against erosion. • Vegetation should be: - Persistent - Drought resistant - Adaptable to local conditions - Shallow-rooted.
		Surface armor	0.15 - 1.5 m	• Slopes can vary from 0.5-1.0 percent to the angle of repose of the waste pile. • 2.5 cm nominal gravel up to boulders approximately 1m in diameter. • Size and thickness of armouring layer should be based on rainfall intensity and slope.
	Support vegetation	Soil	0.15 – 0.6 m	• Slopes can vary from a minimum of 0.5-1.0 percent to 50 percent. • Required thickness will depend on the vegetation type, end use of reclaimed area, and suitability of the underlying mine waste to partially support vegetative growth.

Table 1. (cont')

Layer	Purposes of layer	Layer alternatives	Typical thickness	General requirements
Drainage layer	Minimize percolation and damage to Infiltration barrier. Prevent upward capillary rise of liquids from the underlying waste.	Sand or gravel	0.3 – 0.6 m	• Slopes range from 0.5-1.0 percent to a maximum controlled by stability considerations. • Adequate capacity to handle at least five times the anticipated infiltration rate through the layer above. • The layer should include a gravel toe drain or equivalent to direct drainage flows away from the waste management unit. • In some instances, it may be necessary to place a soil filter or geotextile over the drainage layer to prevent clogging by fines.
		Geotextile Geogrid Geonet	Variable 0.75–3.75mm 30–150 mils	• Performance should be equivalent to the overlying sand or gravel layer.
Infiltration barrier layer	Minimize percolation into the waste	Geomembrane	0.5 – 1.5 mm	• Slopes range from 0.5-1.0 percent to a maximum controlled by stability considerations
		Soil with a low hydraulic conductivity	0.3–0.9 m	• Hydraulic conductivity ranging from 10^{-5} cm/sec to 10^{-7} cm/sec depending on site-specific needs • Should be located below the frost zone.
Special layer	Minimized damage to infiltration barrier	Biotic barrier	0.3–0.6 m	• Large materials, such as coarse gravel, cobbles, etc.
	Support cover and promote drainage	Foundation layers	Minimum 0.6m and up to several metres as required for control of drainage and contouring of surface.	• Frequently can be constructed from mine waste such as centrifuged coarse tailings fractions, spend ore, or waste rock. • These layers may require compaction to assure adequate support of overlying cover layers

Surface Layer

This layer may be designed to support plants or, where the climate precludes establishment and maintenance of vegetation, it may consist of an armouring layer of rock and gravel.

If vegetation is required, the layer should have sufficient plant-available water capacity to enable plants to survive drought periods. The plants established ideally should be native to the area and capable of controlling erosion and surviving with little or no maintenance. Water balance models can be used to calculate the desired depth of the layer for a range of available materials, while erosion models such as the Revised Universal Soil Loss Equation (Toy and Foster 1998) can assist in the surface layer design to achieve the desired soil loss tolerance.

For the containment of sulfidic wastes in semi-arid and arid climates, the potential for reducing oxygen movement to the waste by maintaining a compacted clay (barrier) layer at high saturation (> 80%) is low. For such cases, the concept of store-and-release covers has been developed (Wilson 2000). With such covers, the root zone is made deep enough to absorb all the rain which might fall in a major rainfall event. Vegetation (including shrubs and trees) is then used as a water pump to dry the root zone out prior to the next event.

It is sometimes stated that trees and shrubs should be avoided because of the potential for their roots to invade the drainage layer, infiltration barrier or the underlying waste. However in a nil-maintenance system, natural ecological succession forces will result in establishment of trees and shrubs, and thus the cover system needs to be designed to accommodate these plants.

Where an armouring material is to be used, it is desirable that the material has the following characteristics –

- be capable of resisting erosion during extreme weather events of rainfall and/or wind;
- contains materials that are not likely to weather significantly over an extended period; and
- is able to accommodate settlement of the underlying material without compromising its performance.

Drainage Layer

Such a layer may be required to minimise the amount of water coming in contact with an underlying infiltration (clay) barrier in order to decrease the amount of leachate (Table 1). Its function therefore is to enhance the efficient lateral movement of water to an exit drain. Additionally the layer can function as a capillary break to prevent the upward movement of potentially toxic solution. For climates where store-and-release covers are used, there is no need for a drainage layer.

Infiltration Barrier Layer

The function of this layer is to reduce the amount of water (and oxygen in the case of sulfidic wastes) infiltrating underlying waste. The layer can take the form of a geomembrane, a compacted soil or clay layer, or a combination of both.

A geomembrane barrier layer should have the following characteristics:

- be of adequate thickness to prevent failure under either potential stress during and post construction;
- have no surface unevenness that creates depressions capable of containing or otherwise impeding the rapid flow and drainage of infiltrating water;
- be protected by at least 0.6 m of overlying material; and
- be in direct contact with the underlying waste, and should be installed on a smoothed surface.

Requirements for a soil or clay barrier layer are as follows:

- the material should be compacted in layers not to exceed approximately 25 cm in thickness;
- the compacted material must be free of clods, rock, fractured stone, debris, cobbles, rubbish, and roots, etc., that would increase the hydraulic conductivity or serve to promote preferential water flow paths; and

- the hydraulic conductivity of the compacted layer should be between 10^{-5}cm sec^{-1} and 10^{-7}cm sec^{-1} depending on site-specific conditions and requirements for infiltration control. For sulfidic wastes, conductivities in the range 10^{-7} to 10^{-9}cm sec^{-1} are preferred.

An important issue in the long-term performance of dry barrier layers is the potential for cracking which may come with drying or freeze-thaw cycling. Thus, in semi-arid and arid climates, a sufficient depth of root zone material must be used to buffer moisture changes (Bell and Menzies 2000).

Biotic Barrier

Plant roots and burrowing invertebrates (e.g. termites) and vertebrates may affect the integrity of the drainage and infiltration barriers (Bell and Menzies 2000). The effects of these descriptive agents may be reduced by installing competent rock or coarse gravel between the surface (root zone) layer and waste and infiltration barrier if present.

Foundation Layer

This layer is usually only required on materials too soft to support a cover system, e.g. tailings. It may be necessary to place a geotextile on the surface first to support a layer of waste rock.

Characterisation of Materials

Laboratory characterisation of soil and other materials (overburden, waste rock, mineral processing wastes etc.) is the next step in the process of developing a materials' handling program. This characterisation normally involves mineralogical, physical and chemical analyses; microbiological analyses may also be conducted at the early stage of planning but more commonly find a role in assessment of the performance of the reconstructed ecosystems on the rehabilitated land.

Mineralogical analysis is a useful aid in characterising mine wastes as it can identify the nature of the potentially acid-producing sulfides which can seriously affect plant growth directly through pH values as low as 2 to 3 or indirectly through creation of excessive soluble metal concentrations. A comprehensive discussion of techniques for mineralogical analysis is given in the text by Dixon and Weed (1989).

Tests which can be used to assess physical limitations to plant growth in mine materials are described by Klute (1986), Williams and Schuman (1987), Hossner (1988) and Sobek *et al.* (2000).

The range of tests which can be used to assess the chemical limitations in soils and mine wastes are covered in publications by Williams and Schuman (1987), Hossner (1988) and Sparks *et al.* (1996). Details of tests to predict the magnitude and rate of acid generation from sulfides, and of the measures which can be used to control this problem, are given by Williams and Schuman (1987), Hutchinson and Ellison (1992), Evangelou (1995) and Skousen *et al.* (2000).

Comprehensive coverage of microbiological tests is given by Weaver (1994).

Selective Handling of Materials for Root Zone Construction

Choice of Materials

The reconstructed root zone can consist of soil, overburden spoil, tailings, or various combinations of these materials in mining situations and soil and a variety of waste materials in other cases. The particular combination will depend on the nature of the requirements of the vegetation to be established. The general requirements of the vegetation, previously discussed, need to be considered, but particular vegetation types may require specific needs, e.g. where a return to cropping land is required, the entire soil profile may need to be conserved and replaced in order to achieve original productivity.

Irrespective of the nature of the vegetation which it is desired to have established on a rehabilitated landscape, a major consideration is the depth of favourable root zone necessary to provide sufficient anchorage (particularly for trees in wind-prone areas) and sufficient available water to enable the plant community to survive through seasonal water stress. To achieve these requirements, a depth of 1 to 2 m of root zone material is generally required, but obviously this will be influenced by climate and the nature of the vegetation.

Selective Handling of Soils

Issues which need to be addressed in the rehabilitation program are (1) the necessity for soil retention, (2) the selection of soil horizons to be conserved, (3) the process of soil removal and placement, (4) the effect of stockpiling on soil properties, and (5) the optimum depth of replaced soil. Each of these issues will now be considered briefly in turn.

Necessity for Soil Retention

A decision as to whether soil should be conserved in a mining operation can only be made after a thorough evaluation of the nature and distribution of the soil and overburden types prior to mining. In general, soil should be conserved and used in the rehabilitation program when overburden material or tailings cannot support the desired post-mining land use, even if ameliorative treatments amounting to the cost involved in conserving and replacing the soil were applied. The relevance of soil retention and use in mining rehabilitation programs in Australia has been discussed by Hannan and Bell (1993), and this source forms the basis for much of the following information.

Most surface soils have far fewer limitations to plant growth than overburden material, and the additional cost of soil handling is generally outweighed by greater success in the establishment of the vegetative cover. Occasionally the mine-site soils may be no better than overburden spoil for the establishment of vegetation, however, and thus a decision on the use of soil must be based on a comprehensive characterisation of both soil and the underlying material. Some overburden materials weather rapidly, particularly in subtropical and tropical environments, and may provide a satisfactory medium for establishment and maintenance of vegetation provided that the input of nitrogen to the system is adequately catered for through introduction of nitrogen-fixing plants.

Experience has shown that, where cropping is to be reinstated after mining, soil retention and replacement is essential. Additionally, where the intention is to return to native vegetation following mining, replacement of fresh surface soil is the most economical and reliable way of ensuring the re-establishment of the wide diversity of species which exists in native ecosystems. Where the establishment of native ecosystems is desired, however, the grass seed load in surface soil may be sufficiently high to outcompete direct-seeded native shrub and tree species, and in some of these situations, successful establishment of the latter may be more easily achieved on overburden spoil alone (Table 2).

Table 2. Advantages and disadvantages of soil usage in rehabilitation

Advantages	Disadvantages
1. Supply of seed and other propagules for establishment of native ecosystems.	1. Risk of weed infestation of sown species due to seed of undesirable species present in the surface soil.
2. Contribution of beneficial microorganisms important in symbiotic association with plants and in nutrient cycling.	2. Risk of vigorous competition to direct-seeded shrubs and trees from grass established from soil-borne seed.
3. Possibility of reducing fertilizer requirements due to nutrients supplies from topsoil.	3. Cost of stripping, stockpiling and respreading of soil.
4. More rapid development of groundwater giving improved aesthetics and stability.	4. Greater erosion hazard during high intensity storms (unprotected soil may be more susceptible than spoil).
5. Burial of most surface rock resulting in less damage to cultivation equipment.	5. May increase areas of disturbed land if borrow pits are needed to obtain sufficient material.
6. Amelioration of adverse properties in underlying material.	

Selection of Soil Horizons

Soils vary both laterally and vertically in their properties. For a given soil type, the subsoil material may differ markedly in its plant growth characteristics from the organically enriched surface horizon. The depth of suitable soil which may be stripped for use in the rehabilitation program should be based on detailed chemical and physical analysis and recorded on a soil stripping map. A number of options may be available for stripping, depending on the quality of the soil available and the proposed post-mining land use.

The use of the entire soil profile is usually only advisable if all horizons are satisfactory for plant growth (or able to be made satisfactory through chemical amelioration). The horizons may be removed, and subsequently replaced in order, or they may be mixed. Stripping of the surface horizon separately from the subsoil material provides the opportunity to recreate, as nearly as possible, the original soil profile with the nutrient – and microbial – rich A horizon at the surface where it will receive maximum exploitation by the rooting systems of plants.

Where all the soil horizons are suitable for plant growth, mixing of the profiles during removal and deposition may provide a satisfactory medium for plant growth. In this case, the stripping and replacement operations are less complicated, but there is a dilution of the beneficial effects of soil organic matter, microorganisms and propagules for native plants.

The subsurface horizons of some soils possess undesirable characteristics such as high salinity and sodicity, or extreme acidity and associated aluminium toxicity and/or calcium deficiencies for many plants. The use of the sodic material, on its own, should be avoided in rehabilitation; acidic subsoils, while having chemical limitations, can be ameliorated. The surface horizon of most soils, which varies from 100 mm to 300 mm, is suitable for use as a plant growth medium. Where there is a shortage of soil, it may be possible to strip some of the subsoil B horizon with the A horizon if the material is well mixed and the average salinity, sodicity or acidity does not exceed the critical value for plant growth.

In cases where the re-establishment of native species is desired, as thin a layer as possible of the soil surface should be removed prior to stripping of further soil. Most native seeds are concentrated in the top 50 mm of soil. Additionally the maximum depth of emergence of these species ranges from 30 to 100 mm. Stripping and respreading of a surface layer greater than 100 mm can thus result in a considerable loss of potential seedlings. Ideally the soil should be double stripped and the layers placed in order.

Soil Removal and Placement

Two important aspects of soil removal and placement to be considered are the nature of the equipment to be used and the moisture content of the soil. Both of these factors will influence the degree of soil compaction and structural breakdown that inevitably occurs during these procedures. Severe compaction can be difficult to ameliorate and can lead to a reduction in root growth. Extensive evidence from the USA indicates that, when replacing a considerable depth of soil, compaction is one of the major factors limiting the achievement of premining yields on land being returned to cropping (Barnhisel 1988).

Scrapers are perhaps the most versatile machines for selective removal of soil horizons, but they can cause significant compaction of underlying material during soil placement and have a limited haul distance of 500 m to 1,000 m. Bulldozer spreading of soil from soil piles strategically placed by dumping from trucks or scrapers is one measure that can be used to reduce subsurface compaction. The use of the combination of front end loader, truck and bulldozer for the removal, transport and spreading of soil is the best combination to reduce compaction.

For all soils, there is a moisture content above which it cannot be handled by equipment without being compacted to a point where plant growth will seriously be affected. The bulk density of a soil steadily increases to a maximum as its water content is increased when a constant load is applied. For many soils when moist, a fully loaded scraper can increase bulk densities above the critical values for root growth. Bulk density is an indirect measure of aeration and mechanical impedance which directly affect plant growth, and values above which plant growth is affected for soils at field capacity range from about 1.3 g cm^{-3} for clay soils to 1.8 g cm^{-3} for sandy soils. Ideally soils should be stripped and replaced at a moisture content of between 10 and 15 percent to avoid the adverse effects of compaction and structural breakdown.

Optimum Depth of Soil Replaced

The depth of soil replaced on spoil, tailings or other waste will be governed by such factors as the desired vegetation, the quantity and quality of the surface and subsoil available and the nature of the underlying material.

If chemical and physical tests show that the underlying material does not have major limitations to root growth such as salinity, sodicity or acidity, a layer of soil as thin as 50 mm will aid vegetation establishment by providing a suitable environment for seed germination, by allowing infiltration of water, and by supplying nutrients and microorganisms; additionally, in cases where a return to native ecosystems is desired, this soil may be an important source of the seed of the species required. Once the vegetation is established, the roots will exploit the underlying material for both water and nutrients.

Where the underlying material has adverse characteristics for root growth, the depth of soil which must be applied to achieve long-term productivity will be a function of the nature and severity of the material's properties. Although 100 mm to 200 mm of soil applied to a saline and/or sodic spoil will usually result in satisfactory establishment of native species or improved pasture, the longevity of the vegetation may be reduced by water stress in dry periods resulting form poor root penetration into the spoil. Additionally, if the hydraulic conductivity of the underlying material is low, salt movement upwards into the replaced soil may be sufficiently pronounced as to markedly reduce the beneficial effects of soil replacement. Upward migration of salt will be less when the underlying material has a moderate hydraulic conductivity.

The application of thin layers of soil to try to ameliorate acid-toxic spoil resulting from sulfide oxidation may be successful initially, but the vigour of the vegetation cover will decrease with time as acid continues to be generated from sulfidic oxidation and moves upward into the overlying soil. Heavy applications of lime to the spoil prior to soil addition will assist in delaying the onset of toxic subsurface conditions, but a major objective of any rehabilitation program where sulfidic waste rock occurs should be to selectively place this material well away from the root zone.

In situations where the surface of the recontoured spoil is sulfidic, at least 1m of non-pyritic material may need to be placed over the spoil to act as a root zone. (This is in addition to placement of a compacted layer barrier between the waste and root zone material). This root zone material could consist of the surface and subsurface horizons of a soil placed in order or it could be non-sulfidic spoil alone or capped with a thin layer of surface soil.

Stockpiling of Soil

Ideally soil should not be stockpiled but should be lifted, transported and spread on a recontoured area in the one operation. Weather conditions and the difficulties in timing rehabilitation to suit mining activity, however, dictate that, in some situations, soil must be stockpiled for later use.

Stockpiling for periods longer than about 6 months may cause structural degradation and death of seeds and microorganisms. The deterioration in quality can be reduced by constructing dumps of minimum height (e.g. <2-3 m) and maximum surface area, consistent with the space available. Surface and subsoil material should be stockpiled separately. Seeding of the stockpile with a grass/legume mixture or native species will assist in erosion control and reduce the loss of beneficial soil microorganisms.

Two options are available for the creation and later use of soil stockpiles. One is to continually build new stockpiles and use the old ones in order of age so that no dump remains in existence for longer than about 12 months. A preferable alternative is to stockpile all material removed early in the mine's life. After rehabilitation commences, all other soil that is stripped should be transported directly to reshaped areas for spreading.

Selective Handling of Overburden and Other Materials

Selective extraction and placement of overburden layers in the case of mining is practised for two reasons, viz. to bury material which is adverse to plant growth or which may contaminate surface or groundwater supplies, or to salvage materials which will assist in the rehabilitation program. Particular overburden strata may be undesirable because of their salinity, sodicity or potential to produce acidity through sulfide oxidation. To rehabilitate land already contaminated by industrial or mining waste disposal, there may also be a requirement to collect, transport and bury toxic materials.

No more than about a 2 m thickness of non-toxic overburden or waste material should need to be placed over the adverse material. This is the maximum depth of root zone needed for most types of vegetation. Where the major part of overburden is saline or otherwise unsuitable for plant growth, selective handling should be directed towards salvaging the best available strata for placement at or near the final reshaped surface. Where only a small proportion of the material is adverse, selective handling should be aimed at ensuring that this material does not finish up near the surface.

Although the spreading of soil on the surface of spoil will greatly assist germination and the rapid establishment of a vegetative cover, plants depend for their long-term nutrient supply and drought resistance on penetration of plant roots to 1 m to 2 m. It is thus important that the subsurface of any reconstructed root zone should not contain toxic substances, should not be over-compacted and should have hydraulic conductivity of the same order as the applied surface layer of soil.

There are two important aspects to the handling of potentially acidic or saline overburden layers and contaminated wastes. They should not be placed near the final surface for the reasons mentioned above and should not be placed at a depth where they could contaminate ground water supplies.

Where the pre-mining overburden contains sulfidic material which may produce acid drainage, the surface oxidized zone is a valuable resource, and care needs to be taken to ensure that all of this material does not end up being buried by sulfidic rock at the end of the mining operation. The range of engineering options to minimise the occurrence or control the effects of acid drainage resulting from oxidation of sulfidic material in mine waste dumps and tailings has been considered by Hutchinson and Ellison (1992).

Selective Handling of Mineral Processing Wastes

The capacity of fine-grained mineral processing wastes to support plant growth depends on the nature of the original mineral or energy resource and the extraction process. If the resource contains high concentrations of sulfide, then there is the potential for the tailings to become extremely acid and toxic to plant growth. Where an extraction (beneficiation) process is based on physical methods of concentration (e.g. in mineral sand mining), there is less likelihood that the tailings will have properties which severely limit plant growth.

In those cases where tailings may be toxic to plant growth, surface stabilisation may be achieved by formation of surface crusts or by the application of a rock layer. Where vegetative establishment is required, it may be necessary to construct multilayered caps that provide (1) a satisfactory root zone for plants, and (2) barriers to the movement of water and oxygen into the tailings and to the upward capillary rise of contaminated water from the tailings.

In some situations, it is feasible to produce a final surface layer which is more favourable for plant growth by modification of the particle size of material deposited in the last few metres. Additionally the chemical nature of the surface layer can be modified by leaving a portion of non-toxic ore to be processed at the end of mine life. This approach can be particularly effective in some gold mining operations where the bulk of the ore may be high in sulfides, but the surface oxidized ore is low in these minerals.

Conclusions

The management of soil, overburden, mineral processing wastes and other potentially toxic materials to provide a medium that will support plant growth is a key aspect of a rehabilitation program for sites affected by mining and industrial activities. To achieve the desired vegetation and to effectively contain potentially toxic materials, there are often a number of alternative strategies for construction of plant-supporting covers. To enable a decision to be made on the most economic strategy, the nature and extent of all the potential plant growth substrates must be determined.

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Chapter 10

Remediation of Chemical Limitations

L.C. Bell

Introduction

The limitations to plant growth on land degraded by poor management in agricultural, mining, urban or industrial development may be physical, chemical or microbiological in nature. The physical properties of a medium are often the most difficult to ameliorate and often dictate the growth potential for plants after chemical and microbiological limitations are removed.

Chemical limitations on degraded sites may involve nutrient deficiencies, salinity or elemental toxicities, the latter often being associated with extreme acidity. Remediation of nutrient deficiency, one of the most common chemical limitations on degraded land, cannot be considered in isolation of other chemical limitations. Thus salinity reduction through irrigation may be a preliminary step in remediation. Additionally, where elemental toxicities or deficiencies are the result of extreme acidity (or alkalinity), then adjustment of the medium's pH may be required before the deficiency of nutrients is addressed through fertilization.

This Chapter focuses on the use of fertilizers to alleviate nutrient deficiency and briefly considers the use of liming agents to remediate extreme acidity. Specifically, it addresses the laboratory, glasshouse and field assessment of limitations and remediation requirements, forms of fertilizers and liming agents, and factors influencing amendment efficiency.

Chemical Limitations to Plant Growth

The main chemical limitations to plant growth on degraded land can be summarized thus –

- Deficiencies (and toxicities) of nutrient elements
  - Macronutrients (N, P, K, Ca, Mg, S)
  - Micronutrients (Cu, Zn, Fe, Mn, B, Mo, Cl)
- Toxicities of non-nutrient elements
  - Metals (Al, Cd, Cr, Hg, Ni, Pb, etc.)
  - Metalloids (As, Se etc.)
- Excessive acidity (pH < 5.0 – 5.5)
  - H^+ toxicity
  - Al monomer toxicity (Al^{3+}, $Al(OH)_2^+$, $Al(OH)_2^+$)
  - Mn toxicity
- Excessive alkalinity (pH > 8.5 – 9.0)
  - P deficiency
  - Cu, Zn, Fe, Mn deficiencies
- Excessive salinity

Because degraded sites often have a complex of physical and chemical limitations, it is important to carefully characterize the properties of the medium before embarking on a remediation program. Chapter 5 provides references to appropriate tests for physical characterisation, and Chapters 6 and 9 list sources of chemical tests.

Laboratory Soil Testing for Nutrient Limitations

The basis of soil testing is that the extractant should remove from the medium either the total amount of the available nutrient or an amount proportional to it. In practice, the soil is shaken with a chemical solution, and the amount of extracted nutrient is compared with a previously determined calibration curve which relates the amount of extracted element to plant growth. Soil testing in traditional agriculture has developed to the stage where, for certain crop and soil combinations, the amount of fertilizer required for maximum or economically optimum yield can be assessed from the laboratory test. With degraded sites, it is safer to use the test as a guide as to whether the medium is deficient or not in a particular nutrient. The test can then be used to design more definitive plant growth trials.

A comprehensive coverage of soil testing is given in the text by Westerman (1990).

Laboratory Soil Testing for Acidity Limitations

Non-Sulfidic Materials

Useful references for soil testing for acidity are Black (1993) and Van Lierop (1990).

pH Measurement

The optimum pH of the root zone material for plant growth depends upon the plant species, but growth is depressed at pH values below 5.0 to 5.5 due to the toxicity of aluminium and/or manganese which increases with decreasing pH. A simple pH measurement in the laboratory (or field) can provide a preliminary assessment of the likelihood of whether acidity is a limiting factor for plant growth. This measurement, on its own, however, will not provide the answer to how much liming agent should be added to remove the limitation.

Exchangeable Aluminium

The amount of exchangeable aluminium on the cation exchange sites of soils and waste materials has been used in the past to predict the amount of a liming agent to add to remove the toxicity. Good correlations are obtained for a given soil, but these are poor when comparisons are made across soils.

Exchangeable Aluminium Saturation

This parameter can be defined as the proportion of the effective cation exchange capacity which is occupied by aluminium. The index has been found to be more useful in predicting aluminium toxicity than the absolute amount of exchangeable aluminium, but for a given plant species, the critical saturation percentage often varies widely over a group of soils because the relationship between aluminium saturation and soluble aluminium is not a fixed one.

Soluble Aluminium

The best correlations between plant response and aluminium across soils have been found using the concentration (or better still the activity) of the soluble monomeric forms of aluminium in the solution surrounding plant roots. These forms include Al^{3+}, $Al(OH)^{2+}$ and $Al(OH)_2^{+}$. Both the extraction of the soil solution and measurement of the monomers is difficult, and thus this approach is not yet available as a routine laboratory test.

Lime Requirement

Once acidity (primarily manifest as aluminium or manganese toxicity) has been established as a limiting factor, an assessment needs to be made of the amount of a liming agent to be added to raise the pH to a level where the limitation is removed.

Common methods of determining the lime requirements are (1) preparing a buffer curve for the medium by incubating it with increasing amount of $CaCO_3$ for a set period and thereafter measuring the resultant pH and (2) shaking the medium in buffer solutions and measuring the equilibrium pH. Both approaches allow a calculation to be made of the amount of $CaCO_3$ (or other liming agent) which needs to be added to a given weight of soil to achieve the desired pH which may range from 6.0 to 7.0 and above depending upon the plant species to be established.

Sulfidic Materials

Whereas the pH of non-sulfidic soils and wastes rarely drops below approximately 4.0, the pH of materials containing sulfidic minerals can commonly decrease to as low as 2.0 as a result of the oxidation of sulfides to produce sulfuric acid. Depending on their particle size, mineralogy and environmental conditions (oxygen and water availability and temperature), the sulfides will oxidize at different rates.

Amelioration of wastes containing sulfides requires the estimation of the long term lime requirement. Two commonly used static laboratory tests are used, viz. acid-base accounting and the NAG test.

Acid-Base Accounting (ABA)

The net acid producing potential (NAPP) of the sulfides is calculated from the sulfides content (or total sulfur content if sulfates and organic sulfur are low) assuming it will be converted to sulfuric acid. The potential for the soil or waste to neutralize the acid produced (ANC) is measured by titration with acid, and the difference is calculated as the maximum potential acidity.

$$NAPP = MPA - ANC \qquad (1)$$

where NAPP	=	Net Acid Producing Potential	(kg H_2SO_4 t^{-1})
MPA	=	Maximum Potential Acidity	(kg H_2SO_4 t^{-1})
ANC	=	Acid Neutralizing Capacity	(kg H_2SO_4 t^{-1})

Net Acid Generation (NAG)

A simpler test which gives similar results to the NAPP method is the NAG test which involves shaking the material in H_2O_2 which oxidizes the sulfide. The equilibrium pH measures how effective the acid neutralizing capacity of the material is in neutralizing the acid produced.

The above tests give an assessment of the maximum net acid production if all the sulfide oxidizes. Kinetic tests, which assess the rate of acid production and neutralization, are increasingly being used to provide more accurate assessment of the hazard (and the liming requirement).

Plant Assessment of Nutrient Limitations and Fertilizer Requirements

Assessment of whether a soil or waste on a degraded site is deficient in nutrients for the growth of the desired vegetative cover can be determined from (1) plant symptoms, (2) plant analysis, (3) small pot plant growth trials and (4) field site plant growth trials. The latter two methods also provide the opportunity to determine how much of a given nutrient needs to be added to achieve maximum growth (or a proportion thereof).

Plant Symptoms

Qualitative diagnosis of nutrient deficiencies in plants can often be made on the basis of leaf and other symptoms (Wallace 1961). Diagnosis is made difficult, however, when more than one element is deficient, and the deficiency is not severe.

Plant Analysis

The basis of plant testing is that the growth of a plant is related to the concentration of nutrient within the plant in a constant relationship. For each nutrient and each plant species, it is assumed that there is a certain nutrient percentage required for maximum yield (Fig. 1). The shape of the yield versus nutrient concentration curve and the critical concentrations for sufficiency and toxicity are dependent on the plant species, physiological age and the part sampled (Munson and Nelson 1990). Knowledge of these critical values can be used to (1) diagnose or confirm visual deficiency or toxicity symptoms of pot-trial or field-grown plants and (2) diagnose a deficiency or toxicity in "subclinical" cases where visual symptoms are absent. Plant analysis by itself is not particularly useful in predicting fertilizer requirements.

Use of this technique depends on knowledge of the critical values for each nutrient plant combination.

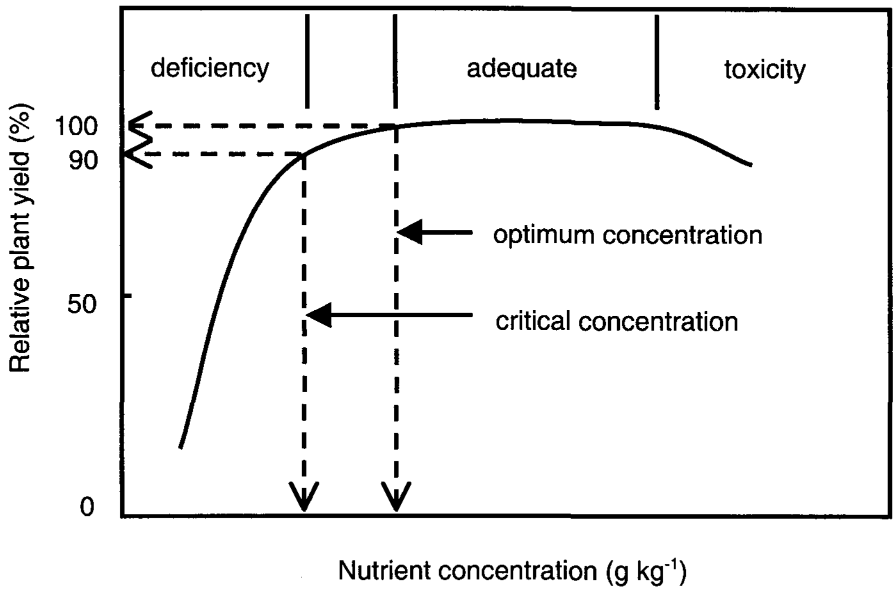

Fig. 1. General relationship between relative plant yield and nutrient concentration.

Pot Trials

Pot trials involving the growth of plants on material from the degraded site provide the opportunity to determine more precisely the nutrients which are limiting plant growth and also to determine the nature of the response curve of the plant to added deficient nutrients. This information also needs to be obtained from trials at the degraded site, but such trials are expensive, and small pot trials are a cost-effective way of narrowing down the number of treatments which need to be tested in the field. Additionally, non-nutritional factors such as temperature, water supply and aeration can be controlled more closely in pots in a glasshouse than in the field.

The objectives of pot trials in a fertilizer assessment program are to assess (1) which elements are deficient for the growth of a selected indicator plant, (2) the response of the species to addition of the different levels of nutrient, and occasionally (3) the optimum fertilizer form in which to add the deficient nutrient. The latter objective is one commonly left until the field trial stage when other aspects of the fertilizer such as method of placement can also be investigated. If it has been demonstrated in the laboratory that the materials from the site may also have non-nutritional limitations, the nutritional trials may be confounded by these limitations. Where the alleviation of the latter is considered feasible in the field (e.g. leaching of excessive soluble salts by rainfall or irrigation or alleviation of heavy metal toxicity in acidic wastes by liming), it is desirable to use pot trials to determine the optimum amelioration treatment prior to the conduct of the nutritional trials.

The types of nutritional pot trials which can be conducted include (1) nutrient omission (subtractive), (2) factorial and (3) rate of addition trials. For each, an important decision is the selection of test plant species.

Nutrient Omission Trials

The nutrient omission or subtractive trial involves growing an indicator plant on a medium in the presence of a complete nutrient treatment and a series of other treatments from which one essential nutrient element is omitted in turn (Middleton and Toxopeus 1973). The yield in the various subtractive treatments is compared with that in the complete (all nutrients) treatment. A zero nutrient addition treatment is included to provide an estimate of the overall nutrient limitations to growth. Because plant growth is limited by the availability of the most deficient nutrient, the yield in the zero treatment is similar to that in the treatment in which the most limiting nutrient element is omitted. The treatments are most commonly arranged in a randomised block design.

The success of this method depends to some degree on how well the levels of nutrients treatment has been selected. The levels must be sufficient to get onto the yield plateau but not sufficient to be toxic. It is useful to include "all x 2" and "all x 0.5" treatments as a test of the suitability of the "all" level selected.

The nutrient omission technique not only indicates which elements are deficient but also demonstrates the relative importance of each deficiency. Where successive harvests of a test species are made, the method also provides an assessment of the rate of decline of nutrient availability. An example of the type of data obtained with omission trials is given in Fig. 2. This trial demonstrated that, for signal grass, the main limitation to growth on the Weipa soil was the extreme deficiency of nitrogen and phosphorus. The soil was also severely deficient in potassium and moderately deficient in copper and sulphur and slightly deficient in molybdenum. A similar result was observed for the legume except that the copper deficiency was very severe, and the level of zinc also markedly limited growth.

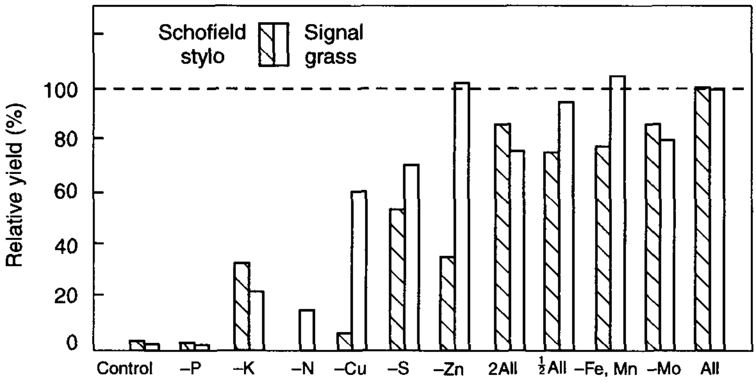

Fig. 2. Response of Schofield stylo (*Stylosanthes guianensis*) and Signal grass (*Brachiaria decumbens*) to various nutrient omissions on the mixed A and B horizons of a lateritic red earth from Weipa, North Queensland.

The advantages of the nutrient omission technique are that (1) deficiencies in a large number of elements can be examined efficiently, (2) large numbers of potential growth media can be screened, (3) the efficiency of the trial is unaffected by the presence of multiple nutrient deficiencies even if these are severe, and (4) the statistical analysis and interpretation of results are relatively straight forward. The disadvantages of this method are that (1) nutrient interactions are concealed, (2) the success of the trials depends on the standard application being close to the optimum rates and (3) the nutrient deficiencies may be exaggerated because of the small volume of soil used.

Factorial Experiments

In their simplest form, factorial experiments involve treatments consisting of the application of each nutrient or factor at two levels (commonly presence or absence). This type of experiment has the advantage of providing information on nutrient interactions. The disadvantages of the method are (1) the size of the experiment can become unwieldy when a large number of nutrients are being investigated, (2) the results are difficult to interpret when the number of factors studied is large, (3) when an extreme deficiency of an element occurs, one half of the pot treatments will be of little use because they will differ very little from the control and thus contribute little to information on marginal deficiencies and (4) the usefulness of the experiment is dependent on the correct selection of the application rate for each element being tested.

For the investigation of a small number of nutrient deficiencies in factorial experiments, external replication can be used. With increasing number of nutrients assessed, however, the experiment rapidly becomes excessively large and single replication or fractional replication can be used. With fractional replication (e.g. one-half, one-quarter and one-eighth replicates), some loss of significant main effects and interactions may occur. An alternative approach is to carry out two separate factorial experiments; one has the macronutrients as treatments with a basal application of micronutrients and the other investigates the micronutrients with a basal application of macronutrients. A disadvantage of this approach is that information on interactions between macronutrients and micronutrients is lost.

Rate Trials

In many mine rehabilitation situations, the deficiency of the macronutrients nitrogen and phosphorus, and to a lesser extent potassium, are the major nutrients limiting plant growth. For these elements, it is desirable to obtain the full response curve in a pot trial in order that field fertilizer trials can be more efficiently designed. Ideally the rates of nutrient addition should go high enough that the region of toxicity is also determined. In these experiments, opportunity also exists for assessing the growth response of the test plant to the nutrient contained in different fertilizer forms (e.g. phosphorus in superphosphate versus rock phosphate) and method of fertilizer placement (broadcast, banded, mixed).

Field Trials

The ultimate assessment of the fertilizer requirements for the establishment and maintenance of the desired vegetative cover must be undertaken on the degraded site where the range of climate x plant x media x fertilizer interactions can be determined. These trials can be established immediately following a laboratory testing program, but for reasons already discussed, it is preferable to delineate the major limiting factors via a pot trial program.

In designing field trials, particular consideration must be given to site selection, treatments and experimental design.

Site Selection

Degraded sites can be heterogeneous in nature with large differences in properties being observed over a distance of several metres. Care should be taken to site field trials in such a way as to cover the most common waste type or the full spectrum of heterogeneity. In order to avoid the danger of placing an entire field trial on an atypical area, it is important to undertake a preliminary survey of field variability.

Treatments

Depending on the objectives of the remediation program, the plant species used in the field fertilizer trials may include trees, shrubs and pasture species known to be climatically suited to the area or those which have shown promise in a preliminary species screening trial at the site. Ideally the selected species should include those previously used in the pot trials.

Fertilizer treatments should include form, rate, placement (broadcast, banded, mixed) and frequency of addition. Whereas in pot trials the addition of a nutrient should be in the form of single salts of the highest purity (e.g. $Ca(H_2PO_4)_2$ instead of superphosphate), the nutrient applied in the field should be in the form of the fertilizer(s) used commercially. The response of plants to a given rate of fertilizer will depend on whether it is broadcast, band placed or mixed into the surface, and each of these factors should be considered. Investigation of yield response to frequency of addition is necessary to separately determine the establishment and long-term maintenance requirements. In the latter case, plant tissue tests are a useful complement to yield assessment in determining the change in availability of the added fertilizer with time.

In investigating the responses of plants to fertilizers, it is desirable to restrict treatments to those fertilizers containing nutrients which were shown to be deficient in the laboratory and/or pot trials. It is good insurance, however, to add, as a basal fertilizer treatment, those elements which the laboratory test has shown to be low or marginal even though no response to the addition of the elements may have been recorded in pot trials. In this case, the nutrient treatments being investigated will not be confounded by appearance of an unexpected deficiency.

Experimental Design

Many of the principles discussed for the design of pot trials are also relevant to field trials. A major difference between the two types, however, is that a constant composition medium can be used over all replicates and treatments in a pot trial, whereas the growth medium at the degraded site can be very heterogeneous.

Because of the heterogeneity of many degraded sites, treatments must be randomly allocated and suitably replicated. Factorial and omission designs can be used, but there is a tendency to use the former so that interactions can be assessed. Arrangement of treatments in a randomised block layout is an acceptable practice with each treatment being represented once in each block and their arrangement within the blocks being at random. The blocks (replicates), which commonly number three to six depending on the site heterogeneity, are normally sited so as to cover the range of variation expected over the waste being investigated. Although the plant response to a given fertilizer treatment may be quite different from one block to another, statistical analysis enables the variability among blocks to be measured. The results of this trial provide much more information about the whole site than if all replicates had been sited on a smaller, relatively homogeneous area.

A useful modification of randomised block designs is that involving split plots. In its simplest form, each plot is split in half, and two treatments are then imposed on the split plots on a random basis.

Forms of Fertilizers and Liming Agents

Fertilizers

There are a wide range of fertilizers available to supply any given nutrient. These range from high analysis manufactured fertilizers to low analysis organic materials such as farmyard manures.

Tables 1, 2 and 3 show the range of fertilizers available to correct nitrogen, phosphorus and potassium deficiencies respectively, while Table 4 lists the content of these nutrients in a range of farmyard manures. Data on the inorganic fertilizers is drawn from Havlin *et al.* (1998) and UNIDO and IDC (1998).

Liming Agents

A range of compounds can be used to raise the pH of acid degraded sites to a level suitable for plant growth. The generic term "lime" or "liming agent" is given to these materials which vary in their chemical effectiveness in neutralizing acidity (Table 5). Other factors also affect the neutralizing capacity of these materials, and these are considered in the following section.

Table 1. Fertilizers for the remediation of nitrogen deficiency

Fertilizer	Chemical form	Nitrogen content(%)
Anhydrous ammonia	NH_3	82
Aqua ammonia	NH_4OH	20-25
Urea	$CO(NH_2)_2$	46
Ammonium nitrate	NH_4NO_3	34
Urea-ammonium nitrate solution	$CO(NH_2)_2+NH_4NO_3$	28-32
Monoammonium phosphate	NH_4HPO_4	11
Diammonium phosphate	$(NH_4)_2HPO_4$	21
Calcium cyanamid	$CaCN_2$	22
Ammonium sulfate	$(NH_4)_2SO_4$	21
Potassium nitrate	KNO_3	13
Sodium nitrate	$NaNO_3$	16
Calcium nitrate	$Ca(NO_3)_2$	15
Ammonium polyphosphate	$(NH_4)_3HP_2O_7$ etc	12-15

Table 2. Fertilizers for the remediation of phosphorus deficiency

Fertilizer	Chemical form	Phosphorus content(%)
Single superphosphate	$Ca(H_2PO_4)_2$, $CaHPO_4$	8-9
Triple superphosphate	$Ca(H_2PO_4)_2$, $CaHPO_4$	19-20
Ammoniated superphosphate	$NH_4H_2PO_4$, $CaHPO_4$ $Ca_3(PO_4)_2$, $(NH_4)_2SO_4$	7-8
Monoammonium phosphate	$NH_4H_2PO_4$	21-24
Diammonium phosphate	$(NH_4)_2HPO_4$	17-19
Ammonium polyphosphate	$(NH_4)_3HP_2O_7$, $(NH_4)_3H_2P_3O_{10}$	25-26
Rock phosphate	$Ca_5(OH,F,Cl)(PO_4)_3$	11-17

Table 3. Fertilizers for the remediation of potassium deficiency

Fertilizer	Chemical form	Potassium content(%)
Muriate of potash	KCl	49-51
Sulfate of potash	K_2SO_4	40-42
Sulfate of potash – magnesia	K_2SO_4, $MgSO_4$	19-25
Potassium nitrate	KNO_3	37

Table 4. Water and nutrient content of manure from farm animals (adapted from Brady 1990)

Animal	Feces/ urine ratio	H_2O (%)	Nutrients ($kg\ t^{-1}$)		
			N	P	K
Dairy cattle	80:20	85	5.0	0.6	3.1
Feeder cattle	80:20	85	6.0	1.0	3.0
Poultry	100:0	62	15.0	3.1	2.9
Swine	60:40	85	6.5	1.6	4.5
Sheep	67:33	66	11.5	1.6	8.6
Horse	80:20	66	7.5	1.0	5.5

Table 5. The relative neutralizing value of different forms of liming agents

Material	Chemical form	Relative neutralising value(%)
Calcium carbonate	$CaCO_3$	100
Dolomitic limestone	$CaMg(CO_3)_2$	95-108
Agricultural lime	$CaCO_3$	85-100
Burnt lime	CaO	150-175
Hydrated lime	$Ca(OH)_2$	120-135

Factors Influencing the Effectiveness of Fertilizers and Liming Agents

The effectiveness of fertilizers and liming agents depends upon (1) the form, (2) rate, (3) placement (banded, broadcast), (4) time of application and (5) the properties of the degraded site material (Havlin *et al.* 1998). Additionally, for liming materials, the rate of reaction depends upon the degree of fineness of the amendment.

Conclusions

Plant growth on degraded land is commonly limited by nutrient deficiencies and/or acidity. Identification of the nature of these limitations and of the amount of fertilizer on liming agent to ameliorate the site can be aided by a systematic approach which involves laboratory, glasshouse and field tests.

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Chapter 11

The Development of Nitrogen Capital

A.D. Bradshaw

Introduction

The ultimate requirement in the remediation and reclamation of degraded or derelict land is a vegetation cover. If this is growing vigorously it provides the following important benefits :-

- imparts stability,
- reduces pollution,
- provides amenity,
- in many cases produces an economic product.

At the same time, in common with other naturally growing objects it :-

- is self-sustaining,
- provides a genuinely economic solution, since it generates its own material

But plants must have the right environmental conditions and the right soil resources if they are to grow successfully and contribute these benefits. It is normally easy to recognise environmental conditions inappropriate for growth - excess heat or cold, or excessively compacted soil etc. But it is less easy to recognise lack of resources - especially lack of mineral nutrients. Although they are well understood and able to be recognised in crop plants, they are much less easy to spot in reclamation situations (see Chapter 10).

Importance of Nitrogen Capital

In degraded land situations, nitrogen is the commonest limiting resource factor. But it is often unrecognised since the main symptoms are often nothing more than reduced growth, although there may be some yellowing of foliage.

It is the commonest limiting resource factor for three reasons. Firstly nitrogen is required by plants in a greater amount than any other nutrient. This is partly due to uptake and turnover, and partly because it is stored as capital. This is true particularly in grassland ecosystems; in woodland ecosystems the calcium store is higher, but the nitrogen uptake is still highest (Table 1)

The second reason for its limiting role is that nitrogen does not come from soil minerals like other nutrients. It is accumulated in the surface layers of the soil by biological fixation, and is then stored as capital in the soil in organic matter. From this it is then released not by normal chemical means but by the decomposition of the organic matter by micro-organisms. The rate of decomposition is from 2% to 10% per year. In a vigorously growing ecosystem nitrogen uptake may be 100 kg N ha^{-1} yr^{-1}. If the rate of release from capital is 10% then the provision of 100kg N ha^{-1} yr^{-1} will require a capital of 1,000 kg N ha^{-1}. In cooler conditions the release might be only 2% but the annual requirement might be only 50 kg N^{-1} ha^{-1}; in which case the capital required would be 2,500 kg N^{-1} ha^{-1} (Table 2).

Table 1. Comparison of capital and uptake of nitrogen and other elements in a temperate forest (from Likens *et al.* 1977)

	Chemical element				
Component	**N**	**P**	**K**	**Ca**	**Mg**
Capital (kg ha⁻¹)	351	34	155	383	36
Above-ground biomass					
Below-ground biomass	181	53	63	101	13
Forest floor	1256	78	66	372	38
Uptake (kg ha⁻¹yr⁻¹)					
Vegetation uptake	79.6	8.9	64.3	62.2	9.3
Vegetation accumulation	9.0	2.3	5.8	8.1	0.7

Table 2. The organic soil nitrogen capital needed (kg N ha^{-1}) to satisfy different nitrogen requirements, assuming various decomposition rates (from Bradshaw 1983)

	Decomposition rate				
	0.02	**0.1**	**0.2**	**1.0**	
Annual requirement					type of ecosystem
200	10,000	2,000	1000	200	warm
100	5,000	1,000	500	100	temperate
50	2,500	500	250	50	cool/arid
Type of ecosystem	montane	cool temperate	warm temperate	tropical	

So a very large amount of N has to be found. In most degraded land situations the original organic matter can be completely lost, and with it the required store of nitrogen, which therefore has to be rebuilt in its entirety. This means finding a minimum of 1,000 kg N ha^{-1} or more to provide the soil capital and a further amount for the capital contained in the vegetation itself. In a developed woodland this can amount to 500 kg N ha^{-1}; in a grassland about 100 kg N ha^{-1}. This is a serious universal problem to be faced. Nitrogen is therefore different from other mineral nutrients which can be present in many degraded soils in reasonable amounts.

The Provision of Nitrogen Capital

There are a number of different ways in which this large amount of nitrogen can be provided.

1. *By storing and returning the original topsoil.* This is obviously a sensible approach if it can be planned beforehand. Modern legislation is now requiring it in many countries. However in many situations the damage has already occurred and the original topsoil has been lost. Sometimes other top soil can be found nearby and imported. However it is not always the complete solution. Original soils may contain 0.1% N in a 200 mm layer of soil. This would represent a capital of 2,000 kg N ha^{-1}.

If the same depth of soil was replaced, with a high nitrogen release rate of 10%, this could release 200 kg N ha^{-1} yr^{-1} which would be more than adequate. But the soil may have been badly stored, halving the release rate, or mixed with subsoil in handling, halving the capital, or perhaps only 100 mm depth is replaced. If all these variations occurred together the release could be down to 25 kg N ha^{-1} yr^{-1} - hardly adequate for satisfactory growth (Table 3).

Table 3. Total nitrogen contents and nitrogen released by top soil layers of different depths, with different N contents, and with different annual rates of mineralization (Bradshaw 1999, from Bradshaw 1989)

		Depth of top soil layer			
N content		150 mm	200 mm	300 mm	
0.02%	Total N	300	400	600	kg N ha^{-1}
	N released				
	2% mineralised	6	8	12	kg N $ha^{-1}yr^{-1}$
	5%	15	20	30	
0.1%	Total N	1,500	2,000	3,000	kg N ha^{-1}
	N released				
	2% mineralised	30	40	60	kg N $ha^{-1}yr^{-1}$
	5%	75	100	150	
0.2%	Total N	3,000	4,000	6,000	kg N ha^{-1}
	N released				
	2% mineralised	60	80	120	kg N $ha^{-1}yr^{-1}$
	5%	150	200	300	

2. *By application of fertiliser.* This is readily available in most areas. But it is impossible to provide more than about 100 kg N ha^{-1} in a single dose on young vegetation on a skeletal soil, for two reasons. In the absence of an established vegetation, because fertiliser nitrogen is very soluble, a large proportion may be leached. If only 50 kg N is applied each time the leaching will be reduced but the application will be expensive and have to be continued over several years.

3. *By application of organic wastes.* Organic wastes are produced by many different operations. These may contain quite high nitrogen contents, as well as other nutrients and their organic matter (Table 4).

Because their nitrogen is in an organic form it can be possible to apply them at high rates, in a single application. If an organic waste such as sewage sludge containing 2% N is applied at 200 t ha^{-1}, this will contribute 1,000 kg N ha^{-1}. The considerable advantage is that the nitrogen capital of the soil can be built up to the desired minimum level in a single application and there will little leaching loss (Byrom and Bradshaw 1991).

4. *By atmospheric precipitation.* There is a very small contribution of nitrogen from the atmosphere, usually not more than 10 kg N ha^{-1} yr^{-1}, although it may be more in industrial areas, up to 50 kg in industrial areas suffering from heavy air pollution. The low levels would appear to be hardly significant, certainly not enough to assist building up the soil capital quickly. But it can be significant for long term maintenance, and the higher industrial levels can provide a more major contribution of immediate value.

Table 4. Nutrient and organic matter content of some different organic materials (Bradshaw 1999, from Bradshaw and Chadwick 1980) (% dry solids)

Material	Nitrogen	Phosphorus	Potassium	Organic matter
farmyard manure	0.6	0.1	0.5	24
poultry manure	2.3	0.9	1.6	68
sewage sludge (air dry)	2.0	0.3	0.2	45
domestic refuse	0.5	0.2	0.3	65
straw	0.5	0.1	0.8	95

5. *By free-living nitrogen-fixing micro-organisms.* These occur naturally in the soil, obtaining energy for nitrogen fixation from organic matter. Although they are of intrinsic interest, their contribution is normally less than 10 kg N ha^{-1} yr^{-1}, and therefore not very significant for immediate build up of nitrogen capital.

6. *By symbiotic nitrogen fixing micro-organisms.* These organisms occur in nodules on the roots of particular plant species, in a special relationship with their host plant from which they obtain the considerable amount of energy needed for the fixation process. The major group of plant species which have this relationship are members of the family Leguminosae, the

micro-organism being a bacterium of the genus Rhizobium. But there are relationships in other species such as the genus *Casuarina* and *Alnus* with various nitrogen fixing Actinomycetes. The amount of nitrogen fixed is usually over 50 kg N $ha^{-1} yr^{-1}$ and may be as much as 200 kg. The nitrogen is accumulated in organic form and as soon as the nodules and the host plant dies becomes part of the soil capital. This material has a low C/N ratio and so decomposes rapidly to release the nitrogen for other plants.

Which Is the Best Option?

There are clearly a number of different method for restoring soil nitrogen capital. Which is best depends on circumstances and desired end use.

Topsoil provides instant restoration and has other advantages (see Chapter 9). In developed countries it is now normally part of planning consent conditions. But it is not such a practical solution where the original soil has been lost, particularly because of the cost of purchase and transport. A 200 mm cover means finding and spreading 2,000 t ha^{-1} of soil.

Fertiliser application is possible in almost all situations, and can be applied with standard agricultural machinery. But many applications will have to be given, extending over several years, and allowance made for leaching losses. As a result it is not a simple operation and will be expensive.

Organic materials are an important option. Their feasibility will depends very much on local availability. Depending on the material they can provide multiple advantages quite apart from their nitrogen content. The possibility of a one shot application can be particularly valuable

Atmospheric deposition will always occur but its contribution is dependant on the situation and will rarely be large.

Free-living nitrogen fixing organisms will never make more than a minor contribution.

Symbiotic nitrogen fixation is universally the most valuable method of building up nitrogen capital, effectively at no cost. There is a wide variety of host plant species with different life-forms, soil, climate adaptations. Table 5 lists the valuable members of the legume family. But there are important species in other families, such as *Casuarina* spp., and *Alnus* spp. Many of the species can be purchased as agricultural or forestry material. Some of these may capable of powerful fixation but

Table 5. Legumes particularly suitable for mined land (Bradshaw 1999, from Bradshaw & Chadwick 1980 and National Research Council 1979)

	soil	climate
Herbaceous		
Amorpha fruticosa (indigo bush)	NC	W
Centrosema fruticosa (centro)	AN	W
Coronilla varia (crown vetch)	AN	CW
Desmodium uncinatum (silver desmodium)	AN	W
Lathyrus sylvestris (mat peavine)	NC	W
Lezpedeza bicolor (lezpedeza)	AN	W
Lezpedeza cuneata (sericea)	AN	W
Lezpedeza japonica (Japan lezpedeza)	AN	W
Lotus corniculatus (birdsfoot trefoil)	NC	CW
Lupinus arboreus (tree lupin)	ANC	CW
Medicago sativa (alfalfa)	NC	CW
Melilotus alba (white sweet clover)	ANC	CW
Melilotus officinalis (yellow sweet clover)	ANC	CW
Phaseolus atropurpureus (siratro)	ANC	W
Stylosanthes humilis (Townsville stylo)	AN	W
Trifolium hybridum (alsike clover)	ANC	C
Trifolium pratense (red clover)	NC	C
Trifolium repens (white clover)	NC	C
Woody		
Acacia albida (winter thorn)	NC	WA
Acacia auriculiformis	ANC	WA
Acacia crassiocarpa (golden wattle)	ANC	WA
Acacia saligna	NC	WA
Acacia tortilis (umbrella thorn)	NC	WA
Albizia lebbek (lebbek)	NC	CW
Calliandra callothyrsus	NC	W
Dalbergia sissoo (sissoo)	ANC	CWA
Gliciridia sepium	ANC	W
Gleditsia triacanthos (honey locust)	ANC	CW
Leucaena leucocephala (subabul)	ANC	W
Peltophorum pterocarpum (copperpod)	ANC	W
Prosopis glandulosa (mesquite)	NC	WA
Prosopis tamarugo (tamarugo)	NC	WA
Sesbania grandiflora (agati)	ANC	W

A acid/ N neutral/ C calcareous
C cool/ W warm/ A arid

require already rather fertile conditions (such high calcium and phosphorus) to grow well. It may be valuable to seek out local wild species with particular tolerance to difficult conditions. Many of the species can be used directly as fodder or timber, or as contributors of nitrogen to other useful non nitrogen-fixing species. Exploratory work may be required to determine the best species and techniques of use - choice should be related to end-use, desired associated species and to soil conditions. They may need to be inoculated with their own particular strain of Rhizobium or other microorganism if this is not present in the soil material (see Chapter 13).

In practice several of these methods may be combined. An initial application of fertiliser can provide an immediate source. Organic wastes can be a good alternative, especially because they will usually not inhibit nitrogen-fixing species in combination to provide a long term build up of nitrogen capital. The contributions from atmospheric and free-living sources will always be present.

Development of a Successful Programme

In practice each option requires investigation. For this a systematic development programme is required (Table 6). Much of this may seem to be part of existing knowledge. But the special conditions that exist on the degraded site concerned makes it important to repeat at least the major steps on site.

Some of this development must be done at outset. But some can be within the reclamation operation itself. This gives appropriate, relevant conditions. But any experiments must be laid out critically - with replication, randomisation, and factorial designs where appropriate. Odd plots containing treatments without proper controls are not satisfactory (see Section IV).

Table 6. Essential features of a development programme for the use of nitrogen-fixing species in remediation of degraded land (Bradshaw 1999)

1 Decide end use/requirement (e.g. stabilisation, agriculture, forestry, nature conservation etc.)

2 Determine likely range of species to be used
  a) native
  b) others

3 Identify N-fixers within these

4 Examine literature for other possible N-fixers

5 Establish trials of N-fixers on relevant soils
  a) unamended
  b) with various amendments

6 Establish trials to assess importance of inoculation by micro-organisms and of use of particular strains

7 Establish trials of N-fixers
  a) with other species
  b) with different management regimes

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Chapter 12

The Use of Tolerant Plants and Hyperaccumulators

A.J.M. Baker

Introduction

Metalliferous wastes, spoils, tailings and soils frequently contain concentrations of heavy metals (notably, lead, zinc, cadmium and copper) which are well above the toxic thresholds for most plants or which are at least high enough to restrict plant growth. Direct establishment of plants on to untreated wastes using commercially available seed, such as agricultural grass/legume mixes, is not usually a viable option for revegetation (Williamson *et al.* 1982). The impact of the metal toxicities can be reduced or overcome by various ameliorative techniques such as liming (for acidic wastes), incorporation of organic materials and fertilizer application (see Chapter 7). However, successful vegetation establishment may depend on continued waste treatment and regular fertilizer inputs. Metalliferous sites are rarely devoid of all vegetation cover. Frequently, existing cover comprises only isolated clumps or individuals of grasses such as (in the UK) bent grasses (e.g. *Agrostis capillaris*, *A stolonifera*) or fescues (e.g. *Festuca rubra*, *F. ovina*) which have been established in the spoil and subsequently spread vegetatively. These species are known as metallophytes. Rooting directly into the substratum, they can bring about surface stability. If such plant colonists are tested for tolerance to the various heavy metals which are elevated in the spoil, they are found to have evolved strong tolerances. They have been naturally selected for metal tolerance and also tolerance of other stress factors of the mine spoil environment, such as nutrient deficiency and drought. Such evolution is localized just to those populations growing on the mine waste.

The Exploitation of Heavy Metal Tolerant Plants in Mine Revegetation

The potential for an adaptive approach to metalliferous soil revegetation was first investigated in the early 1970s. Selection lines of metal-tolerant races of grasses were developed from propagation under glass of plants collected at mine sites in North and mid-Wales and from the South and North Pennine orefields in the UK. These lines were tested extensively in field trials, the most promising genotypes identified and the most effective ameliorative measures for different wastes specified. Field experiments showed that naturally occurring tolerant populations grew faster and persisted longer than normal commercial varieties. They were found to give an excellent stabilizing cover provided adequate fertilizer was given, and to persist for over nine years with little loss of vigour, even with minimal fertilizer treatment. The potential for this approach to metalliferous mine spoil revegetation has been reviewed by Bradshaw (1975) who concluded that good establishment could be achieved, producing a rapid and persistent cover. In the studies outlined above, the most successful populations at each test site were those with the highest tolerance to the metals occurring in that waste, provided that the species was appropriately adapted to other local soil conditions (e.g. pH, calcium status, water availability). Smith and Bradshaw's (1979) selections also suggested that some populations of the creeping grass *Agrostis stolonifera* would be suitable for calcareous lead/zinc wastes, but cultivars have not been developed, since seed production is poor and seedlings are vulnerable to drought. Stolons of this grass can be planted by hand where labour costs are low since it spreads very rapidly. This technique has been employed successfully on damp metalliferous mine tailings in Zimbabwe using other grasses.

The potential of direct revegetation on a large-scale was demonstrated by Smith and Bradshaw (1979) at Trelogan and Nenthead zinc mines in the UK. Lower seeding rates than are usual for amenity grassland establishment were used. Under most conditions, spring seeding is preferable to autumn as climatic conditions for germination and seedling establishment tend to be more favourable. A fertilizer addition is necessary to promote early seedling establishment. By using a slow release fertilizer or organic material incorporation leaching losses can be minimized.

The particular benefits of using metal-tolerant materials for revegetation may also be reflected in the costs. Smith and Bradshaw (1979) contend that the cost of reclamation by this technique will be a fraction of the outlay with conventional methods and present estimates that suggest costs could be as low as one-sixth of soil cover methods. Direct revegetation is not necessarily a substitute for cover systems and the choice of reclamation technique must reflect the needs of the site. Three grass cultivars have been produced commercially as a result of the early field trials and selection, all of which were initially developed by the National Seed Development Organisation at Cambridge, UK;

- *Festuca rubra* cv "Merlin" - suitable for neutral and calcareous lead/zinc wastes and dry nutrient-poor materials;
- *Agrostis capillaris*, cv "Goginan" - for acidic lead/zinc wastes;
- *A. capillaris* cv "Parys" - for acidic copper wastes.

"Merlin" is still available from Johnsons Seeds (UK) Ltd. and has proved of considerable value in revegetation work (even on non-metalliferous materials) in view of its notable tolerance to nutrient, drought and low-temperature stresses. It has been used extensively for revegetation work in the UK and elsewhere, e.g. Sweden. The two *Agrostis* cultivars are no longer available from the NSDO but are listed by Barenbrug (UK) Ltd, and Johnsons Seeds. Their availability is however limited by variable seed harvests.

Using metal tolerant plants in revegetation mixtures does not remove the hazards of metal toxicity to grazing animals as such plants still accumulate metals in the above-ground parts, albeit at generally lower concentrations than their non-tolerant counterparts. As a result there is still a need to fence off areas revegetated in this way to restrict access by grazing animals. Although there will be less surface run-off from a well vegetated spoil heap, any run off may still be contaminated. A directly sown sward is often not robust enough to withstand erosion on slopes particularly if this is exacerbated by trampling by man or animals, disturbance by rabbits or sheep or continual flow of water. Direct revegetation is therefore not a suitable method for use close to watercourses, and an engineered solution (see Chapter 6) may be necessary.

Exploitation of Metal Hyperaccumulator Plants

At many locations, soils have become contaminated with heavy metals by human activities. Around smelters and mines, metals residues or soils often cause severe and extensive phytotoxicity and harm to ecosystems. Bioavailable metals represent a potential threat both for colonizing plants and also through food chain transfer to herbivore grazers and subsequent trophic levels. Present clean-up technology is too expensive for these sites. Removal of metals from these soils is the goal of phytoremediation.

Metal accumulation by vascular plants can range from a slight elevation relative to background concentrations to a degree where the accumulated metal constitutes a significant percentage of the plant dry matter. Some plant species endemic to metalliferous soils have been demonstrated to accumulate exceptionally high metal concentrations. Brooks *et al.* coined the term "hyperaccumulator" in 1977 for serpentine plants capable of concentrating Ni to more than 1,000 $\mu g\ g^{-1}$ (0.1%) in their leaf dry matter. The first report of a Ni-hyperaccumulating plant was the discovery in 1948 by Minguzzi and Vergnano of Ni concentrations of about 1.2% in the leaf dry matter of the Italian serpentine endemic, *Alyssum bertolonii.* Subsequently, more than 300 taxa have been described that can concentrate Ni to values in excess of the 1,000 $\mu g\ g^{-1}$ threshold, with some as high as 4.75% (Table 1). The majority of these discoveries were made from analysis of herbarium materials of plants collected from ultramafic regions of the world. Problems of sample variability and possible soil contamination have led to the tightening of the definition of a hyperaccumulator plant by Reeves: "a plant in which a [Ni] concentration of at least 1,000 $\mu g\ g^{-1}$ has been recorded in the dry matter of any above-ground tissue in at least one specimen growing in its natural habitat". A concentration threshold of 1,000 $\mu g\ g^{-1}$ has also been used to delimit exceptional uptake of Cu, Co, Pb, whereas for Zn and Mn the limit is raised to 10,000 $\mu g\ g^{-1}$ (1.0%) because of the greater background concentrations of these metals. For Cd, 100 $\mu g\ g^{-1}$ in leaf dry matter is exceptional and has been provisionally set as the concentration representing Cd hyperaccumulation. In the last few years, the first reports of thallium, antimony and arsenic hyperaccumulators have been published. Critical lower limits for the hyperaccumulation of other elements, notably Cr, Mo, U, Ag, and Au have yet to be established.

Geographical and Phylogenetic Distribution of Metal Hyperaccumulator Plants

Metal hyperaccumulation is a phenomenon generally associated with species endemic to metalliferous soils and it is found in only a very small proportion of such metallophytes. Most, but not all, hyperaccumulators are strictly endemic to metalliferous soils. The approximately 415 taxa shown in Table 1 include representatives of many families, ranging in growth form from small annual herbs to perennial shrubs and trees. They have been discovered in all continents in temperate and tropical environments. Notable centres of distribution are for Ni: New Caledonia, Cuba, SE Asia, Brazil, Southern Europe and Asia Minor; Zn and Pb: NW Europe; Cu and Co: South-central Africa. Some families and genera are particularly well represented in Table 1; e.g., for Ni: Brassicaceae (*Alyssum* and *Thlaspi*), Euphorbiaceae (*Phyllanthus, Leucocroton,* and Asteraceae (*Senecio*, *Pentacalia*); Zn and Cd: Brassicaceae (*Thlaspi*); Cu and Co: Lamiaceae, Scrophulariaceae; Se: Fabaceae (*Astragalus*).

Table 1. Numbers of hyperaccumulator plants based on all records currently available

"Metal" concentration criterion (% in leaf dry matter)		No. of taxa	No. of families
Antimony	>0.1	2	2
Arsenic	>0.1	2	1
Cadmium	>0.01	2	1
Cobalt	>0.1	26	11
Copper	>0.1	35	15
Lead	>0.1	14	7
Nickel	>0.1	317	37
Selenium	>0.1	20	7
Thallium	>0.1	1	1
Manganese	>1.0	10	5
Zinc	>1.0	13	5

Use of Hyperaccumulator Plants in Phytoextraction

To date, there have been rather few large-scale demonstration trials of the potentials for soil clean-up using hyperaccumulator plants. However, before phytoextraction of soils is possible on a large scale, a number of important issues must be addressed. Firstly, hyperaccumulator plants are relatively rare, often occurring in remote areas geographically and being of very restricted distribution in areas often threatened by devastation from mining activities. Population sizes can be extremely small. There is thus an urgent need to collect these materials, bring them into cultivation and establish a germplasm facility for large-scale production for future research and development and trials work.

Secondly, the potential exploitation of metal uptake into plant biomass as a means of soil decontamination is clearly limited by plant productivity. Many of the temperate hyperaccumulator plants are of small biomass, although considerable natural variation exists within populations. In view of their infertile native habitats, it is surprising to find that plants like *Thlaspi* and *Alyssum* spp. are responsive to agronomic management such as irrigation and nutrient additions, so enhancing their growth potential. Early trials by Baker *et al.* (1994) and subsequent experiments by other workers have shown that even small-growing herbs like *Thlaspi caerulescens* (Brassicaceae) can be used to remove metals such as Zn, Ni and Cd from superficially contaminated soils.

Selection trials are needed to identify the fastest growing (largest potential biomass and greatest nutrient responses) and most strongly metal-accumulating genotypes. However, such a combination may not be possible and a trade-off between extreme hyperaccumulation and lower biomass (or vice versa) may be acceptable. Selection can also identify the individuals with the deepest and most extensive and efficient root systems, and those of greatest resistance to disease. Breeding experiments are required to incorporate all these desirable properties into one "crop" ideotype.

Other current approaches to phytoextraction have employed fast-growing, metal-accumulating cultivars of brassicaceous crop plants such as Indian mustard, *Brassica juncea*. However, whilst such plants are readily available as bulk seed from the plant breeder, their ability to accumulate moderate concentrations of metals are not coupled with the intrinsic metal tolerance, characteristic of the hyperaccumulators. Their utilization relies upon the application and timing of suitable soil amendments such as chelating agents (e.g. EDTA), combined with agronomic practices designed to mobilize metals in the rhizosphere. The approaches have been fully summarized in recent reviews (see Raskin and Ensley 2000). The resultant effect is to kill the phytoremediation crop just prior to harvest, a process referred to as "induced phytoextraction". This technology has been developed commercially by Phytotech Inc. in the USA, for the remediation of Pb- and U-contaminated sites. Phytotech (now Edenspace) has performed a number of induced phytoextraction field trials during the last 10 years. Trials at brownfield sites at Trenton and Bayonne, NJ have both been reported as being successful. The majority of the treated areas of these sites had Pb levels reduced to below industrial standards after one summer of treatment. In the summer of 1997, the US-EPA (Environmental Protection Agency) coordinated the Phytotech trial at Trenton NJ, and they reported that after the application of EDTA the plants in the field had in excess of 800mg kg^{-1} Pb in shoots on a dry weight basis. Of ongoing major concern to both regulators and potential users of this technology, however, is the possibility for chelate-induced leaching of metals from the soil and into the groundwater. In order to establish the likelihood of this, Phytotech performed extensive leaching studies during the field trial outlined above. The data from this and similar studies are very important in establishing the validity of this approach.

Another approach to phytoextraction, using hyperaccumulator "crops", is a process of "continuous phytoextraction", which exploits the use of hyperaccumulator plants with the capacity to accumulate metals throughout their normal life cycle, rather than induced metal uptake just prior to harvest. The optimal plants for this type of process should be capable of solubilizing metals in the rhizosphere (without the need to apply synthetic chelates to the soil), efficiently transporting them to the shoot where toxic effects of the metals are tolerated, and where they accumulate to high concentrations (Fig. 1). Several hyperaccumulator plants appear to satisfy this requirement.

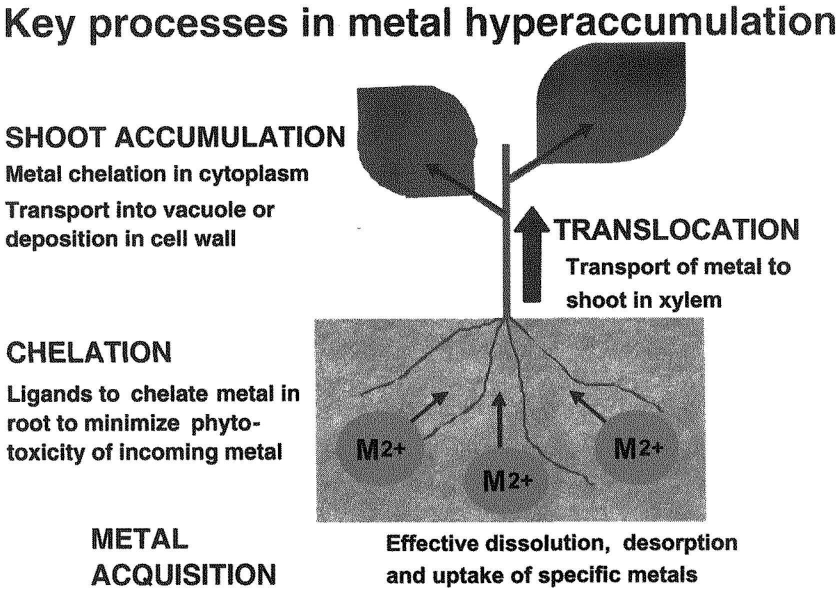

Fig. 1. Processes involved in metal hyperaccumulation.

Very encouraging results were obtained by Baker *et al.* (1994) in trials in which a range of hyperaccumulator plants and ordinary crop species were grown in marginally-contaminated soils resulting from 20 years of metal-enriched sewage sludge application to a sandy loam agricultural soil. The contamination was all in the first 27cm (plough depth) of soil and the highest Zn concentrations were 444 mg kg^{-1} total Zn. UK and Belgian populations of the Zn-hyperaccumulator, *Thlaspi caerulescens,* accumulated concentrations of Zn 16 and 11 times those in the soil, respectively, with total above-ground uptakes of up to 150 times greater (Table 2) than those of the non-accumulating crop species. The rate of removal of Zn by *T. caerulescens* was greater than the allowed maximum annual addition of Zn to soils; the Belgian population of this species could remove twice this amount (Table 2). Thirteen croppings with this *T. caerulescens* would be required to extract the excess loading of Zn (374 kg ha^{-1}) in the experimental soil to bring the total soil Zn concentration down to below CEC (EU) limits, from 444 mg kg^{-1} to

300 mg kg^{-1}. This calculation assumed that subsequent crops would remove metals at the same rates as the first crop. This metal removal equates to over 800 croppings with *Brassica napus* (oil-seed rape) and more than 2,000 croppings with *Raphanus sativus* (radish), both non-accumulating crop plants (Table 2). For Cd, the UK population of *T. caerulescens* could remove 95% of the permitted addition in a single cropping which is more than 10 times the rate of extraction by a non-accumulating species. Subsequent work with more efficient Zn-hyperaccumulating strains of *T. caerulescens* has reduced the timescale of soil "polishing" to 7-8 years.

Table 2. Extraction efficiencies for the removal of zinc by the different plant species and the number of croppings required to reduce the total soil zinc to a concentration of 300 mg kg^{-1} (from Baker *et al.* 1994) (see text)

Plant species	**Plant uptake (kg ha^{-1})**	**Removal as % of annual permitted addition rate**	**Number of croppings**
Hyperaccumulator species:			
Thlaspi caerulescens (Belgian pop.)	30.1	201	13
T. caerulescens (UK pop.)	27.6	184	14
Non-accumulating species			
Brassica napus	0.5	3	832
Raphanus sativus	0.2	1	2046

Future work could involve the use of natural or artificially-generated metal-accumulating mutants or genetic engineering to further improve metal-uptake characteristics, if the genes for metal accumulation can be identified and manipulated. Present work suggests that the possibility now exists to transfer genes for metal hyperaccumulation into a very productive (but inedible), sterile host plant. Excellent opportunities also exist through protoplast fusion techniques. There are very few hyperaccumulator plants discovered to date that have a capacity for multiple metal accumulation. Some, whilst primarily accumulating a single metal, do also show enhanced uptake of others. However, there is some experimental evidence to indicate metal antagonisms may limit uptake from multiply metal-contaminated soils. The list presented in Table 1 is only the tip of an iceberg as new hyperaccumulator plants are constantly being discovered. In the last few years nearly one hundred new Ni-hyperaccumulators have been identified - almost all from Cuba. Increasing systematic effort in screening plant materials for these characteristics will most certainly reveal new hyperaccumulator plants - and new potentials both for phytoextraction and biorecovery.

To date, there has been little attempt to select specific hyperaccumulator plants for phytoextraction of radionuclide elements, but field and pot studies have suggested that species do vary greatly in their ability to take up and translocate these elements. Phytoextraction of radionuclides has been carried out successfully under glasshouse conditions but there have been few trials at field scale. There is an urgent need for a more intensive screening of the biological resource base to identify and select plants suitable for further exploitation under field conditions.

The commercial possibilities for phytoremediation (*sensu lato*) have been recognized internationally and the technology has shown massive interest from all agencies involved in land decontamination, soil clean-up and minimizing environmental contamination in the food chain. The field remains wide open for extensive and rapid development in the next decade.

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Chapter 13

The Handling of Microbes

A.G. Khan

Introduction

Many microbes are closely associated with the soil environment and play important role in mineral nutrient recycling and thereby contribute to the sustainability of life (see Chapter 8). Derelict lands often support characteristic plant species, the roots of which are often associated with symbiotic microbes such as mycorrhizal fungi and N-fixing bacteria (Khan 1981, Khan *et al.* 1998). Recently, Khan (2001) reported dual symbiosis in roots of trees of *Populus euroamericana* (possessing both ectomycorrhizae and arbuscular mycorrhizae) and *Delbergia sissoo* (possessing both arbuscular mycorrhizae and N-fixing root nodules) growing on chromium polluted and tannery effluent contaminated soils.

Universal and ubiquitous symbiotic mycorrhizal associations are known to benefit plant nutrition, growth and survival, due to greater exploration of soil for nutrients (Smith and Read 1997). Pioneer plants growing on nutrient deficient derelict soils are mycorrhizal and their rhizospheres contain propagules of these symbionts. This is important because the symbiotic microbes introduced in combination with their host plants at a derelict site may survive better than bacteria often introduced for bioremediation. These plants and their associated symbionts have evolved a tolerance to the environmental conditions (Leyval *et al.* 1995, Wang *et al.* 1995).

The infection of roots of such plants with symbiotic microbes leads to improved survival and plant growth in such soils (Khan *et al.* 2000). N-fixing trees of *Acacia* (leguminous species bearing rhizobial N-fixing root nodules) and *Casuarina* (a non-leguminous tree bearing actinomycetal N-fixing root nodules) inoculated with appropriate microbes and transplanted onto unsterilized bituminous coal waste site showed improved growth compared to non-inoculated controls which failed to survive on the site, (Khan 1979).

This suggests that plants with dual symbiotic associations are successful as primary colonizers of pioneer and derelict habitats, and that manipulation of symbiotic associations for re-vegetation purposes has great potential in the reclamation of drastically disturbed land. The isolation of, and inoculation with, appropriate and ecologically adapted mycorrhizal fungi and N-fixing bacteria offer a challenging but not yet fully exploited opportunity. By populating the rhizospheres of these plants with selected microbes during the process of revegetation of derelict lands, it should be possible to enhance the process. This chapter reviews the prospects and practical techniques used for selecting inoculant mycorrhizal fungi and N-fixing bacteria, their mass production, and their application in inoculation of derelict lands.

Inoculation of Derelict Land with Mycorrhizal Fungi

Mycorrhizae and plants are highly interdependent and mutualistic associations between soil fungi and plant roots occur in most vascular plants. There are many different types of mycorrhizal associations involving different groups of fungi and host plants (Table 1).

Mycorrhizal fungi are a major component of mycorrhizospheres of most vascular plants (Jeffries 1987) and they play important role in natural and managed ecosystems. They have evolved and adapted to a wide range of soil/environment/host factors and can be selected for use in inoculation programs in order to establish vegetation on derelict land. The potential for manipulating mycorrhizae to increase plant establishment during ecosystem recovery after severe disturbance, is under-utilized and overlooked due to poor understanding of the management of soil and mycorrhizae (Jasper 1994b). The functional diversity of mycorrhizal fungi provides opportunities to select fungi, especially the ubiquitous AM fungi found in most soils and universal symbiont of most vascular plants as well as EM fungi associated with many gymnosperms and angiosperm forest trees, adapted to specific derelict soil and environmental conditions, and use them as valuable biological resource for phytoremediating such land. Sufficient AM propagules are not likely to be present in derelict soils; it may be valuable to introduce both EM and AM fungi by inoculation during the revegetation of disturbed habitats (Jasper 1994a, Khan 1978, Pfleger *et al.* 1994).

Table 1. Types of mycorrhizal associations and their characteristics (after Smith & Read 1997)

Type	Fungi involved	Host plants	Characteristics
Arbuscular Mycorrhizae (AM)	Zygomycetes Glomales	Most Vascular Plants	Fungi produce arbuscules and/or vesicles within root cortical cells
Ectomycorrhizae (EM)	Mostly Basidiomycetes	Gymnosperms / Angiosperms	Fungal hyphae form a mantle around roots & a Hartig net between cortical cells
Orchid Mycorrhizae	Basidiomycetes	Orchidaceae	Fungal coils within roots/stems
Ericoid Mycorrhizae	Ascomycetes/ Basidiomycetes	Ericales	Fungal coils in outer cells of 'hair roots'
Ectendo Mycorrhizae	Mostly Basidiomycetes, some Ascomycetes & Zygomycetes	Gymnosperms/ Angiosperms	Similar to EM with or without mantle, some hyphae within root cortex
Arbutoid Mycorrhizae	Mostly Basidio, some Asco- & Zygomycetes	Ericales	Similar to EM with some specialized anatomical features
Monotropoid Mycorrhizae	Mostly Basidiomycetes, some Ascomycocetes- & Zygomycetes	Monotropaceae	Similar to EM with some specialized anatomical features

Arbuscular Mycorrhizae

AM (Glomalean) fungi differ in their effectiveness, efficacy and infectivity (Khan 1981). There is a need to select those that can increase growth of plants in derelict soil by improving nutrition and soil conditions due to increased soil aggregation and stabilization. These fungi produce large asexual spores and coenocytic hyphae distributed throughout the soil, but we know very little about their genetic diversity. The classification of the AM fungi is based largely on spore morphology (shapes, sizes, colour, ornamentations, wall layers and staining reactions, spore contents, spore germination, soil hyphae, etc. (Morton 1988, Morton and Benny 1990). Characteristic colonizing patterns inside host roots can also be used to identify different genera of Glomalean fungi in some cases (Brundrett *et al.* 1996).

The AM spores can be separated from soil samples by various techniques involving sucrose density layers or gradients or/and wet sieving and decanting techniques (Pacioni 1992, Tommercup 1992). Healthy looking mature spores so collected should be used to start pot culture propagation in order to produce inoculum (Sylvia and Jarstfer 1994). But it is time-consuming, bulky and often not pathogen free. To overcome these problems, soil free methods such as soil-less growth media pot cultures (see Jarstfer and Sylvia 1993), hydroponics and aeroponics (Elmes and Mosse 1984, Hung *et al.* 1991, Mosse and Thompson 1984), have been proposed. Recently, Mohammad *et al.* (2000) described an improved aeroponic technique to produce inocula of AM fungi by using the latest ultra-sonic nebulizer aeroponic technology for the concentration of high-quality AM isolates which can be used in small doses to produce a large response, which is a prerequisite for commercialisation of AM technology.

Since each AM fungal species and isolate has specific ecological requirements, the screening of their wide diversity is necessary in order to select the most superior, effective and efficient isolate for successful introduction into plantings. Furthermore, sound experimental design is critical before embarking on field experiments as establishment of field experiments is very labour-intensive and expensive. Excellent practical descriptions of field experiment planning and designing have been provided by Brundrett *et al.* (1996).

Ectomycorrhizae

There are greater opportunities for using EM in establishing vegetation on derelict land because of the capacity of many EM fungi to be grown in sterile cultures and the specificity between host trees and many EM fungi. The majority of EM associations are formed predominantly on the fine root tips of many trees (mostly coniferous), shrubs, and to some extent in some herbs. The hyphae of EM fungi are widely distributed throughout the mycorrhizospheres of the host plants, and must make a large contribution to nutrient uptake and cycling in many forest ecosystems. EM roots are characteristically branched and short due to slow growth and more frequent branching, usually with a thick layer of mantle hyphae covering the root surfaces and Hartig net hyphae between epidermal or cortical cells of the root. These features are used to identify EM roots (Smith and Read 1997).

The taxonomy of EM fungi is poorly known. They are predominantly Ascomycetes and Basidiomycetes. Most EM fungi produce sexual fruiting bodies (in response to seasonal changes in environmental stimuli such as rainfall and temperature) such as mushrooms, toadstools, corals, puffballs and truffles, and the taxonomy of EM fungi is based almost exclusively on characteristics of their sexual fruiting bodies (Smith and Read 1997). But, the absence or abundance of fruit bodies of a particular species cannot always be predicted and should not be used to confirm or deny EM associations. Fruit bodies, when formed, are always found near ectomycorrhizal plant species and are rarely found beyond the root zone of the host plants.

The sexual spores, produced by EM fungi, vary in colours, sizes, shapes, wall structures and ornamentation. These propagules, including mycorrhizal roots, fruiting bodies, forest litter, etc. can be used directly as inoculum (Molina and Palmer 1982). Alternatively, they can be used to initiate pure cultures on nutrient media with antibiotics and a fungicide to reduce contamination (Erland and Soderstrom 1990). Axenic cultures, from a single germinated spore, have also been successfully achieved by many workers (Hutchinson 1991), and this biomass may be used directly as inoculum.

Once isolates of EM fungi have been produced, they can be maintained on nutrient agar by subculturing them onto fresh media at regular intervals, and used as a source of propagules for inoculating seedlings. For ease of handling, inoculum biomass is often mixed with a carrier such as peat vermiculate. These inocula can be used to synthesise EM associations in seedlings of host plants under glasshouse conditions to test host-fungus compatibility (Burgess *et al.* 1994, Peterson and Chakravarty 1991). For large-scale EM inoculum production, the inoculum should be cost-effective to produce, efficiently transported and stored before use, and easy to produce (Kuek 1994).

If the aim is to inoculate plants to be used for phytoremediation of derelict land, it is desirable to screen EM fungal isolates for their performance in particular soils and climatic conditions. The success of mycorrhizal inoculation of seedlings should be monitored before and after they are outplanted (Brundrett *et al.* 1996).

Inoculation of Derelict Land with N-Fixing Bacteria

Derelict land is often infertile, and particularly lacking in organic matter and nitrogen. To overcome this, and to establishing self-sustaining inputs of carbon and nitrogen from the atmosphere, many attempts have been made to use leguminous plants with N-fixing bacterial nodules on such lands (see Chapter 11). Derelict soils are unlikely to contain appropriate rhizobia, and inoculation is required for effective and efficient N-fixing root nodule formation. Occurrence of nodulated plants on degraded lands (Khan 2001) means that the soil already contained indigenous rhizobia able to nodulate the host. In metal-contaminated soils this is likely to be due to the selection of metal-tolerant rhizobia. Giller (1987) studied the survival of *Rhizobium leguminosarum* biover *trifolii* in metal contaminated soils and found the original effective population altered by the pollutant and only a strain ineffective in N-fixation surviving. It was found that free-living heterotrophic rhizobial bacteria do not survive in metal containing sludge-polluted soil, but they are protected in root nodules. Rhizobium populations may depend on the introduction and survival of selected and adaptive strains, as the sensitive part of the bacterial life cycle is its free-living phase.

Even without inoculation, it may be possible for a newly introduced legume on derelict land to have a few nodules arising from seed- or dust-born or from native legumes with functional nodules. But many of these organisms are not particularly effective and do not benefit the plant or the subsequent plantings. To overcome this problem, it is recommended to use host plant cultivars that, on one hand, nodulate normally with specific inoculant strains, and, secondly, exclude indigenous rhizobia. Several cultivars of leguminous plants are shown to restrict nodulation by indigenous strains but nodulate normally with the specific introduced inoculant strain (Kipe-Nolt *et al.* 1992). If inoculation is required, the strain employed must form effective nodules, be tolerant to extremes of environmental conditions characteristics of derelict soils and genetically stable, and be competitive in nodule formation and persistent in soil. Like mycorrhizal fungi, inoculant rhizobia should be selected after extensive screening by field trials ideally at derelict land sites. Various commercially prepared pure cultures of rhizobia mixed with peat or other carrier material for seed and soil inoculation are now available in the market (Somasegaran and Hoben 1994).

Derelict lands are normally nutrient, especially P, deficient. But P sufficiency is an essential condition for effective and efficient nodulation. Because arbuscuar mycorrhizal (AM) fungi can enhance P uptake under otherwise limiting P regimes, they can indirectly stimulate nodular activity. Laboratory and greenhouse experiments using N^{15} isotope dilution technique have revealed that inoculation with AM improved the N fixation of legumes (Barea *et al.* 1987, Ganry *et al.* 1985, Michelsen and Sprent 1994, Singh 1996). Jidan *et al.* (1995) showed that seedlings of *Acacia mearnsii* and *Leucaena leucocephala* with dual AM/rhizobium associations had greatly improved numbers of nodules, nitrogen fixation and P absorption and growth compared with controls.

Selection of AM-fungal isolates for improvement of legume plants, as recommended by Bethlenfalvay (1992), should therefore take into account intersymbiont compatibility in addition to host plant compatibility. The tripartite interactions between AM fungi-legume-*Rhizobium* should be exploited in attempts to revegetate eroded and desertified soils (Barea *et al.* 1992). The use of dual inoculation in woody plants is likely to benefit their establishment on degraded ecosystems. The phenomena of dual symbiosis should be further exploited as a biotechnological tool for the management of N_2-fixing trees in restoring and maintaining soil fertility.

Conclusions

An understanding of biotic and abiotic factors is essential to select and manage symbiotic fungi and bacteria that can be introduced successfully, will persist, and are effective and efficient in establishing vegetation on derelict land. Selected tree seedlings to be used to plant on a site can be inoculated in the nursery phase before transplanting onto the site. It is essential to select and breed highly adapted strains of these microbes which can successfully grow in the rhizosphere and the roots of the plants, compete with indigenous strains, and gain dominance. Better understanding of symbionts matching with their hosts and site conditions is required for the full potential of large scale inoculation programmes to be realised.

Using mixed inocula consisting of more than one AM and EM fungi and *Rhizobium* strains is likely to be more appropriate and likely to allow the restoration of soil microbial community and reestablishment of a greater diversity of plants. Mixed inocula will also ensure the persistence of inoculants at derelict sites which are low in nutrients and contain none or inadequate natural symbiont densities.

In addition to microbial inoculation of derelict land, soil management strategies such as ameliorating the disturbance effects, avoiding leaving soil in deep stockpiles for a long period of time, etc. will also optimise the growth and diversity of plants in revegetation by reducing death of potential inoculants already present. Several areas of inoculum production and application technology merit further investigation in order to provide the most efficient inocula for use on derelict land.

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Chapter 14

The Problems of Domestic Wastes

A.D. Bradshaw

Introduction

The unimaginative ways waste disposal sites have usually been operated in the past means that it is commonly believed that they cannot escape being i) unattractive ii) sources of environmental problems. This has lead to a negative view by the general public, and resulting antagonism against authorities trying to finding new sites.

Landfill sites do have problems, yet they represent unique opportunities - especially since they are usually situated close to conurbations. They are refuse-disposal sites - in which the refuse may or may not be used for *filling* voids in the land surface. Yet equally, the refuse can be used for land *building*. The term *refuse-disposal* will remind us of their serious characteristics better than the commonly used term *landfill*. Because of the nature of the waste they contain, especially its high organic matter content, they are unstable, produce gas and leachate, and show settlement over the long term. So erection of buildings is not possible. Instead, the open space, with the possibility of creating desirable land forms, suggests that creation of landscapes for public benefit is the best and most practical option.

In older sites the waste was tipped into any convenient hollow or excavation, or even on top of previous fields. Once filled or covered, either nothing was done or just enough soil was applied to cover the material. This allows water to penetrate, leach through the waste and emerge from the bottom of the heap in a highly organic, de-oxygenated, state. At the same time the decomposition of the waste generates quantities of landfill gas, which although not poisonous can drive out the oxygen from the surface covering and kill plants growing there by asphyxiating their roots. But the presence of decaying material near to the surface provides an excellent store of fertility. There are many such sites on the outskirts of cities in both Europe and Asia.

In modern sites the material is capped with an impermeable barrier layer, usually of clay but sometimes of plastic (Department of Environment 1986) (Chapter 15). The material may be completely enclosed. This prevents water entry and controls gas escape. The gas is then drawn off through pipes to prevent its inadvertent escape from the sides of the heap. It can be used for heating or electricity generation. The presence of a clay cap can however cause problems for plant growth by restricting rooting..

Limiting Factors and Their Treatment

Older, uncapped, sites would appear to have the worst problems, suggesting that plants will grow with difficulty. Inspection of different sites shows this is not the case. There is usually a dense vegetation cover, particularly if the final soil cover is less that 20 cm thick. Since the refuse behaves like a compost heap, a thin soil cover gives the plants good access to the fertility it contains.

However, where gas comes to the surface, bare patches may occur. Landfill gas, normally methane with a variable proportion of carbon dioxide, is not toxic, but displaces oxygen from the soil. The upper 5-10 cm is usually not affected because of downward diffusion of atmospheric oxygen. As a result, shallow rooting plant species survive. But shrubs and trees with deeper roots are killed. The presence of methane can be tested for by normal gas sampling. But the important anaerobic conditions are best looked for visually - normal brown soils turn black and smell foul, The most accurate method for identifying anaerobic conditions is by the insertion of bright mild steel rods. These rust in aerobic layers of the soil, but remain bright, although sometimes grey, in the anaerobic layers. The gas can be controlled by active gas collection, usually by a simple series of gas wells operating at a slightly negative pressure to draw off the gas. But the decay process decreases with time and after 15-20 years there are unlikely to be many gas problems.

Leachates from the material are high in ammonia, nutrients and biological oxygen demand (BOD). Such leachates are a problem if they are released into the general environment. They are usually controlled when the site is established by the construction of a special treatment plant, or by sending the leachate to the nearest waste water treatment plant. But leachates will not affect plant development on the surface of the heap.

Modern, capped, sites have a substantial cover - normally about 1m of clay, or a plastic membrane, to control gas emission and water entry, with a further 20 cm covering of subsoil. All this is usually highly compacted (see Chapter 15). Engineers, however, consider that plant growth on the cap, especially of trees, will puncture the cover and release methane into the atmosphere. If trees are not permitted this seriously limits landscape treatment. However such damage by tree roots has now been shown not to occur (Bending and Moffat 1997, Handel *et al.* 1997). But plants can have difficulty in rooting in the compacted capping material. What is required is a deeper layer of subsoil, or other waste soil material, on top of the sealing layer, tipped loosely or well ripped to relieve compaction. This material may have nutrient deficiencies but these can be readily ameliorated with fertiliser, or by using nitrogen-fixing species or organic wastes (see Chapters 6 and 10). Loose material will have an important function in retaining water falling on the heap as precipitation, and making it available for the plants forming a vegetation cover. It will therefore reduce surface run-off (see Chapter 9).

Revegetation Potential

Old uncapped sites have a variable potential. If the sites are recent and there is no control of methane there will be patches of failure where the gas is diffusing to the surface. This is serious for forestry, but not for wildlife and amenity, because it will add diversity of habitat and landscape interest. The vegetation and trees in unaffected areas will grow vigorously. Grasses will cope with all but the worst areas. Tolerant tree species, normally those tolerant of waterlogged soils, such as *Salix* spp., will also grow well.

Many older sites have been taken back into cultivation. While may be acceptable on sites not containing industrial materials, there may be problems from contaminants contained in the original wastes, particularly heavy metals. As a result, food crops should only be taken after careful chemical analysis to ensure that they are not contaminated with toxic materials.

On capped sites, if the physical and nutrient deficiencies of the cap material are treated systematically (see earlier Chapters), excellent growth can be achieved by all species especially if the subsoil cover is more than 1 metre and the final cover of soil is about 500mm.

There is therefore no excuse for any sites to remain bare and miserable, antagonising the public. There is now a lot of experience on effective methods of treatments, particularly for wildlife (Watson and Hack 2000).

Vegetation Establishment

Unassisted natural colonisation can be used on any site. It leads to a complex vegetation cover. But the direction of development is uncertain. It is affected by species arriving first, and by what species are present in vicinity. Important species may be missing. Colonisation may be slow, although on uncapped sites whatever arrives will grow vigorously. But it is the least costly method, and all stages provide important habitats for wild life (see Chapter 16).

Assisted natural colonisation. This allows some control to be exercised and development to be speeded up. If there is a scarcity of colonising species, an inoculation process can be chosen to create a desired endpoint. Deficiencies and other problems can be treated - e.g. ripping to relieve compaction. The introduction of seeds by birds can be encouraged by planting small groups of trees to form attractive roosting places for passing migrant birds (Handel 1997).

Artificial planting. In many cases a landscape may be wanted quickly. However it is often considered to be difficult to establish and expensive. Yet if the limiting factors are dealt with, a herbaceous cover is especially easy to establish. Legumes are particularly valuable because they are floriferous and attractive, and because their N-fixing ability ensures their vigorous growth on most substrates. Woodland can be readily created from fast growing species. But for long term sustainability slower growing species will be more resilient and better for the maintenance of biodiversity.

Other chapters deal with these points in more detail.

Endpoints

This suggests that all sites, but especially the older ones, have considerable reclamation potential, This is certainly born out in practice, although the establishment of food crops should be contemplated with caution.

The alternative approaches involving different methods of establishment are not mutually exclusive. They can be combined to create major landscape effects and opportunities for wildlife and recreation. There are many possibilities, for example:-

i) a framework created by planting selected tree species, and the rest left to natural colonisation;
ii) where there are no effects of methane, systematic planting, with diversity formed by glades of selected herbaceous species;
iii) for immediate effects, the sowing of simple mixtures of legumes or wild flowers; this is an excellent primary treatment for all sites; it can be allowed to develop naturally, or added to; performance will be best on poor soils since the competitive effects of grasses will be reduced;
iv) for the production of biomass for fuel or mulches, plantings of fast growing tree species which can be coppiced within a few years; this will be particularly successful on older uncapped sites;
v) ecological purists will welcome areas allowed to develop on their own; tall herbaceous vegetation of weedy species is particularly valuable for wildlife, especially for seed eating birds, mammals and their predators.

It is important to plan the ultimate layout and use when the landfill site is first being considered, in order to guide the shaping of site and early landscape treatment. The refuse disposal phase provides unparalleled landscaping opportunities. Because of the impression of nastiness, it is commonly believed that best thing is to find holes to landfill with the endpoint being flat ground. But waste disposal creates opportunities to create bold and attractive landscaped hills, doubling the amount of rubbish the site can receive. In Germany there is a tradition of "rubbish mountains".

How public access, amenity and wildlife are combined together will depend upon particular characteristics of sites. Where there are uncontrolled methane or leachate emissions, public access will be unwise until these have decreased naturally after 10-15 years. Over this period wildlife is a valid alternative, but with a landscape treatment designed to allow public access later. In other areas clever combinations of wild life, amenity and public access - hollows, ponds, paths and glades can be added to enhance both amenity and wild life potential.

Refuse disposal sites offer unparalleled opportunities for the creation of valuable and attractive landscapes for wildlife and for people (Watson and Hack 2000). If anyone would like to see a first class example they should visit Jiang Shan Park in Beijing, once the rubbish dump of the Imperial Palace.

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Chapter 15

The Treatment of Modern Landfills

N.M. Dickinson

Introduction

On a global scale, only slow progress is being made to reduce the amount of waste produced and to increase waste treatment and recycling. In the UK, for example, 85% of the total of more than 130 million t of household waste currently goes to landfill. In the future, waste minimisation and recycling will undoubtedly reduce the number of new landfills created but, even when this happens, it is likely that landfill will still be used for residual wastes. Fortunately, improved environmental awareness has brought better controls of waste disposal. In most developed countries, at least, landfilling now operates under stringent requirements and post-closure activities assume greater prominence than in the past. The aim of modern landfill design is to achieve the controlled deposition of waste to land with no resultant detrimental effects. One important aspect of this is the restoration to be undertaken once the site has been closed. In well-planned sites some restoration actually should be possible before closure.

Modern Approaches to Landfill Design and After-use

Landfill Design

Design and construction of modern landfill sites involves carefully planned deposition and containment of wastes and control of the products of waste decomposition – landfill gases and leachates. Landfill gas and leachate control systems are now prepared at the design and planning stage and are coordinated with after-use requirements.

When selecting sites for landfill, obviously the geographical and geological suitability is paramount. The lining of modern landfills usually consists of 1 m of engineered clay (or a bentonite / sand mixture) underlain by geotextile and covered with 2.5 – 5 mm membrane of high density polyethylene (HDPE) which has a minimum of 30 years guaranteed lifetime. Site development takes place in phases involving cells, each typically 1 – 5 ha in extent. The base level of the cells is generally situated at least 1 m above maximum recorded groundwater levels. The HDPE lining membrane is continued from the cell base to cover the inner face of its bunds thus ensuring the complete containment of the cell (Fig. 1). One cell is prepared and then, as this is filled with waste, the next is prepared. Surface soils (subsoil and topsoil) are stripped and stockpiled or replaced on the previously filled cell.

Monitoring probes to detect leakage are placed in the different layers and a system of drains collects leachates into extraction wells, from which the leachate can be pumped regularly for treatment. Sites are generally licensed to accept certain types of waste: in the UK stringent Duty of Care legislation ensures operators conform to this. Once the cell is filled, an impermeable cap (generally clay or similar material, but sometimes HDPE) is placed on top to prevent water ingress and gas leakage. The cap is covered with some combination of subsoil and soil on which vegetation can establish. As part of restoration, networks of drainage channels are laid to collect and control surface water run-off. Monitoring boreholes are also inserted around the site boundaries, to detect any lateral leakage of leachates.

A gas recovery system is also an integral part of the design. Landfill gas is generated for up to 30 years after completion of landfill. This is a valuable energy resource, even though collection efficiency is generally poor - about 20% of the gas produced. Landfill waste containing 50% organic matter can theoretically produce 0.4 m^3 t^{-1} biogas on decomposition, of which half is methane. In practice, less than half this amount of biogas is produced. Nevertheless, this is potentially highly valuable; for example, landfill gas could realistically provide 5% of the UK total energy needs.

Nevertheless landfill occupies increasing amounts of land and is a wasteful process. In the UK, therefore, to encourage recycling instead of landfill, a landfill tax has been imposed on landfill operators since 1996. But 90% of this tax can be rebated if contributed directly to environmental organisations for certain categories of activity, which include the restoration of closed landfills. The revenue stream for this amounts potentially to £100 million per annum.

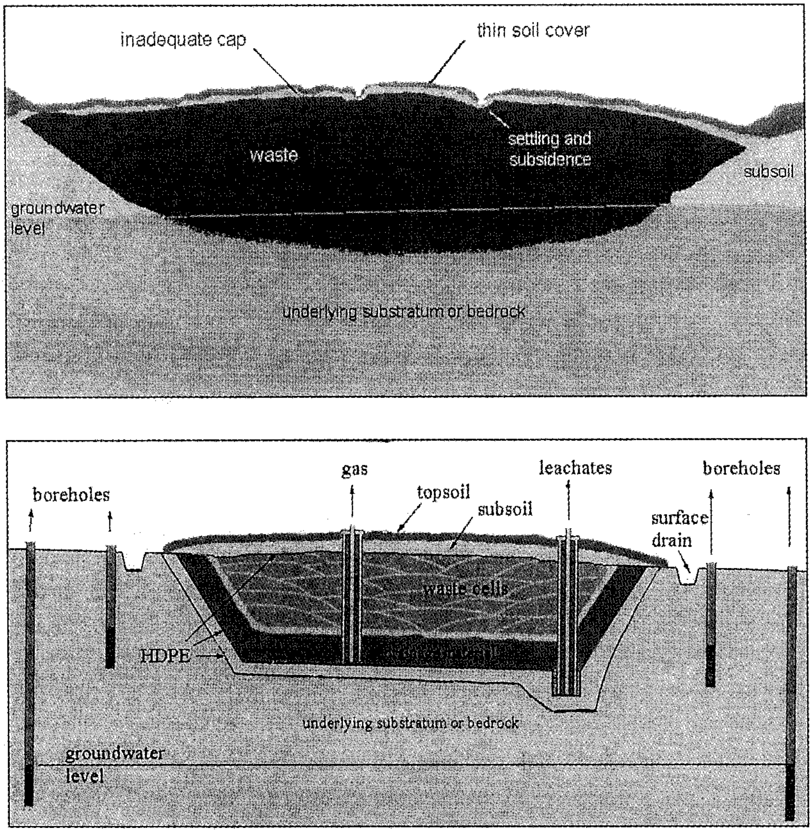

Fig. 1. Improved standards of landfill design from old-style landfill (upper figure) to modern sanitary landfills (lower figure).

Appropriate Soil Coverage

The impermeable cap of the landfill is covered with a suitable substrate for vegetation, preferably with subsoil and topsoil saved from the site before tipping began. In some situations, it may also be possible to restore the original vegetation, although landfill sites are frequently located on land that is low grade or has been substantially disturbed already. In practice, at least some additional covering materials usually have to be brought in from elsewhere.

This requires an understanding of the problems associated with soil removal and replacement. Numerous studies have shown that it is much better to try to achieve good soil conditions at the outset rather than to rely on remedial actions during a subsequent aftercare period (Fox *et al.* 1989). Loose tipping of the final soil cover is preferable to allowing heavy machinery to compact soil during landscape work and then loosening this, for example, by ripping to 70 cm. A combination of treatments is better still – loose tipping, followed by ripping into the subsoil with a winged tine using agricultural machinery.

The required depth of cover material really depends on the desired after-use of the site (Watson and Hack 2000). The recommended minimum settled coverage for arable land and productive grassland is 200 mm topsoil above 800 mm subsoil. For amenity land use, 150 mm of topsoil above 500 mm may be sufficient. Topsoil is not the ideal covering for some habitat types; it may not be required at all for nature conservation and woodland establishment. Usually, however, if subsoil is used alone it will require some addition of organic matter to provide soil structure and baseline nutrients. As an alternative or in addition to subsoil, other materials have been successfully used including brick rubble, colliery spoil, rocks, gravels and paper mineral fibre waste. There are numerous options for sources of organic matter including sludges, manures, composts and domestic wastes (Bradshaw and Chadwick 1980).

In the first years of reclamation, soil may be compacted to some degree and the physical properties of the soil may be very poor. The soil covering will lack the characteristics that define undisturbed soils; a soil profile with distinct horizons between the uppermost organic layer and the underlying parent material or bedrock. Even with extreme care, mechanical handling and a shallow depth of topsoil lead to high bulk density, low organic content, poor crumb structure and low porosity, leading to inadequate soil aeration, water holding capacity and water infiltration. The particle size distribution of the mineral fraction will provide a soil texture with particular proportions of sand, silt and clay. The proportions may not form an ideal loam, but will directly determine the drainage and fertility of the soil and, in turn, the vegetation that can be successfully established on the landfill.

Soil coverage is the most important determinant of the type of habitat that can be created on landfills. Decisions taken at the early stages of restoration will provide the driver for soil development that, in the longer term, will also be determined by the influence of plants and soil organisms. The problems are similar to those discussed for mining wastes (Chapter 9).

Agriculture

Modern landfill sites are not necessarily particularly hostile or difficult places for vegetation, particularly on sites where substantial amounts of subsoil and topsoil have been placed over an impermeable cover. Agriculture has therefore been a common end land use. However, although most modern landfill sites had conditions to achieve restoration imposed as part of their planning permission, in many cases, desirable standards of restoration simply have not been achieved. This can be particularly apparent where agriculture is the end-use. Good agricultural crops demand soil of high quality in good physical condition, but the formation of fertile topsoil is a very slow natural process. If, prior to landfilling, the soil was of high quality there would seem to be little reason why it should not be replaced. However the handling and stockpiling can cause loss of physical structure and even mixing of the different soil horizons, leading to lowered soil fertility. Scrupulous handling is therefore crucial. In particular the layers should be kept separate and no handling carried out when the soil is wet. If possible the soil should be replaced by loose tipping with tracked machinery, and not by box-scraper (Department of the Environment 1986).

Subsequent treatment should be aimed restoring an appropriate working soil depth, structure and fertility to support crop growth. This entails ripping and cultivation using tracked machinery, and the establishment of a crop. A simple grass/clover ley is commonly sown initially, in order to protect the soil from erosion and to start the improvement of soil structure. If there is evidence of nutrient deficiency appropriate fertilizer can be applied (MAFF 2000). Soil improvement can also be achieved by the application of organic manures. The grass can then be grazed by sheep and, later, by cattle, to help the return of organic matter and nutrients. Essentially, this is improving the physical and chemical structure of the soil to establish biological communities that enhance soil processes through the activity of microbes, fauna and plant roots. Achieving a macro-aggregrate crumb structure and discing to provide a suitable seed bed tilth is essential if this is to be followed by arable crops.

Natural and Semi-Natural Habitat Creation

Recently owing to agricultural surpluses, there has been a shift away from agriculture towards other land uses. This means that costs can be kept down because there is less need to ensure a high quality soil surface, although productive forestry probably still requires at least 1.5 m subsoil as a starting point. Whether or not this can be achieved at any particular landfill site, there is nowadays much more interest in *habitat creation* - the establishment of more natural plant communities - and to use this as the basis for planning restoration (Table 1). The most favoured options are now nature conservation, amenity, and community forestry. We have moved towards an ideal of replicating a semi-natural habitat of conservation value on landfill sites. This means creating appropriate conditions for nature to take over and do the rest (Watson and Hack 2000).

How this can be achieved is discussed further in Chapter 16. Detailed guidance and further discussion of many of these options is also provided by Watson and Hack (2000).

Multi-Purpose Forestry

The UK Department of Environment advice that existed in 1986 recommended that trees should not be planted on landfill sites. The same is true in the USA. There was a reluctance to establish woodlands on landfill sites due to uncertainty over survival and performance, as well as potential fears that tree roots would damage clay or synthetic impermeable landfill caps. However, it has now been shown this is unlikely and that woodlands are an attractive option for restoration of landfill sites (Dobson and Moffat 1993). This changed attitude has particular relevance in view of both the desire to improve urban environments and the large amount of land occupied by landfill in urban areas.

Table 1. Some options for habitat creation on landfill sites

Site options	Considerations and questions to be addressed
Choice of appropriate habitat	Does the habitat occur naturally in the local area? Habitat should be appropriate to the existing (or achievable) soil type Is fertility, pH, water level, exposure, appropriate for the chosen community? How will naturalistic planting be achieved?
Habitat types	Recognised types of semi-natural vegetation: e.g. grassland, heathland or woodland Select appropriate communities of plants Consider the faunal communities that will be supported by chosen vegetation
Existing ecological interest	Can form the basis of design for the site (e.g. by developing valuable habitat features, such as wetland areas)
Planting material	Use of local native species and provenance (e.g. by collection of seeds locally) Selection of appropriate seed mix. Are rooted plants required for species that are difficult to establish from seed? Is total habitat or species translocation feasible? Do exotic or alien species have a role (e.g. on difficult sites, for soil stabilisation, or in early stages of restoration)?
Habitat development	Is there a requirement for nurse plants (e.g. for trees, or on nutrient-poor sites)? Is fencing required during establishment phase (e.g. to prevent grazing)? May require additional planting at later date, e.g. of understorey plants and ground flora (shrub and field layers) Will site disturbance, mowing or grazing be required to maintain species diversity? Will weed control be required (undesirable or controlled species, or around planted trees)?
Biodiversity	Application of national and local Biodiversity Action Plans (BAPs) Contribution of the site to local BAPs Has full consideration been made to diversity within-species, between-species and of ecosystems?
Site diversity	Examples include: different communities associated with site variables (e.g. aspect and slope); creation of wetland habitats in waterlogged areas or around edges of landfill; creation of habitat corridors Is thinning of trees or later planting necessary to achieve naturalistic vegetation (e.g. non even-aged stands of trees)?
Aftercare and longer-term management	Aftercare and management of at least 5 years is usually required What effort and costs is required? What is the future source of funding? Monitoring of success is required

In Britain, high priority is currently being given to lowland forestry and the revitalisation of the urban and urban fringe areas. Twelve multipurpose "Community" forests are being developed in an area of 4,500 km^2, within the boundaries of which live one third of the country's population. Closed landfills within these areas account for some 3,000 ha of which nearly half are in the Mersey Forest area (around Liverpool) and most of which have been inadequately restored. Furthermore, for example, no part of the Mersey Forest is more than 16 km from an active landfill site. For this reason, there is a major interest in creative conservation and planting trees in relation to landfill restoration. In Hong Kong there are 13 closed landfill sites occupying 300 ha, or 1.6% of the urban land area. Three currently active strategic landfill sites are operated with advanced management, under the supervision of the Environmental Protection Department. All will require imaginative treatment, for which forestry is an important option.

There are effectively nine factors any of which can be important in determining how well trees may establish on landfills (Table 2). UK guidance in 1995 proposed a scoring system of 0-6 for each of these factors. It was suggested that a zero scoring for any one of these factors

Table 2. Assessment of landfill site characteristics to determine suitability for tree planting (Dobson and Moffatt 1995)

Site characteristic	Details
Waste type	Depth of waste and whether biodegradable or inert
Cap thickness	Of concern if <1 m thick, low permeability ($<10^{-9}$ m s^{-1}) or no HDPE cap
Gas control	Whether active, passive or absent
Landfill gas	Occurrence of hot spots or high concentrations in soil
Soil thickness	1.5 m required for productive tree growth
Soil placement	Loose tipping without heavy machinery to avoid compaction
Soil bulk density	>1.3 g cm^{-3} may inhibit root penetration
Soil type	Extreme sand or clay materials may limit growth
Slope	<1 in 20 (< 4°) may give insufficient drainage and lead to waterlogging

meant that anything as demanding as woodland should not be contemplated. Then, depending on the total score achieved, this system can be used to decide whether the site is suitable for a wide range of tree species or just pioneer species, or whether site improvement is required. If site improvement is necessary, it may need to take the form of a radical treatment such as removal of contaminated soil, installation of gas or leachate controls, or addition of further soil or sub-soils.

In the UK, a standard methodology has recently been developed using a staged pathway to assess the best practical remediation strategy for woodland establishment on all types of landfill sites (Nolan 1999). This is based on six stages devised at an average total cost of £500 - £1000 per hectare. The methodology may be used for sites where original restoration plans were lacking or inadequate, or where a change of after-use to forestry is sought at a later date. As progress is made along the staged pathways (Table 3), a decision is taken concerning the most appropriate remediation strategy for forestry. After the soil quality survey, the guidance allows the results to be compared against minimum soil quality standards for productive woodland, naturalistic woodland or rotational coppice, for which minimal soil thicknesses (depths) are 1.2 m, 0.8 m and 0.3 m respectively. In extreme cases, the best practical remediation strategy may involve (i) deep ripping of soils using 600mm deep wing-tines with or without addition of organic matter, (ii) total excavation and replacement of existing soil, or (iii) importation and loose tipping of extra soil to achieve greater depth of cover, which are progressively more expensive options. However, field projects at 15 sites in north-west England have shown that successful community woodland and multi-purpose forestry can be achieved at most sites with minimal site amendment .

Recent Advances and Future Goals

We do now have the knowledge to implement and direct the recovery of a landfill disposal site, but there is always room for improvement. Even on the most modern landfill sites, transportation, disturbance and spreading of soil materials inevitably results in a poor structure, altered fertility and low organic content, as well as at least temporary disruption of the biological integrity of the soil. There is still an opportunity for faster, more efficient and effective restoration, better management of landfill gases and leachates and longer-term site monitoring.

Table 3. Staged pathway to assess the suitability of a landfill site for forestry (from Nolan 1999)

	Pathway	Decision
Stage 1	Inception	Desk study to investigate suitability
Stage 2	Preliminary assessment	Walkover, landscape, planning and ecology study to identify potential planting areas
Stage 3	Soil quality survey[1] • trial pit • chemical analysis • gas survey	Do minimum standards exist for productive woodland, naturalistic woodland or rotational coppice?
Stage 4	Risk assessment	Can risks be safely managed?
Stage 5	Best practical remediation strategy	Is strategy compatible with any constraints identified above?
Stage 6	Developing the design	

A negative decision at any stage of the pathway requires a return to previous stage.

[1]Assessment of soil thickness, stoniness, compaction, root impedance, soil aerobism, phytotoxic contamination, zootoxic contamination and windthrow hazard (see Table 1).

Drought stress is invariably one of the major factors limiting plant growth and development on landfill sites, particularly in areas with low or erratic rainfall. The general principles have been discussed in Chapter 9. In Hong Kong, where 80% of rainfall occurs between June and September and is low and erratic, drought is a major limiting factor. Waterlogging and drought, seemingly apparent opposites, are frequently significant limiting factors on closed landfills at different times of the year. Liang *et al.* (1999) have shown that one solution may be to recirculate diluted landfill leachates to surface soils. High concentrations of leachate have an adverse affect on tree growth, but low concentrations used as irrigation water during the dry seasons improve plant growth. Leachate has also been applied to stands of *Salix*, grown as short-rotation coppice in experimental studies at landfills in Hatfield and Hertford in England. After 3 years, the leachates can provide a valuable source of water and nutrients during the growth season. Soil salinity builds up during summer, but does not appear to affect soil processes including nitrifying bacteria and is washed out during the winter recovery period. However current UK legislation only allows leachate recirculation under the provision of a waste disposal licence from the Environment Agency.

In north-west England, a 3 year field experiment involving planting 21 species of trees on 11 different landfill sites without any prior remediation, the main constraints to tree establishment and growth have been shown to be the common and well established factors of weed competition, soil depth and compaction, waterlogging and soil aerobism, rather than anything more subtle. There is always concern about toxicity from heavy metal contamination, but this has not been found to affect tree growth. It can be argued that current guidance concerning the significance of elevated heavy metals is unnecessarily cautious where trees are to be established (Dickinson *et al.* 2000).

Unfortunately little is known about the feasibility of facilitating restoration of the populations of decomposer organisms in the soil by inoculating microbes (including mycorrhizae) and soil fauna. Earthworms are well known to be important promoters of soil structure and fertility, and there have been several studies of their colonisation of closed landfill sites. One study in the UK has shown that after four years earthworm communities on landfills can generally be typical of more normal environments, with 2-5 species and population numbers of 10-400 m^{-2} (Judd and Mason 1995). Some species (e.g. *Lumbricus rubellus*, *Allolobophora chlorotica* and *A. caliginosa*) are more successful colonists due to their high reproductive rates and powers of dispersal, although natural migration rates may only be about 5 m yr^{-1}. Sometimes a small number of individuals are introduced with cover materials. These inocula are important in allowing the less invasive species like *Lumbricus terrestris* to establish quickly. The main soil parameters which influence earthworm distribution are soil organic matter, soil nitrogen and soil moisture. Low pH (<6) can be particularly detrimental but is not usual in most imported soil materials.

Much of the leading research on landfill restoration has been carried out by groups in Hong Kong. Natural rates of colonisation of landfill sites in Hong Kong are impressive compared to examples in temperate zones. Species invasion by legumes and ruderal herbaceous plants can create considerable species diversity, although this does tend to be dominated by exotic species. Trees such as *Acacia auriculiformis*, *A. confusa*, *Casuarina equisetifolia*, *Lophostemon confertus* and *Melaleuca quinquenervia* show particular tolerance to landfill gas and drought problems, but their most significant attribute is their nitrogen-fixing abilities. Natural colonisation by local species is important. In four sites at a Hong Kong landfill, two were planted as grasslands and two as woodlands. Two species of grasses were hydroseeded to form the grassland, and a total of 21 woody species planted in the woodlands. After 3 - 7 years, 49 woody species (30 of which were natives) and 40 herbaceous species (28 natives) were recorded. Nevertheless good natural colonisation can often only occur on modern landfills in temperate zones if some assistance is given (see Chapter 16).

The rapid provision of a functional soil in order to achieve effective vegetation cover is usually a priority on post-closure landfill sites. This can be achieved by applications of sewage sludge and other organic wastes, but nitrogen-fixing herbs or trees are an obvious alternative solution (see Chapter 11). The invasive nitrogen-fixing leguminous tree *Leucaena leucocephalla*, which is a native of Mexico, widely introduced elsewhere in the tropics and sub-tropics for forage, firewood, timber, paper pulp and reforestation, has been shown to have considerable value on landfills (Chan *et al.* 1997, 1999). However, it may be an ecological mistake to make these sites highly fertile since this is not necessarily compatible with high biodiversity. Care also need to be taken with introduced species, as found with the planting of Australian wattles for restoration; in South Africa, for example, there are problems with controlling the invasion of two Australian wattles (*Acacia mearnsii* and *A. longifolia*) which put a large demand on water resources. Some exotic species may not be very tolerant and responsive to landfill conditions.

The aim of a good design for the restoration of modern landfill sites is to achieve a remediation strategy that is a balance between factors of aesthetics, economics, ecology and the landowners' aspirations, and which will, as far as possible, be self-sustaining and meet the needs of the local people. It should provide a cost effective solution to problems on the site. By working with the site and recognising its characteristics, it should be possible to achieve a sustainable site in terms of long-term manageability. Answers are now required to broader ecological questions than simply whether vegetation can be established. Achieving merely a simple grass cover or a productive agricultural crop is now often not the most suitable or sensible treatment. We should aim to achieve a healthy soil, sustainable vegetation and biodiverse habitats in these newly-created landscapes.

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Chapter 16

Using Natural Processes

A.D. Bradshaw

Introduction

Restoration is an urgent matter under some circumstances. For instance, where there is a need for rapid soil stabilisation, a vigorous vegetation cover may be required to be established within three years. But in other circumstances we have come to realise that restoration does not always have to be so urgent. Perhaps a stable vegetation only needs to be established within ten years.

Allied to this is a new interest in ecological processes, and the possibility that we can harness them to do our restoration work for us, and thereby achieve economies. There are powerful natural processes occurring in primary succession, which have produced the world's present natural vegetation and ecosystems unaided, on a variety of raw and skeletal substrates. There are many examples. Perhaps the most spectacular is what happens on glacial moraines after retreat of the ice, and on raw materials produced by volcanic eruptions (Crocker and Major 1955). But we can equally look at what happens on new mudflats formed in estuaries, on sandbars left by rivers, or on mining wastes (Leisman 1957). There can be complete development of a vegetation cover within ten years and functioning soils within twice this. Such new ecosystems, having come about by natural processes, have the particular advantage that they are self-sustaining.

However, on artificially degraded land, the restoration tends to be achieved rather slowly, and there are situations where the natural processes can take up to 100 years to achieve a satisfactory vegetation cover. These are usually areas where the material being colonised is rather extreme, such as coarse volcanic lavas, or materials containing heavy metals.

Therefore, although we can view reclamation from a new ecological perspective, using natural processes, we need to examine the component processes in more detail in order to see which may need some assistance if the end-point is to be achieved in a reasonable time. We can then decide what that assistance has to consist of. If we are trying to save cost and effort, it will be necessary to determine the minimum treatments required. In doing this some of what is proposed is similar to the traditional treatments which have been described in the previous chapters. But there is an essential difference in that all treatments should be absolutely minimal, and many traditional treatments can be omitted altogether (Bradshaw 1997).

There is one important point. If we are to let natural processes do the work for us, we have to understand that end-point may not be able to be controlled. Nature will operate in its own way, and we shall have to be prepared to allow it to develop its own particular community of plants. Nevertheless we may be able to guide it, by suitable assistance, especially by ensuring that the species we would like to have in the final product are able to establish and develop.

Effective restoration can be achieved by making use of natural processes, although it is likely that some assistance may be necessary. But since

a) the work on site can be much reduced,
b) the result is likely to be self sustaining, and
c) biodiversity will be supported,

using the processes of natural succession is a valuable technique which deserves the attention not only of ecologists but also of engineers.

But How? - If Using Natural Processes, Which Processes Likely to Need Help?

There are a series of processes involved in natural succession (Miles and Walton 1993, Bradshaw 2000), which have been outlined in a previous chapter (Table 2, Chapter 1). These need to be examined in turn. Many of the suggested treatments have already been discussed in previous chapters. They are suggested again here as low level treatments just to overcome serious problems, but not to be used otherwise.

Immigration of Appropriate Plant Species

Natural processes of dispersal, by seed and vegetative growth, can bring many species into a new habitat. This leads to the idea that the arrival of species into the area we wish to restore can be left to nature. In some situations it can, and has the particular advantage that it can bring in species and populations with valuable locally evolved characteristics such as metal tolerance (see Chapter 7).

But much of our experience is from observations on the performance of specialised weedy species with excellent powers of dispersal, invading fertile land where conditions are not hostile. In areas where restoration is required, conditions are likely to be hostile, and ecologically appropriate species, adapted to the particular characteristics of the environment to be restored, may not be available in immediately adjacent areas - for instance where a quarry is surrounded by arable land, or an acid colliery spoil heap by neutral grassland. Chemical waste heaps, particularly, can be very poorly colonised after 100 years, because of lack of appropriate species in the vicinity (Ash *et al.* 1994).

The solutions are

a) to bring in the desired appropriate species by hand;
b) to encourage the activities of dispersal agents, such as birds, to assist in the process.

If the species are ecologically suited to the site, it will not be necessary to provide more than small seed islands from which the species can spread naturally.

Establishment

The species may arrive and be appropriate. But their establishment may be limited by some simple factor such as the hardness of the soil surface or surface erosion of the soil. Some simple treatment may be required to overcome this.

The solutions are several, depending on the problems

a) surface cultivation - a broken surface will provide many different suitable microsites for seed establishment;

b) local amelioration - by the deposition of unwanted rubbish or rubble on the surface to provide a better seed bed;

c) mulch - this can be a specially prepared material (often expensive, as in hydraulic seeding), or locally produced waste product (usually very cheap, such as sewage sludge) into which seeds of the desired species can be introduced - equally the mulch can be chopped straw scattered by hand or machine;

d) nurse species - a fast-growing ephemeral species such as a cereal species like rye can be sown at low density in combination with the desired species, to grow up quickly and die, to make a protective framework over the young seedlings.

Nutrients

In many situations the substrate may be very infertile, just raw subsoil or rock, lacking in most plant nutrients. The solutions are essentially very simple:-

a) To introduce species ecologically adapted to match these site conditions - tolerant of low nutrient supply, unless they are already present. But such species can be rather slow growing and unsuitable for restoration work.

b) So some nutrient addition may be necessary. However if species which are already ecologically adapted are used, only a small amount of nutrient will be required. Careful soil analysis, set in relation to low requirements can provide guidance.

c) Nitrogen is nearly always deficient in degraded soils. Because it is the nutrient required in largest amount by plants, deficiency can exert an over-riding effect (see Chapter 6). Although a small amount of nitrogen fertiliser can be used, the application may have to be repeated. Nitrogen fixing species are usually a better alternative, used either to form the main vegetation cover, or to provide the nitrogen for other species. It is necessary to find the appropriate nitrogen fixing species, which have themselves to be adapted to the other site conditions. Many of the species are legumes host to the nitrogen fixing bacterium *Rhizobium*, but there are a range of other species such as *Casuarina* and *Alnus* which make use of an Actinomycete.

d) It may be possible to find an organic source of nitrogen, such as sewage sludge or animal manure by which the nitrogen required can be given in a single application, and at the same time used as a mulch.

Organic Matter Accumulation, Breakdown, and Nutrient Cycling

An essential part of all soils is the organic matter it contains, which has considerable beneficial effects on its physical characteristics. This accumulates as litter from above-ground sources as well as from roots etc. But an ecosystem cannot function properly without recycling of major plant nutrients. This entails the decomposition of a proportion of this organic matter annually, releasing the mineral nutrients it contains. The incorporation of litter into the soil and its breakdown can only take place by the activities of organisms, both the larger ones such as earthworms and ants, and the multitude of micro-organisms, particularly bacteria and fungi.

The latter are usually very mobile, carried by small amounts of soil and wind. But the bigger soil animals such as earthworms may find colonisation difficult. The solution is

a) to inoculate the area being treated with small amounts of fertile soil likely to contain the desired organisms, and then let them spread naturally which they will do quite rapidly;

b) to provide a similar inoculum taken close to woody plants known to have a special relationship with mycorrhizal fungi which assist their nutrition directly;

c) to provide an inoculum of those nitrogen-fixing bacteria which have specialised relationships with individual host species. In some cases it may be necessary to use a laboratory based inoculum; otherwise soil from where the species is normally to be found can be used.

This is discussed in more detail in Chapter 13.

Toxicities

Soil and waste material produced by mining for coal or metals in particular may be toxic to plants due to acidity produced by oxidation of exposed sulphide compounds, especially iron sulphide (pyrites). Soil pH can be as low as 2.5, preventing plant growth completely. Other mine wastes can be high in toxic metals such as copper, lead and zinc, which again completely inhibit plant growth (see Chapter 7).

The solution normally used for high acidity is

a) to reduce the acidity by addition of lime. However a complete neutralisation of the acidity can involve large quantities of lime which is expensive. The more ecologically sensible solution is
b) to reduce the acidity only slightly with a small amount of lime and then to introduce species which are acid tolerant, or to allow them to colonise naturally, if they are already present.

The treatment normally used in toxic metal situations is to cover the area with inert non-toxic material, because there is no other simple treatment. However in some situations a more natural approach is possible. This solution is

a) to reduce the metal toxicity to a small extent by the addition of lime or organic matter;
b) to encourage colonisation by local plant material which has evolved tolerance to the metals naturally, and then be patient. On all nearly metal contaminated areas evolution and spread of tolerant material occurs, and can be encouraged by limited amelioration (Gunn 1995);
c) to introduce material, known to be metal tolerant, from other areas and allow it to colonise.

Finally - Assembly Rules

A final problem is one that exists particularly in ecological theory. Species can be shown to interact in the process of natural succession, particularly by the presence of one species assisting the incursion of another - *facilitation* - or by preventing the incursion of another - *inhibition* (Connell and Slatyer 1977). This suggests that to achieve a desired endpoint care has to be taken to ensure that species come into the developing ecosystem in a certain order.

A good example of facilitation is the part than can be played by nitrogen fixing species in supporting the growth of other species by the accumulation of nitrogen. Equally tree cover may be important for the growth of woodland herbaceous species.

The effects of competition are perhaps more obvious. It may be very difficult for particular species to enter a developing ecosystem if other particular species are already present. This can be particularly significant if to achieve a rapid vegetation cover a fast growing species has been introduced artificially.

But in practice in natural situations it is rare to find such processes operating uniformly and completely. The solution is

a) to have a relaxed approach to what the natural processes will deliver and will allow the growth of certain species to be interfered with, or assisted, by others, because the effects are rarely complete;
b) to take steps to provide desirable facilitation by introducing nurse species or nitrogen fixing species, as already discussed;
c) to reduce competition by allowing a patchy development of species to occur.

Practical experience suggests that, while these processes can be important, few are over-riding, and that assembly rules should not frighten restorationists, although it is a topic that does need more research.

Conclusions

General experience in the use of natural processes in restoration is that the most critical problems are

i) whether or nor appropriate species can get to the site in the first place;
ii) whether the site conditions are appropriate and sufficient for them.

Initial success depends on a fair analysis of these two problems and the necessary minimal steps being taken to overcome them. Then the final balance depends on what species do come in, and the balance of the site conditions in relation to species requirements. The ongoing management, for instance whether grazing is permitted, will, of course, be critical.

If care and common sense is applied, this naturalistic, ecological, approach can deliver successful restoration with minimum input, and at low cost. It is possible that the final product may not end up exactly as expected. But the solution, being natural, will have adaptation and resilience, and natural biodiversity.

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Chapter 17

Ecosystem Degradation and Restoration Ecology in China

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Introduction

Human activities dominate much of the earth's land surface. Humans exploit and use the natural resources around them for existence and development. As a result, many natural ecosystems have been destroyed in the past century, becoming an increasing problem. Conservation of natural resources, restoration of degraded ecosystems, and achieving ecological sustainability have become central issues (Aber and Jordan 1985, Cairns 1988, Dobson *et al.* 1997, Hobbs and Norton 1996, Yu and Peng 1995). Restoration ecology represents an emerging synthesis of ecological theories and allows for the testing of ecological theories during the restoration process (Bradshaw 1987). Restoration ecology has developed quickly around the world especially in developed countries. Restoration ecology in China has its own characteristics. Due to language barriers and the past closed-door policy, little of the research and practice in restoration ecology in China is known to the world. Thus, the main objective of this paper is to review some of the major historical developments and achievements in restoration ecology in China.

The Area and Display of Degraded Ecosystems in China

The total land area of China is 960 million ha (9.6 million km^2), of which developed areas are cultivated land (14.6%), orchard (0.5%), grazing land (41.6%), forest land (17.2%), and industrial, communication and urban use (2.6%), water (3.5%); desert and permanent snowfields (27.2%) cover the remaining area, as of 1995. (National Statistical Bureau 1995).

According to incomplete statistics, Zhang (1993) estimated that the area of degraded ecosystems was about one-fourth of the total nonagricultural land in China. Regional diversity and the lack of agreement on the definition of a degraded ecosystem make it difficult to make an accurate inventory. Table 1 shows the areas of main ecosystems and their degraded parts in China.

Table 1 The area of main ecosystems and degraded ecosystems in China in 1995 (ha)

Ecosystem type	Total area	Degraded ecosystems	Rate(%)
Cropland	140,000,000	28,000,000	20%
Grassland	400,000,000	132,000,000	33%
Forest land	165,200,000	31,200,000	25%
Desert*	130,000	--	--
Freshwater area**	743,000	245,000	32%
Derelict mining land***	2,000,000	--	--

Note: Data from Cheng and Cheng (1995), National Statistical Bureau (1995), Yu and Peng (1996), Ren and Peng (1998b).
* Desert includes sand, Gobi and oasis, the area of sand and Gobi is 109,500,000 ha, the remainder is oasis, the degraded oasis is about 6,800,000 ha.
** Does not include rivers or streams.
*** No data, most derelict mining lands were not rehabilitated.

Ecosystems degraded rapidly from the 1950s to 1990s with net increase of more than 150,000,000 ha during the past 40 years (National Statistical Bureau 1995). All the degraded ecosystems: crop land, grassland, forest land, freshwater area and derelict mining land showed different levels of degradation.

The reclamation of agriculture is necessary to feed the huge Chinese population. Most of the fields were historically shifted from forest, rangeland and wetland (Cheng and Cheng 1995, Li and Lai 1995). The main crops in China are rice, wheat, corn, soybean and cotton. Rice is mainly planted south of the Yangtze River, while others are mainly distributed north of the Yangtze River. Because of the primitive farming techniques, lack of funds, chemical pollution and shortage of water, soil structure has changed and fertility seriously decreased. In addition, agricultural biodiversity has declined (both above and under ground), crop breeds degraded, and soil eroded. Soil erosion, soil salinization and declining fertility are among the most urgent problems in China (Peng

1998, Ren and Peng 1997). About one-fifth of the cultivated land has become salinized, or fertility has declined, and about half of the crop land is suffering soil erosion (Cheng and Cheng 1995).

The grassland area in China is large, with more than 50% distributed in the northern part of the country (between latitudes 35°-51° N), reflecting both the east-west precipitation gradient and the effect of the high elevation of the west (Wu and Loucks 1992). The region extends from the tall grasslands of the Songnen plain in the east, to the deserts and steppes on the former-Soviet border in the west (National Research Council 1992). Because of inappropriate conversion to agriculture, wood harvesting and overgrazing by livestock, grassland degradation has continued to increase (Li 1994). The total number of grazing animals in China more than tripled from 100 million to 340 million from 1949 to 1989. Compared with the 1960s, more than 30% of grassland has been degraded in northern China, and the grass biomass decreased by 30-50% in the 1990s. More than 20% of the northern grazinglands are not usable, while an even larger portion is in a degraded state (Li 1994, Liu 1990, Zheng and Li 1993).

Forest destruction is not a new problem in China. China suffered from deforestation due to massive building construction more than 1,500 years ago. It became more widespread with the development of industry over 40 years ago. Both plant species and habitats have been lost at a historically unprecedented rate (Cheng and Cheng 1995). More than 80% of the virgin forest has disappeared and forest cover less than 18% by 1998. Furthermore, the main types of existing forests are plantation, shrubbery, or young forest (National Statistical Bureau 1998). The productivity and biodiversity of the forests are low, and ecosystem services such as those regulating flood and purifying water, are weak (Cheng 1993). Fortunately, plantation forest area has begun to increase rapidly in richer South China after 1985. This may be a trend with economic development (Yu and Peng 1996).

There are about 24,800 lakes in China, with a total freshwater area of about 743,000 ha. Most of them are in eastern and central China. Because of reclamation, overfeeding fish, and agricultural nonpoint pollution, most of the freshwater ecosystems have been contracting, eutrophicated, or depleted of their biodiversity (Cheng and Cheng 1995, Qiu and Wu 1996, Xu and Huang 1998).

Early exploitation damaged only small areas of land close to cities and towns, but as demand for resources has increased, a large amount of land has been destroyed for economic benefits. Little or no attention has been paid to the wasteland, whether by industrialization or mining. The wasteland problem in China has become very serious. The government has recognized that land which had been damaged by industrial and other development is incapable of beneficial use without treatment. Despite the various steps taken recently, there still exists a great deal of wasteland. The derelict mining land is about 2,000,000 ha and the annual increase rate about 20,000 ha. The rate is likely to reach 30,000 ha after 2000. Most mining land has not been rehabilitated for many different reasons (Bai *et al.* 1998, Lan and Shu 1996).

Reasons for Ecosystem Degradation in China

Ecosystem degradation means detrimental changes in the structure, function and dynamic of an ecosystem, and a reduction in its capacity to benefit humanity. It results from a series of social, economic, cultural, political and biophysical forces operating across a broad spectrum of time and spatial scales (Daily 1995). The main reasons for the degradation of ecosystems in China include ecologically flawed policies, irrational exploitation, and lack of management plans. Direct causes are agricultural activities, overgrazing, deforestation, and overexploitation for fuel wood, industrial activities, and natural disasters (for example fire, earthquake, flood and drought).

Mao Tse-tung and his government believed that people were China's greatest resource and that humans could overcome all obstacles, including the limitations of the natural environment. Although a century of war and natural disasters (flood and drought, mainly) limited population growth to only 540 million by 1949, the peace and policy had led to a doubling, to 1.1 billion in 1990. The fast growing population needed more food. Large numbers of peasants moved into marginal frontier areas to cultivate the land for more grain, yet the average crop land per individual continued to decrease after 1949. The results of this philosophy and the population policy led to many natural ecosystems shifting to controlled ecosystems, such as farmlands and orchards. The second policy problem was the "contract and responsibility system" in rural area reforms after 1978. Most of the common forest, grassland, field, and pond were assigned to peasants. Driven by the short-term benefits, the peasants cleared large amounts of forestlands and overgrazed vast quantities of grasslands in the first year. The government fast put an end to the actions, but the consequence of uncontrolled and overused resources continued for many years.

Both the land area and the population of China are huge, but the average amount of land each individual occupies is less than that of the world average level (Cheng and Cheng 1995). It was not surprising that China has been over-cultivating, overgrazing, deforestation, overexploitation for fuel wood, industrial pollution, and natural disaster. All this led to the degradation of ecosystems. The absolute and relative scarcities of natural resources manifested by growing population pressures, food and land shortages, fuelwood dependency, and inequalities in access to land, have been key factors of degradation. In addition, China began its large-scale industrialization at the middle of this century, and the industrial output was raised by 12% per year from the middle of 1980s to 1990s. At the same time, there has been a considerable increase in environmental pollution, urbanization and industrialization.

Development of Restoration Ecology in China

The idea of humans living in harmony with nature in China dates back to its ancient history (Wu and Loucks 1995). As the Chinese proverb goes, "people who live in the mountains eat what's produced in the mountains, while people who live around water eat what's produced in the water". Primitive tribes, which depended on hunting, fishing, and food gathering, needed knowledge of where and when their quarry might be found. The establishment of agriculture increased the need to learn about the practical ecology of plants and domestic animals about 5,000 years ago. The people created many agroforestry models such as mulberry-silkworm-fish, which greatly advanced agricultural productivity (Li and Lai 1995). Ideas and practices that are relevant to restoration ecology can be found in many ancient Chinese books, such as <Shi Jing>, <Shan Hai Jing>, <Nong Zheng Qian Shu>, <Beng Chao Gang Mu>, and <Tian Gong Kai Wu>. These books contained information involving protection of water and soil, rehabilitation of vegetation, increased soil fertilization, recovering wetland, harnessing rivers, and restoring habitats (Cheng 1993, Cheng and Cheng 1995, Li and Lai 1995). However, modern science and technology arrived in China rather late due largely to the corrupted feudalistic government and its close-door policy from the 1800s to the 20th century, among other reasons. Ecology was first introduced to China in 1930s, but its development was very slow.

Science and technology in China experienced a rapid development after 1949, partially but importantly, because of the return of Chinese scholars from Europe and the United States of America. Education and research in ecology were greatly influenced by the schools of thought (e.g., geobotany) developed in the former Soviet-Union (National Statistical Bureau 1990). The government organized several natural resource expeditions in the 1950s which accumulated important survey data for ecological studies carried out afterwards (Wu 1980). Due to the "making steel and iron campaign" orchestrated by the government in 1958, many forests were cleared for fuel, which led to serious degradation of the environment across the entire country. The scientists and the government recognized the problem, and thus a "vegetation improvement and natural recovery plan" followed after 1958. The Chinese Academy of Sciences (CAS), the main research organization in China, was in charge of the study. CAS organized its institutes and scientists to study the method of vegetation rehabilitation or reconstruction in 1958. The South China Institute of Botany established a field station, the Xiaoliang Tropical Forest Ecosystem Research Station (XTFERS), to study the vegetation rehabilitation in tropical coastal eroded lands in 1959 (headed by Prof. Yu Zuoyue). Soon, Lanzhou Institute of Desert Research established the Sapotou Research Station to develop revegetation methods and techniques for fixing shifting sand dunes with herbaceous and woody plants. About the same time, Xi'an Institute of Water and Soil Conservation began to develop water and soil protection models in Loess Plateau, and Kunming Institute of Botany initiated the tropical rainforest management and proper use program. In addition, some universities and other institutions started forest, grassland and field recovery experiments (Cheng and Cheng 1995, Yu and Peng 1996). Unfortunately, all these experiments and studies were interrupted between 1966 and 1978 because of the "Cultural Revolution" except those carried out by South China Institute of Botany. During this period, Chinese ecologists did little of any research in restoration ecology or in ecology in general.

Yu (1977) sorted out 28 years of field data and published a paper entitled, "The benefits of vegetation reconstruction in the coastal eroded land". Later, He and Yu (1984) wrote another more detailed paper, "The vegetation rehabilitation on the tropical coastal eroded lands", and clearly presented the theory and methods of vegetation rehabilitation that were particularly suited for South China. The Chinese Academy of Sciences paid much attention to Yu's work and supported his field station, in addition to establishing another long-term field station located in the subtropics in 1983. Both of the stations have become well-known for restoration ecology in China (Cheng and Cheng 1995, Ren and Peng 1998b, Yu and Peng 1996). In the late 1970s, Ma Shijun, a prominent Chinese ecologist, developed the concept of ecological engineering which emphasized the social, economic and environment harmony development during production activities (Kang 1990, Ren and Peng 1998a, 1998b). Wuhan Institute of Aquatic Biology initiated the degraded lake recovery project in 1983. In the same year, Beijing Institute of Botany started the restoration of degraded grassland project. Some universities and institutes began forest restoration in 1985 (Ren and Peng 1998b, Xu and Huang 1998).

Chinese activities in restoration ecology, however, basically began with a key project on restoration ecology supported by the Chinese Academy of Sciences in 1985. More than 10 institutes, including South China Institute of Botany and Lanzou Sand Institute, took part in the project. By 1985, more and more Chinese scholars began to attend restoration ecology meetings, to learn, visit and cooperate with other professionals in Europe and North America. For example, Sino cooperated with West Germany on " tropical forest rehabilitation", with the USA on "degraded hilly land", the British with "mining wasteland", Japan on "dessert control", and the French on "grassland utility"(Bradshaw 1989, Marrs and Bradshaw 1982, Ren and Peng 1998b, Yu and Peng 1996). For Chinese scientists these activities, and personal contact with well recognized restoration ecologists, provided an inspiration and impetus to the field of restoration ecology in China.

The concept of restoration ecology first became widely known among Chinese Ecologists in 1989, when the Ecological Society of China met jointly with the British Ecological Society in Beijing, China. The scientists from both countries published about 10 papers on restoration ecology in Chinese (ACTA ECOLOGICA SINICA, 1990, 10) and in English (Journal of Applied Ecology, 1989, 26). The first government agency to create an official unit for forest restoration in China was the Department of Forestry in 1990. Parham sponsored a workshop about improving degraded lands in South China and Hong

Kong in 1993 (Parham *et al.* 1993). The Chinese National Science Fund held a meeting about Chinese ecology development in 1995; the scientists suggested that restoration ecology be a key research area China should emphasize.

The Chinese Academy of Sciences and Chinese National Science Fund provided the initial opportunity to pinpoint for the wider scientific community this new frontier with both theoretical and practical importance. The Chinese Natural Science Fund supported the first restoration ecology project with the "restoration of a subtropical degraded ecosystem in China" as a key task from 1994 to 1997. With economic development and environmental realization, a lot of restoration programs of forests, agricultural lands, grasslands, aquatic ecosystems (such as lake, stream, river, wetland), derelict mining lands and islands, were committed. Based on the works, Chinese papers on restoration ecology increased rapidly after 1995. There are two books on restoration ecology in China. One is "Studies on degraded ecosystems in China" (Cheng and Cheng 1995), the other is "The vegetation rehabilitation of tropical and subtropical degraded ecosystems" (Yu and Peng 1996a).

Restoration ecology has emerged recently and generated considerable interest in China. The expansion of the field in China has been rapid over the past five years. It has attracted significant numbers of leading ecologists and scholars from related disciplines, in addition to involving many young researchers and practitioners. It has strengthened ecology, forestry, engineering, social sciences, economics and other fields by creating recognized subfields, and has created an embryonic discipline with its own body of theory and application in China.

The Main Achievements of Restoration Ecology in China

The achievements of restoration ecology in China can be classified into two parts, one is in practice, the other is in theory (Ren and Peng 1998b).

As mentioned above, China started restoration ecology in order to improve environmental deterioration and increase productivity. According to incomplete statistics, a net increase of restoration area was more than 200,000 ha, and direct values beyond 1 billion dollars, in the past 40 years (Cheng and Cheng 1995, Ren and Peng 1998a, 1998b, Yu and Peng 1996). In addition, the government's effort to deal with the problem of ecosystem degradation was contained in making law. Chinese government introduced legislation to prevent any further increase in the total area of degraded land in 1980s, since then the nation and some provinces have issued 19 laws and rules about nature resource preservation and exploitation.

Chinese scientists began to study restoration ecology in 1959, followed by the development of related research activities. But a great deal of research has been undertaken over the last ten years. The Chinese Academy of Sciences, several universities, the Chinese Research Academy of Environmental Sciences and a series of provincial institutes have carried out most research on restoration ecology. All these research organizations were supported for fundamental research by the country. About 50 papers and works on restoration ecology were published until the middle of 1999. Most of the publications covered such topics as soil restoration, vegetation restoration, and rehabilitation techniques. The studies of Chinese scientists have contributed to the restoration ecology theory in the following eight disciplines.

Achievements in the Theory of Restoration Ecology

Many Chinese ecologists believe that ecosystem succession is not irreversible in natural conditions whereas the succession of a degraded ecosystem may go either way and can be manipulated through engineering technologies. Ecological restoration may not restore an ecosystem to its former state, but will restore and rebuild an ecosystem to a healthy state with structure and functions that fit the local environmental conditions, economy and society. As loss of species and destruction of habitat are the main obstruction for restoring a destroyed ecosystem, introduction of appropriate native plant species and improvement of habitat through suitable physical and chemical methods are the key technology to restoring an ecosystem. Based on realistic conditions of China in environment, economy and society, restoration possibility of all kinds of degraded ecosystems have been discussed through detailed data analysis and successful example explanations (Cheng and Cheng 1995, Li 1994, Qiu and Wu 1996, Ren and Peng 1998b, Shu and Liu 1998, Zhang and Xu 1999).

Yu and Peng (1995) first defined the term "restoration ecology" in China. They considered restoration ecology as a science to study the causes and mechanisms of ecosystem degradation and to develop appropriate methods and techniques for restoration and reconstruction of degraded ecosystems. The definition focused on the technology, method and mechanism during ecosystem restoration, because China faced huge population pressure and had a many degraded ecosystems. Cheng & Cheng (1995) considered restoration to precise predisturbance structure and function was impossible because of the complexity of organisms and environments. Several years later, Ren and Peng (1998b) described restoration ecology as the return of the degraded ecosystem to a close approximation of its structure, function, dynamic and service prior to disturbance. That is to say, although the natural ecosystem could not be copied during the restoration process, ecosystem restoration sought certain aspects of the predisturbance ecosystem; characteristics included structure, function, and dynamics. The success criteria was to return the natural ecosystem states at the same zone, and lessons came from primary and secondary succession.

Probably, the best known restoration experiment in China was the one carried out at Xiaoliang Tropical Forest Ecosystem Research Station, which is located at 110°54'18"E and 21°27'49"N. Prof. Yu organized scientists from more than 10 different disciplines and established a research station in Xiaoliang coastal erosion region in 1959. They constructed four samples, the first was the contrast (bare land), the second was pure pinus plantation, the third was secondary forest behind a village, and the fourth was seven plots of broad-leaved mixed forest. Most species of the community were native, and the structure of the community was modeled the secondary forest. They continued to observe the change of species and abundance (plant, animal, and microbe), the relationship of organisms, biomass, hydrological characteristics, climate, soil structure and fertility from 1959. The results of the studies in 40 years showed: (1) the tropical forest could be restored artificially after extreme disturbance; (2) the stability of the ecosystem was led by the diversity of the organisms, and the diversity of plants was the basis of the stability of the restored ecosystem; (3) the change of the forest structure led to the alteration of the function of the ecosystem, the good function occurred in the good structure; (4) the restoration process of a severely degraded ecosystem should be divided into three stages, the first was reconstruction of pioneer community, the second was shifting from pioneer community to broad-leaved mixed forest, and if necessary, the third was reconstruction of agroforestry ecosystems; (5) the restoration of species composition may be achieved in about 40 years, but the restoration of soil fertility and biomass may take more than 130 years (Peng 1997, Ren and Peng 1998a, Wen *et al.* 1998, Yu and Peng 1995, Yu and Peng 1996).

The Chinese Academy of Sciences sponsored the Chinese Ecosystem Research Network (CERN) Plan in 1991. It organized its 29 field stations to cover all the country to form a network. The network focused on long term changes in the structure, productivity, dynamic, and utility of the main ecosystems in China. The scientists from CERN basically had learned the process of ecosystem degradation and restoration of all the main forest ecosystems and grassland in China. For example, the climax (evergreen broad-leaved forest) will become coniferous-broad leafed mixed forest under stress or disturbance, further degradation will lead to coniferous or shrubbery, while the restoration process will be the reverse (Cheng and Cheng 1995, Yu and Peng 1996). Cheng (1990) reviewed most degraded ecosystems and found some common characteristics such as changing species composition, community structure simplifying, productivity decreasing, soil and micro-environment deteriorating, and the relationship of organisms changing. He found that the vegetation type of a degraded ecosystem was not limited by the zonal ecological conditions, because the environments of degraded ecosystems tended to be similar. For instance, the *Vitex negundo* shrub community appeared from the tropical zone to the Temperate Zone.

Achievements in Research Methodology

The aim of restoration ecology in China is generally to take both the control of the degraded environment and the speeding up of economic development into consideration. Most projects are intended to build up ecological vegetation. The basic procedures of the projects included investigation and diagnosis of degraded ecosystems, strategy-selecting and ecological planning, plant selection, plant community designing, assembling and putting into implementation, with monitoring and optimization to follow.

Recently, Li and Lai (1995), Zhang and Xu (1999), Ren and Peng (1998a) concluded more than 60 applicable techniques for the restoration and reconstruction of degraded ecosystems in China. They classified restoration type as soil (soil fertility, water and soil erosion conservation, soil contamination removal), air (air pollution control, global change), water (economizing water, water purifying), species (native species breeding, reintroduction), population (regulating population dynamic and behavior), community (risk assessment, component assemble), and landscape (agroforestry, watershed and landscape design). Following the methodology mentioned above, satisfactory economical, social, and ecological effects on artificial restoration had been attained in different parts of the state.

Restoration of Aquatic Ecosystems

The main causes of the degradation of lake ecosystems in China are considered to be progressive artificial eutrophication, blockage between lake and river resulting from the construction of sluice gate, and irrational fishery manipulation. The decline of aquatic macrophytes and biodiversity, the overgrowth of algae, and the ensuing deterioration combination of water quality, which imposed detrimental effects on the lake functions, generally characterized the degradation. They suggested that revegetation combined with the overall optimization of aquaculture and the structure of ecosystem should be undertaken to restore the degraded ecosystem and redress the equilibrium of ecosystem. The restoration and maintenance of the dominance of submerged macrophytes has been considered to be the optimum choice for the lakes which were mainly used as drinking water sources, and the consideration of a semi-natural wetland system has been put forward to control the diffuse pollution (Cheng and Cheng 1995, Qiu and Wu 1996, Xu and Huang 1998).

Flood is one of the most important disasters in China. Based on extensive investigations and remote sensing techniques, scientists have concluded that, in the development of the Dongting Lake region, Boyang Lake region, Tai Lake region, and the Cao Lake region, environment management and ecological construction have been neglected. The relationship between mankind and land and between mankind and lake have not been soundly harmonized. The soil and water erosion in the upper and middle reaches of the Yangtze River has been aggravated, the sediment deposited in lakes, the lands at lake marshes excessively reclaimed, and the cropping system at high water level zones irrational. Consequently, the flood-regulating capacity has been reduced, the level and duration of flooding raised and prolonged, and the damage increased. They provide some suggestions for alleviating flood damage to the governments (Xu and Huang 1998, Wang 1998).

Vegetation Rehabilitation

Several scholars have studied plant species diversity of different types, different levels of degraded ecosystems, and their correlation with human disturbance and succession through field investigation. Their results have shown that slightly degraded communities have higher species diversity, while the seriously degraded ones have a lower diversity. In the course of degradation, plant community richness slightly increased and then decreased. In respect to different layers, species diversity of tree layer, shrub layer and herb layer decreased with a slight increase in shrub layer and herb layer in the first phase. Species diversity of shrub layer and herb layer is larger than that of tree layer in the degraded forest types. This pattern is different from that of zonal forests in which species diversity of shrub layers is larger than that of tree layer. The species diversity of herb layer is the smallest. If a different place or different stage is used, instead of time course, community species diversity could increase and then decrease in the succession of communities. As pioneer sun species degenerate, other species enter more in to the process of vegetation restoration, while they enter less as the climax species develop. The change in species number, in the vegetation developing process toward the climax, quickly increases in the early stage (2-20 years), decreases in the mid-stages (50-60 years), and remains constant in late stages (>150 years) in tropics and subtropics.

Based on aerial images of four periods, Guo et al (1999) analyzed the forest landscape heterogeneity and its dynamics of Guandishan Mountain forested area (111°21'E, 37°45'N) since the end of 1950s and identified that the landscape patchiness index and the landscape contagion changed obviously during the forest rehabilitation. The landscape patchiness index decreased and the landscape contagion increased at the first stage, then both of them increased at the second stage, and at last both of them gradually decreased.

Soil Recovery

Although the term soil recovery first appeared in China in about 1960s, it was Zhang (1992) who developed the concept extensively from his studies about loess plateau. The Loess plateau, which is located in Northwest China, has suffered serious erosion. Zhang and his colleagues have established several models of land production. Another example of soil recovery comes from Zhang and Xu (1998), who have found the Three-Gorge reservoir areas in Central China are typical mountainous regions with fragile eco-environment and intense population pressure. Because of long-term over-use, over-cultivation and disturbance, soils in the area have been degraded heavily. The restoration and reconstruction has included the rehabilitation and recovery of soil structure, nutrients and soil environment. The standards of soil recovery are as following: the thickness of soil should be more than 50 cm; phosphorus and potassium are the main objective of soil nutrient restoration in the area. They have outlined the method of soil environment reconstruction, which includes increasing the soil surface coverage and percentage of forest cover (the standard of forest cover >41%); to strengthen the construction of basic farmlands to control water and soil loss; to establish complex agroecosystem for slope lands; and to optimize the proportion of fertilizer application and increase organic fertilizer.

Shen (1998) has studied plant-based remediation techniques, which are showing prospects for use in contaminated soil with organic and inorganic pollutants. Two contrasting approaches were being pursued, decontamination and stabilization, both of them included phytoextraction, phytodegradation and phytostabilization.

In addition, the biological characteristics of degradation and remediation of red soil as well as its relationships with eco-environmental conditions have been discussed by Xie *et al.* (1998). They have found, with biological cycles as the focal point, that the development feature of red soil niche has changed. Furthermore, he provides the guidelines and methods for restoring the degraded red soil ecosystems.

Mining Wasteland Reclamation

With the combination of investigation, analogy, simulation, field test and demonstration, the characteristics of land disturbance and the suitable techniques for ecological rehabilitation at several coalmines have been studied from 1980. After the original vegetation was destroyed, it was very difficult to restore the original vegetation. The rehabilitation based on landscape ecological planning and design was aimed to use depleted mined land reasonably and make it properly productive, to keep its relatively stable ecological equilibrium and coordinate it with its surroundings, in order to attain the goal of ecological holism (Zhao 1993). Depleted mined land can be classified as diverse types, and there are different ways of rehabilitation for different land types. Meanwhile, depleted mined land is also concerned with different landscape scale. Therefore, only by working out reasonable macro landscape patterns and setting up suitable micro ecological conditions based on landscape ecology, can the goal of rehabilitation be realized (Bai 1998, Lan and Shu 1996, Wang and Han 1998).

Agroforestry

Investigations have indicated that the tropics and subtropics in China have been the regions most seriously stressed by human population and environment. The destruction of natural ecosystems and the increasing area of degraded ecosystems have been the key factors limiting the development of agriculture. Several long-term studies on restoration ecology shown that integrated management has had a great ecological economic and social effect on the restoration and reconstruction of degraded ecosystems. The forest-fruit-herbage-grazing-fish complex ecosystem stems from the practice of restoration and reconstruction of degraded ecosystems. As an agroforestry model with high yield, high quality and high efficiency in hilly areas, it has provided an efficient approach to enhance the development of local agricultural economy (Li and Lai 1995, Peng 1998).

Grassland and Desert Restoration

Liu (1990), Zheng and Li (1993) and Li (1994) have pointed out that the structure and function has deteriorated due to overgrazing, and argue that grazing time and intensity strongly influence animal performance, vegetation regrowth, and future production. They also recommend grazing time should be limited and have developed optimal management plans for the grassland. Based on many years' studies, Xia *et al.* (1991) provide the methods of desertification control, including windbreak forest networks, desalinization treatment, steppe seeding and restoration, and rotation grazing systems.

The Future for Restoration Ecology in China

The "Chinese 21 Century Agenda" points out that the sustainable development of China is based on both the sustainable uses of resources and sound environments. The Nation protects the systems, which support the life systems, and the integrity of ecosystems preserves biodiversity, and solves the key environmental problems such as water, soil erosion and desertification; The Nation conserves the natural resources, keeps the sustainability of resources, and avoids impairing the fragile ecosystems. The Nation plants tree and improves the environment of cities and rural area. The Nation prevents and controls environmental deterioration and pollution, and actively harnesses and restores the degraded and polluted environment. In addition, the Nation takes part in protecting the global environment and international cooperation (Zhou 1996). The Chinese Natural Science Fund gives priority to the support of restoration ecology from 1995 till 2005. Restoration ecology is supported by many scientists who are joining together all over the nation, forming groups and association.

The situation of China is different from developed countries; developed countries focus on resource restoration and protection. China emphasizes both productivity exploitation and environmental rehabilitation. Some degraded ecosystems that cannot be restored to a climax state will have to be reconstructed to become controlled ecosystems. China will need to shift the emphasis of restoration ecology from resource use to sustainability.

Because the temporal and spatial scales of ecosystem restoration are large, it is necessary to develop a national policy. In fact, the Chinese government formulated an environmental restoration plan after the flood of the Yangzte and Huanghe rivers in 1998 caused serious damage from flowing water. It is very important to set further national restoration goals and implement the plan to relieve natural disasters (flood, drought mainly).

Restoration ecology in China needs to focus on 1). studying the main ecosystem processes and their responses to human-induced disturbances; 2). establishing a national long-term monitoring system to prevent or delay different kinds of ecosystem degradation; 3). establishing a research, classification and evaluation system of degraded ecosystems; 4). studying and exploiting the technologies of restoration and reconstruction of degraded ecosystems. The methods used for restoration should emphasize the interaction and balance between the natural succession processes and human intervention, and integrate ecological with engineering approaches so as to improve the biodiversity and functionality of degraded ecosystems.

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Chapter 18

Reclamation After Tin Mining in Malaysia

C.P. Lee and E.B. Yeap

Introduction

Malaysia was the largest tin producer in the world from around 1900 to 1985 due to its fabulously rich alluvial tin deposits. A total of 20,000 km^2 or 2% of the total land area in Peninsular Malaysia has been mined for tin. The richest of these were found in the Kinta Valley Tin-field (29,661 ha) around Ipoh and the Kuala Lumpur Tin-field (11,773 ha) in the Klang Valley (Fig. 1). The thick tin bearing alluvium in these two places mostly overlie buried karstic limestone bedrock that trapped the heavy cassiterite tin ore in the depressions on its uneven surfaces.

Methods of Alluvial Tin Mining

Alluvial tin mining requires the extraction of the heavy cassiterite tin ore from the lighter matrix of gravel, quartz sand, clay and peat in which it was encased, by washing and gravity separation. The two main methods of alluvial tin mining are dredging and open cast gravel pump mining.

Tin dredging is a highly mechanised procedure in which the tin bearing alluvium is scrapped up by a moving conveyor of steel buckets onto a floating platform in a man-made pond where strong jets of water, sieves and mechanical separators are used to extract the tin ore. The buckets cannot reach the areas between the highly irregular limestone pinnacles which often house the richest tin bearing alluvium which would need to be subsequently mined by the open cast method.

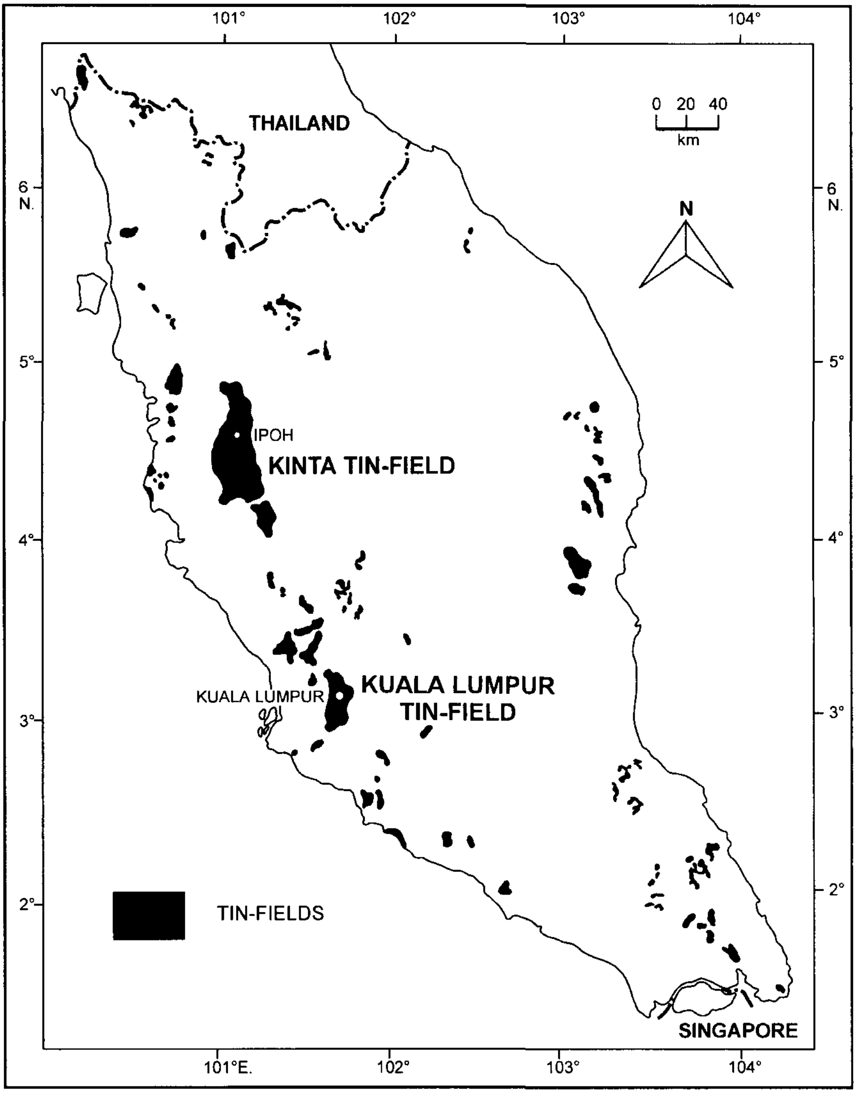

Fig. 1 Tin-fields of Peninsular Malaysia (Modified from Geological Survey Malaysia Mineral Distribution Map 1995)

Open cast gravel pump mining involves the removal of barren overburden which includes mined out alluvium or topsoil to access the rich tin bearing alluvium sitting on the irregular surface of the limestone bedrock. Hydraulic pumps are employed to shoot strong jets of water to break up the alluvium (Fig. 2). The slurry is pumped up to a screen house where the coarse gravel is removed by sieves and the finer tin bearing slurry is channeled to a series of sluices or *palongs* with riffles to trap the denser tin ore. The lighter sand and clay are washed down the *palong* as tailings that are dumped into a tailings pond. The heavier sand settles quickly and forms delta-like aerially stacked piles while the finer slime accumulates and settles out in the tailing pool. Mixed tailings are created by the on/off discharge cycles and shifts in position of the point of discharge as mining progresses. The water in the pool is reused or released into a river.

At its peak in the 1970's, there were 700 to 1,000 open cast gravel pump tin mines and over 50 modern tin dredges in operation in Malaysia producing between 50,000 to 70,000 t of tin concentrates per annum. After the tin market crash in 1985, tin production has declined significantly and there are less than 20 alluvial tin mines and only one dredge still in operation.

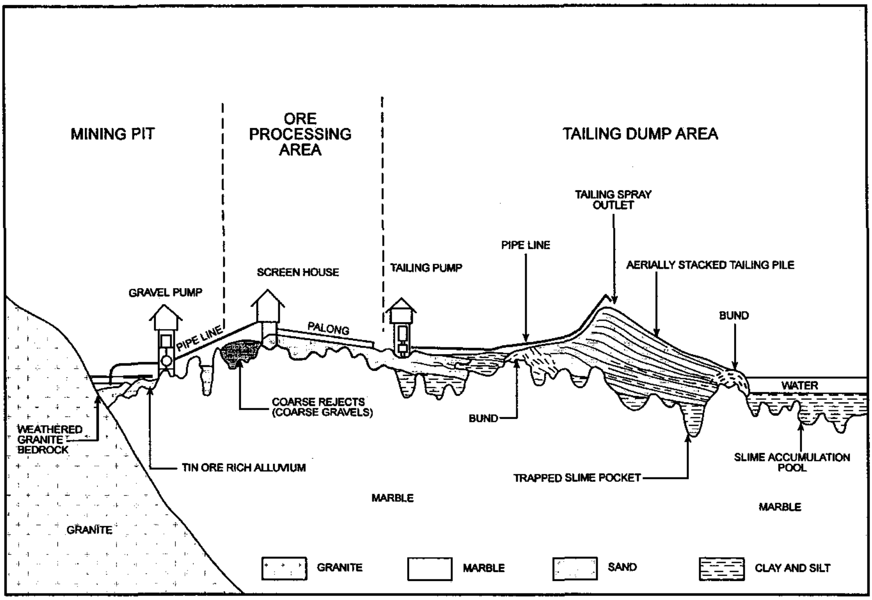

Fig. 2. Schematic section of an open cast gravel pump tin mine in Peninsular Malaysia

Legacy of Tin Mining

What is left behind on completion of tin mining is a vast expense of flat sandy disturbed land stripped off its topsoil and some big holes in the ground which are rapidly filled with water once pumping stops. These mining pools are variable in the composition of its water and bottom sediments. Those with sandy bottoms tend to be clear while those with slime are usually more turbid initially. Water and soil pH varies from alkali in mining areas in contact with limestone bedrock to acidic in parts which are rich in oxidized pyrite within graphitic schist and peat (Shamsuddin *et al.* 1986).

Resources Created by Tin Mining

Several resources are created as by-products after the tin ore is removed. These resources include:-

1. large open pits for waste disposal and other uses,
2. flat land for construction of houses and commercial buildings especially near urban centres where land is a premium,
3. agricultural land after rehabilitation,
4. exposed limestone bedrock which can be quarried for aggregate or cement manufacture,
5. water supply for agriculture, industry and domestic consumption,
6. sand and gravel for construction material and as a source of silica for ceramics and glass manufacture,
7. clay for lining waste disposal sites and for the manufacture of bricks, tiles, pipes, pots and other clayware, and
8. *amang* or non-tin heavy mineral concentrates such as ilmenite, tourmaline, zircon, monazite, xenotime, hematite, magnetite, struverite, tantalite, columbite and pyrite which are of use to the manufacturing industries.

Uses of Ex-mining Land

Ex-mining land in Malaysia has been put to a variety of uses depending on the proximity of their location to urban centres. Those that are located near towns and cities have been used for construction, recreation and waste disposal.

Construction

Almost any flat created by tin mining near an urban centre is valuable for construction if suitably rehabilitated. Mining pools have to be backfilled and those with slime at the bottom have to be treated or have the slime removed mechanically. So far only the latter has been done as the cost for treating the slime using flocculating agents such as polyethelene oxide is too expensive. A group of researchers from Malaysia and Mc Gill University in Canada have proposed a cheaper alternative of using the locally abundant natural polymer latex after extensive research but this has not been adopted in practice to date because physical removal of slime is still the cheapest option (Tan 1992). Other techniques for reclamation are accelerated *in situ* consolidation of slime using preloading, geotextile and wick drains.

Recreation

Ex-tin mining lands with their unique mixture of flat to gently undulating topography juxtaposed with ponds of various sizes and shapes are ideal for recreational development after rehabilitation. This is especially true if they are located near or within densely built–up urban areas where the need for "green-lungs", parks and gardens for relaxation and entertainment is most acutely felt. Many ex-mining ponds and land around them have been creatively landscaped and turned into city parks, golf courses, sports complexes, water sports venues, recreational angling ponds, educational wetland reserves and water theme parks.

The two most ambitious and successful developments in this area are two integrated development projects located on the outskirts of Kuala Lumpur, the capital of Malaysia, named Sunway Lagoon and Mines Resort City.

Sunway Lagoon

Sunway Lagoon is located about 15 km south of Kuala Lumpur. It is part of the Bandar Sunway town ship developed since the 1980's in an area immediately south of the suburb of Petaling Jaya. Most of the flat ex-mining land in the township has been used for building residential houses and shops or industrial premises. The lagoon itself is part of two very large holes left in the ground of a 202.5 ha plot on completion of tin-mining and subsequent limestone quarrying at the site. The limestone bedrock was never exposed at the ground surface but buried from 15 to 40 m beneath the tin bearing alluvium. It is very uneven and consists of rock columns, dolines and uvalas typical of karstic geomorphology.

Sunway Lagoon was first developed as a water theme park around a lake 37 m below the ground surface within the quarry pit to enhance its unique mine setting and give it an interesting perspective. This required continuous pumping to dewater the site. With water slides, fun rides, an artificial wave pool for surfing and other watery attractions it became an instant hit with especially the young urbanites and visitors from in and out of the densely populated Klang Valley. Its popularity was further enhanced with the addition of more attractions such as a dry theme park, a shopping mall cum entertainment complex named Sunway Pyramid, the Sunway Lagoon Hotel, Sunway College (Monash University Malaysian Campus), Sunway Clubhouse, corporate buildings and residential apartments in the integrated complex surrounding the water theme park.

The technical aspects of preparing the old mine and quarry pit to transform the wasteland into suitable land for construction of the theme park and township were presented in a paper by Phang (2000) at the 6th International Mining and Mineral Resources Conference. Careful planning and exhaustive engineering works were undertaken including programmed landfill, compaction, monitoring of settlement, and installation of proper subsoil and surface drainage systems. Extensive stabilization work on the rock faces damaged by blasting during earlier quarrying was carried out. Clever landscaping and creative utilisation of the rock walls and some natural features such as rock columns in the old quarry and mining pit have imparted a unique depth dimension to the theme park giving it an amphitheatre-like setting. Massive "greening" by planting a very large number of trees and shrubs was needed to turn the bare landscape into a verdant area. This is probably the best example in

Malaysia of rehabilitation of a drab mining landscape to a park which is already a house-hold name in Malaysia and beyond.

It is interesting to note that other "copy-cat" water theme parks that were built on a much smaller scale in other places were rather unsuccessful in attracting visitors. This shows that a venture of this nature cannot be attempted on a small scale as the drawing power is not there.

Mines Resort City

Mines Resort City is built around the former Sungei Besi Mine which was at one time the largest and deepest (>100 m deep) open cast alluvial tin mine in the world. It was active between the 1950's to 1975. The mine was located at the boundary between limestone bedrock on the west and granite on the east at Sungei Besi that is on the southern fringe of Kuala Lumpur. Its development started later than Sunway Lagoon and its proximity (10 km) to the water theme park makes a similar venture not viable.

It is also geologically not suitable as the tin bearing alluvium occupied a deep and often overhanging channel which was over 100 m deep in places and dipped underneath the buried karstic limestone bedrock. The sides of the pit were dangerously unstable and unsuitable for construction. The presence of a large thickness of peat in the alluvium over the limestone bedrock was also a source of concern as acidic organic waters it produced could dissolve the limestone. An alternative development that capitalises on its strengths (lots of empty land since there was no prior construction around the mine pit) and mitigates its weaknesses must be adopted for the project to be viable.

The developers decided to flood the mine pit and turn it into a huge lake and built a resort city on the 405 ha of land around it. It has a night theme park featuring a high-tech musical fountain laser show and a parade of lighted floats. The Mines Wonderland theme park has a snow house that allows many Malaysians who have never experienced winter to get a taste of freezing weather.

It has an 18-hole golf course on the undulating eastern side of the lake built over uneven granite terrain. Surrounding the golf course are bungalows for the rich and famous. The Mines Shopping Fair on its southern shore is located next to the Mines Beach Resort Hotel adjacent to the golf course. A unique feature of the shopping cum entertainment complex is the canal that runs through it. A popular attraction for visitors is a ride in the water taxis that ply the canal. Immediately adjoining the shopping complex is the International Design and Export Centre housed within the Malaysia International Exhibition & Showroom. It is Malaysia's premier exhibition centre that takes advantage of the vast amount of space available next to the mine pit. Another luxurious hotel, the Palace of Golden Horses, is located next to the Selangor Turf Club at the northern edge of the lake. On the western shore of the lake is the Mines Waterfront Business Park, leased to corporations for their commercial activities. This integrated development has turned the RM2 billion (US$ 500 million) Mines Resort City into a most sought after venue in the region for meetings, incentives, conventions and exhibitions where trade, tourism, business and leisure are all found in one place.

Land Use in Rural Areas

Those in the outskirts or away from urban centres are used more for agricultural purposes. These include fresh water fish and prawn cultivation, duck rearing, vegetable gardens, lotus ponds, fruit orchards, oil palm, rubber and forest plantations and grazing land for cattle and goats. Aquaculture is not limited to just food production but also includes a thriving tropical aquarium fish industry.

Much research has been done on the rehabilitation of tin mining land for agricultural purposes by scientists from Universiti Putra Malaysia (the former Universiti Pertanian or Agriculture University of Malaysia) and various government bodies dealing with agriculture and soils. The early findings were summarized in a paper by Lim *et al.* (1981). Tan and Khoo (1981) published a paper on the utilization of ex-mining land in Peninsular Malaysia. Mok and Lim (1985) published a comprehensive paper on the reclamation of tin tailings for crop production which reviewed the UPM-Belgium Joint Soil Research Project on the subject. Several papers on the subject were presented at a seminar on "Ex-mining and Bris Soil - Prospects and Profit" organized by the South East Johore Development Board, the Agricultural University of Malaysia and the Soil Science Society of Malaysia in October 1990. They not only covered the various land–based agricultural aspects of the subject but aquaculture and recreational development as well.

In all cases, fertility must first be restored to the sandy mined-out land by the importation of soil or the addition of slime, peat or organic wastes to improve the physical conditions of the sand tailings. Chicken dung has been found to be a more effective nutrient provider than inorganic fertilisers (Mok and Lim 1985). Overburden mixed with slime, peat and sewage sludge increased the yield of mungbean by 78% and 300% respectively and yield from mulched plots was 85% higher than unmulched plots. It was concluded that reclamation of sand tailings for cropping requires the incorporation of 10%-20% slime and 5%-10% organic wastes. Slime tailings on the other hand, require proper drainage with deep ploughing and rotavation to improve the compact structure. Mixed tailings and overburden have the least constraints and require minimal soil amendment for crop production.

What made the use of rehabilitated mining land for agriculture so attractive is the easy availability of water and the abundance of well drained flat land in these areas. Duck farms in particular need a lot of water and space for healthy development of the birds. Duck droppings are easily put to good use for fertilising the ponds for fish rearing and planting vegetables and fruits.

Problems on Usage of Ex-mining Land

The problems that are associated with the utilisation of ex-mining lands are many and varied depending on the mining legacy and the intended usage.

Problems of Construction on Ex-mining Land

Leachates and methane gas are the main problems associated with mine holes that had been turned into unsanitary garbage landfills without proper treatment and subsequently covered with soil before being constructed over. The presence of slime or very soft silty clay at the bottom of some pools affect ground settling. Piling to bedrock can mitigate this settling effect to a certain extent but some mining pits are too deep for such purposes. Sinkholes beneath the limestone bedrock has in some instances been opened up or reactivated after the mining pools have been filled and buildings or roads and other infrastructures have been built on top. Detailed subsurface geophysical investigation is thus needed to ensure this problem is detected and catered for in the siting of the structures and their engineering design.

High concentrations of radioactive minerals, mainly uranium and thorium found in the zircon, monazite and xenotime, present in *amang* waste stockpiles left in some mining areas can be potential health hazards. Fortunately, the discovery of new uses for these formerly regarded waste products of tin mining has turned them into a valuable commodity and most of these stockpiles are now sold to processors who extract the useful minerals especially ilmenite, zircon, monazite, xenotime, tantalite and columbite for industrial use.

Problems of Growing Crops on Ex-Mining Land

The main problem is of course the loss of fertile top-soil to access the tin-bearing alluvium beneath. The mining process leaves behind a legacy of segregated sandy and slimy deposits devoid of nutrients and low in organic content. Soil structure is destroyed and water drains away very rapidly in the sandy tailings affecting nutrient retention adversely. Soil temperature in the light coloured quartz sands can rise to 40 – 50°C on hot days. Slime tailings on the other hand are compact and tend to retain water. They are soft when wet and very hard when dry. Although they retain nutrients better, their compact structure affects aeration and penetration of plant roots. Mixed tailings are more amenable to agricultural used. Mixing can be natural or artificial and the addition of organic matter to improve soil structure and retention of nutrients is essential. Mulching helps to lower soil temperatures. The Malaysian Agricultural Research and Development Institute (MARDI) has found that the application of Palm Oil Mill Effluent and mulching with Empty Fruit Bunches, both produced abundantly as waste products by palm oil mills, helps to minimise moisture loss and lower soil temperatures in sandy ex-mining land (Khor 2000).

Conclusion

It is hoped that this Chapter will enlarge the views of those who are concerned with the reclamation and rehabilitation of ex-mining lands to look beyond just trying to put back the soil cover and grow trees on it as part of our efforts to undo the damage done by mining. There are many more ways that we can creatively explore to rehabilitate and use not only the land but also the other resources created by the mining process. It takes lateral thinking and human ingenuity to turn problems into opportunities and this has been amply demonstrated in the examples given in this paper, where impoverished ex- mining land and big holes in the ground have been creatively turned into productive income generating ventures, as well as recreational facilities that enhances the health and well-being of the people.

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Chapter 19

Metal Mine Tailings in China

H.W. Dai, L. Gao, L.P. Ren and C.L. Wang

Background

1. Mineral Resources

Mineral resources are the cornerstone of the national economy of China and the mining industry functions as one of the pillar industries. Statistics show that 95% primary energy, over 80% of industrial raw material, most agricultural productive materials and 1/3 drinking water come from mineral resources. Until now, 182 kinds of minerals have been developed. Before 1949, there were only over 300 intact mines in China. However, with 50 years mineral resource development, there are over 10,000 mines and 182,000 enterprises related to mining industry now, which are located in more than 2,000 counties in China. The annual steel output reaches over 100 million t and the output of iron ore and metallurgical flux exceeds 200 million t, while the amount of excavated and waste rock or overburden amounts to over 600 million t. The annual output of non-ferrous metals exceeds 6 million t with the amount of excavated waste rocks up to 5 billion t, only second to the former Soviet Union and America in 1990 (Zhu 1999).

2. Environmental Problems in Mining

The purpose of mining is to obtain mineral resources so as to improve living standards. However, long term development of mineral resources, in fact, is at the expense of sacrificing our living environment causing environmental pollution or destruction. Open-pit mining leads to fundamental changes of the ecosystems and natural landscapes on areas several times bigger than the mining area. Huge voids resulting from steep deposit mining and stockpiles over several hundred meters high cause the loss of original landscape for ever. Mining activities destroy native vegetation and ecological systems, cut off underground water passages or routes that have evolved over thousands of years, and lead to decrease of ground water level on a local or regional scale. Furthermore, underground mining can cause subsidence, cracks on hills, collapses and landslides. Recently, the chaotic mining and excavation by rural and township enterprises have aggravated soil and water erosion and speeded up environmental degradation.

Large amounts of solid wastes such as tailings, waste rock and various slags are produced by mining and its related industries. It is estimated that for each 10,000 t of ore produced, around 3.5 ha of land will be occupied. Each year, according to statistics, the total amount of excavated volume of all mines in China exceeds 600 million t. In 1998, the amount of solid waste produced by non-ferrous mining amounted to over 90% of the excavated materials, 200 million t of tailings were produced, and the accumulated amount came to 1.5 billion t (Council of China Environment 1998).

Characteristics of Tailings Ponds

In China, tailings dams are important facilities for disposal of the fine materials produced by the processes by which ores are concentrated. They have the following characteristics compared with other kinds of waste disposal facilities.

1. Occupying Large Areas of Land

As a result, tailings occupied large areas of land. Tailings may be deposited in dry heaps. But usually they are carried by water and deposited in tailings dams or ponds. There are all together 1,500 large and medium sized tailings dams for metal mines including non-ferrous metal mines in China. Among them, tailings dams with over 100 million cubic meters capacity often cover areas of dozens of square kilometers (Li *et al.* 1996a).

2. Low Grade Ores and a High Proportion of Tailings

In China, non-ferrous metal mines, especially rare metal mines are characterized by low grade ores often below 1%, some even as low as below 0.1%. Therefore, the proportion of tailings may reach over 90% or 95% (Li *et al.* 1996b).

3. Fine Grade Distribution

Tailings usually have a high ratio of fine particles. That is to say, more than 60% of tailings have a diameter smaller than 200 mesh. Some ores may be ground as fine as 400 mesh. The implementation of back-filling technology makes the tailings finer with 200 mesh particles over 90%, which are transported into tailings dams. Because of their fine grade, the tailings have low permeability and retain water over long periods, some even more than 10 years (Group of the Facility Design for Tailings Pond 1980). Therefore, the slime sections of existing tailings dams are basins of slurry, with dry beaches as "artificial deserts" with medium and fine tailings sand. With the rapid development of mining industry and urbanization, certain old tailings dams may even be located within city areas, which can cause serious harm to urban environments.

4. Complex Composition of Tailings

In China, metal deposits often contain associated metal ores with multi-metal elements. At present, comprehensive recovery rates of mining products feasible in terms of economics and technology only reach 30% (Council of Comprehensive Utilization Handbook of Mineral Resources 2000). The diversity of mineral processing technologies and processing agents used leave a number of elements in tailings at low concentration and hard to recover.

5. Serious Pollution

Tailings usually are mixed with water and discharged into tailings ponds. Thus, under different pH conditions, some metals enter tailings ponds in ionic form at high concentrations. They will flow into external environments with water, causing pollution. In addition, organic mineral processing agents also bring about adverse impacts and contamination. Some may release irritant odours. Research indicates that some organic agents are slow to decompose under natural conditions. Therefore, they become long-term contaminants. The residual organic agents can cause pollution of the fish living in tailings ponds. Tailings water can also contain other pollutants such as cyanide (Li 1991). In some mining areas, water quality of wells cannot meet drinking water standards due to ground water pollution from tailings ponds. Dust pollution is another common problem resulting from tailings ponds. In the northern part of China where it is rather dry in spring and winter, especially during March to May when strong winds blow frequently, dust storms may occur with the visibility less than 1 to 2 m, and the distance affected by tailings reaching several kilometers. Consequently, mining companies often spend considerable resources to remove the blown-out tailings back to the dam. Such dust storms can also cause considerable trouble for local residents.

6. Thermal Absorption

Unlike natural soils, tailings have no particle or granular structure and possess considerable proportions of quartz. Under direct sunlight in summer, surface temperatures can reach over 50°C even in the northern part of China. In winter, tailings disperse heat quickly leading to bigger temperature differences compared with normal soil surfaces. Therefore, the presence and growth of plants are restricted.

7. Ecological Damage

Apart from potential pollution, most tailings are poor in retaining water. Moreover, they lack organic materials, and nutrients are hard to retain even if fertilizers are employed. As a result, natural vegetation is very rare even if the tailings pond has been dry for many years. It is obvious that tailings ponds impose far-reaching impacts on soil, vegetation and animals, and therefore on the whole ecological balance.

Even mosquitoes and flies can not be seen on some tailings ponds.

Advances in Mine Site Rehabilitation in China

Tailings ponds therefore impose a series of safety, environment and ecological problems. The pioneers of land reclamation in China began their early practice of rehabilitation and restoration of tailings dams in the 1950s and 1960s. A closed tailings dam at Huai Ren Lead and Zinc Mine was covered with soil before planting with vegetation in 1957 (Peng 2000). Xiao Guan Bauxite Mine was the first non-ferrous metal mine in which the rehabilitation of the destroyed land was brought into the general plan of the whole mine development. In 1958 a seepage-proof layer with 10 – 20 cm of clay was built into its tailings dam and a water flow channel placed underneath. This measure effectively solved seepage problems, enhanced dam stability and facilitated the collection and usage of discharged water (Yan 1989). A dry skating arena was built on a closed tailing pond at Pangushan Tungsten Mine. However, deep cracks appeared after it had been in operation for several years. Site investigations indicated that high concentration of sulphur accounted of the phenomenon. Sulphur in the tailings reacted with air in the covered soil and produced a large amount of harmful gas that swelled and destructed the terrazzo surface. The mining company planted gladiolus on the slope of dams and built a small green park on the tailings pond, which became an entertainment site for local pupils and middle school students. A basketball field equipped with lighting on an abandoned void was also built, which greatly facilitated the off-work live conditions of local people (Investigation Group of Non-ferrous Tailings Pond 1988).

In the late 1970s and early 1980s, Bizigou Mine of Zhongtiaoshan Copper Mining Company has created nearly 30 ha of farmland by covering the Hanjiagou and Mojiawa Tailings dams with loess on which crops such as winter wheat, maize and some vegetables were planted. From 1987 to 1990, a research team of Beijing General Research Institute of Mining and Metallurgy jointly with the mining company investigated the food chain problems. At the same time, water and soil erosion observations (using simulated rain) were conducted on the dam slope in order to work out countermeasures. Investigations on soil cover, selection of plant species, soil fertility improvement, prevention and control of heavy metal pollution, and the monitoring of environmental changes were also carried out (Shu *et al.* 1999). In the late 1980s, grass and bush vegetation was successfully established on the high-gradient dam slope of Xihuashan Tungsten Mine to prevent water and soil erosion. Zhongshan University and Hong Kong Baptist University jointly investigated on the re-vegetation of No. 2 Tailings Pond of Fankou Lead and Zinc Mine (Guangdong Province). The investigation included acidification control, biological treatment of tailings water, strategies for native plant establishment, soil medium improvement and the selection of appropriate plant species that can tolerate heavy metals (Wong 2000). In Zhaoyuan Gold Mine in Shandong Province, the mining company provided local farmers with funds, and the village offered labour and land for rehabilitating 128 ha of waste land (Tang and Gao 2000). On Nanshan Iron Mine an acid resistant economic forest had been planted on a tailings dam in the same manner.

In the 1990s, more and more mining companies have become involved in mine site rehabilitation. For example, the Research Center for Eco-Environmental Science, Chinese Academy of Science has cooperated with Dexing Copper Mining Company. More than 40 adapted pioneer plant species were selected and planted using proper planting techniques (Gao *et al.* 1999). Dayie Mine in Hubei Province, has planted bushes on rehabilitated tailings ponds.

From 1993 to 1997, China-Australia Research Institute for Mine Waste Management (CARIM) of Beijing General Research Institute of Mining and Metallurgy implemented a research program on mine site rehabilitation. Research activities included the studies on dam stability, tailings dam integrity against water pollution, rehabilitation design, revegetation, dust control, community development and public health. The program has established two demonstration sites: one for agricultural use in Hujiayu Mine in Shanxi Province using a loess cover and another a direct planting site on Wugongli Tailings Pond in Anhui Province. In addition, the program also established a modern environmental laboratory and greenhouse. An acid-proof rehabilitation design for a site in Yingping Mine in Jiangxi Province was also established to investigate acid mine damage. Moreover, the stability designs for No. 2 Tailings Pond of Dexing Copper Mine in Jiangxi

Province were also accomplished. At Qian'an Iron Mine in Hebei Province, the arid resistant plant species *Salix mongolica* has been established under the conditions of annual precipitation of 200 mm. After four years, the plant has grown well and reached a height of 2 m high with intensive root systems. This has effectively controlled dust pollution previously caused by the tailings (CARIM 1997).

Focus on Research Problems

Although mine site rehabilitation practice can be dated far back, it was in the late 1970s and early 1980s that rehabilitation and application work properly began. During the past ten years, the most active aspects and achievements made in mine site rehabilitation include selection, improvement and cultivation of appropriate pioneer plant species; planting techniques; fertilizer implementation and soil improvement; physiology and ecology studies on grass-bush-tree mixed planting; optimization of rehabilitation mode; fast ecological restoration of local eco-systems; the applications of computer assisted design (CAD); and geographic information system (GIS) in mine site rehabilitation; the development of biological approaches and erosion-resistant rehabilitation processes; clean mining technology and mine site ecological protection; long-term stability of post-rehabilitation landscapes; sustainability of revegatated ecological systems; biodiversity; long term control and management of mine wastes and the establishment of checking standards to identify the sustainability of the local eco-systems produced (Dai and Ren 2000).

Ten years have been passed since "Regulations on Land Rehabilitation in the People's Republic of China" were promulgated. Since then considerable progress and achievements have been made in the field of mine site rehabilitation. About 1 million ha of various kinds of wastes or disturbed lands have been restored and utilized in China, which amount to 8% of the total. Among them, the mining industry has reclaimed over 0.4 million ha, accounting for 10% of the total derelict lands in mining industry. Nevertheless, many problems still exist. These problems include: In what way can we accelerate the pace of minesite rehabilitation in China? How can we meet the objectives on restoring degraded land resulting from mining practice, which are set out in "Land Management Law", "Mineral Resources

Law" and "Environment Protection Law" of the People's Republic of China? How can sustainable development in the mining industry be realised? Investigations are needed to support this work, especially on reasons for success and failure, so that it is scientifically rather than empirically based. Technical debate should be carried out before restoration for destroyed land, on principles of design which ensure sustainability. Establishing technical standards for restoration is particularly important, so that shortsighted views dominated by short term economic benefit can be avoided.

Mine site rehabilitation is an emerging new environmental protection industry with broad market and development prospects in China. It will promote both social stability and economic development in the mining regions.

The total amount of disturbed land due to the mining industry has reached 2 million ha with an annual increment of 30,000 ha. There will be more than 100 tailings ponds needing ecological restoration during the state period of "Tenth-Five" Planning (2001-2005) (Ministry of Science and Technology 2001) in China. As the rate of rehabilitation is only 8% in the year 2000, heavy tasks are awaiting us (Group of Tailings Dam of Engineering 1980, China Non-ferrous Metals Industry Corporation 1990, Sijing 2000, UNEP 1998).

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Chapter 20

Control of Agricultural Land Degradation in Sri Lanka

R.B. Mapa

Introduction

Land is a limited natural resource in Sri Lanka, primarily used for agriculture. The total land area is 6.56 million ha, of which only about 3 million ha are arable, due to unsuitable terrain, forest reserves and inland water bodies. In 1870 when the population was 2.7 million the per capita land area was 2.7 ha. Based on the present estimated population of 18 million, the per capita availability of arable land has reduced to about 0.15 ha, indicating heavy pressure on agricultural lands. When the land use is viewed from the forestry perspective, the forest cover has been declining throughout the years in Sri Lanka. The forest cover, which was 90% during 1900 when the population was 3.5 million, declined to 50% in 1953 with increase of population to 8 million and further reduced to 23% in 1982 when the population was 15 million. At present the forest cover is estimated as less than 20% with a population of 19 million. This is much less than the world average of 30% forest cover. More and more forests with fertile soils are being converted to agricultural lands due to demographic and political pressures. Of the present forest cover in the country only 9% is in watershed areas showing the importance of relocating them to environmentally sensitive regions. Measures must be taken therefore to arrest land degradation and to improve already degraded lands to feed the increasing population.

The main reasons for land degradation are soil erosion by water, reduction of organic matter and plant nutrients leading to fertility decline, salinization caused by improper water management, and soil compaction. Soil erosion is the major factor responsible for land degradation in Sri Lanka where more than 33% of the land is exposed to erosion

(Nayakekorala 1998). Soil erosion rates as high as 40 to 200 Mt $ha^{-1} yr^{-1}$ have been reported from lands under vegetable and tobacco cultivation in up-country areas (Anon 1991). Krishnarajah (1984) documented that as much as 30 cm of top soil has been lost from upland areas of Sri Lanka over the past century, which is equivalent to 40 Mt $ha^{-1} yr^{-1}$. The most recent estimate suggests that on and off site losses due to soil erosion are about US$ 40-50 million annually. The impact of soil erosion on irrigated agriculture due to sedimentation, and damage to irrigation channels are estimated at US$ 5 million per year (Griggs 1998). These are very conservative estimates, excluding intangible offsite losses resulting from events such as flooding, impact on health and recreation. The inadequate attention to land management leads to serious environmental problems such as siltation of reservoirs, pollution of ground and surface water bodies, land slides and threats to bio-diversity.

The changes of the area occupied by major crops reflect the land degradation in the country. As an example, from 1946 to 1992, tea, rubber and coconut lands decreased by 10%, 25.5% and 10.6% respectively while the increase was only in lowland paddy lands, amounting to 8.7%. According to the Central Environmental Authority of Sri Lanka the major environmental issues regarding to land are directly or indirectly related to soil erosion (Anon 1991). These include inadequate attention paid to the conservation of lands above 1,550 m elevation, continuous practice of shifting cultivation which still covers about 15% of land area, encroachment of hydrologically critical areas such as streams and reservoir reservations, and degradation of large areas of tea lands in the plantation sector. All these show the importance of understanding the present status of land degradation. This will lead to proposals for controls to arrest the land degradation in the future, maintaining soil fertility as well as environmental conservation. The objective of this chapter is to evaluate the present status of land degradation in Sri Lanka and propose control strategies.

Soil Erosion

Even though the major cause of soil degradation is listed as soil erosion, not much research work has been done on this aspect. Krishnaraja (1988) has reported soil erosion rates measured under different land use systems in four agro-ecological regions of Sri Lanka (Table 1). The wet, intermediate and dry zones refers to areas receiving mean annual rainfalls of >2,500 mm, 1,750 – 2,500 mm and less than 1,750 mm. Up country, mid country and low country refers to elevations of >1,000 m, 300-1,000 m and <300 m above sea level.

As seen from these data all these rates are high and exceed the tolerable limits. Krishnaraja (1988) also showed that well managed tea with conservation practices could reduce the soil loss to 0.24 t ha^{-1} yr^{-1}. The least soil erosion rate was observed in the mixed home gardens in the mid country wet zone, where many multi-purpose tree species are grown. In this system plant canopies at different heights protecting the soil from erosive rainfall, as well as mulch layers reducing the surface run-off, minimize the soil loss. The tolerable soil erosion rates, which are the allowable soil losses without causing decline in soil fertility status were estimated by Krishnarajah (1984). These were estimated using the existing rooting depth, the soil organic matter content and the clay content (Table 2). Environmentalists, with the argument that even a minimum rate of soil erosion causes damage to areas down stream due to sedimentation and pollution, do not accept these limits.

Table 1. Measured soil erosion rates under different land uses without any soil conservation measures in four agro-ecological regions of Sri Lanka

Agro-Ecological Region	Land Use	Soil Loss (t ha^{-1} yr^{-1})
Mid country - wet zone	Seedling tea	40
	Mixed home gardens	0.05
Mid country - intermediate	Tobacco	70
	Vegetables	18-38
Up country - wet zone	Vegetative propagated Clean weeded tea	53
Low country - dry zone	Sorghum/pigeon pea	21
	Cotton	22

Table 2. Tolerable soil loss rates for different soils of Sri Lanka

Agro-Ecological Region	Soil Order	Potential Rooting Depth (cm)	Tolerable Soil Loss ($t\ ha^{-1}\ yr^{-1}$)
Up country - wet zone	Ultisols	180-240	13.2
Mid country - wet zone	Ultisols	120-150	9.0
Low country - dry zone	Alfisols	90-150	6.7

Most of the eroded soil causes sedimentation of reservoirs down stream causing siltation, while the finer particles interfere with power-generating equipment. This water is subsequently released for irrigation in the dry zone where these finer particles causes many off-site environmental problems. It is documented that in the Mahaweli irrigation system the Polgolla reservoir has silted to 40% of its capacity in 12 years after its commissioning. Dhramasena (1991) reported that nearly 60% of the capacity is lost in most of the village tanks in the dry zone due to siltation by soil erosion. The sediment yields from selected sub catchments of the Upper Mahaweli watershed as reported by Wallingford (1995) are shown in Table 3. As seen from these data, sediment yields are higher in lands which are disturbed annually for vegetable and potato cultivation than in permanent vegetation such as tea and home gardens.

These results give a clear picture of soil erosion in the country as the major soil degradation process. The worst affected area is the mid country, which ranges from 300-1,000 m elevation due to steep slopes, high rainfall intensities and more erodable soils. Not much work has been conducted in measuring soil erodibilities other than a value of 0.31 reported for tea soils by Greenland and Lal (1977) and the values reported by Joshua (1977) (Table 4).

Table 3. Sedimentation of selected catchments in the mid county wet zone of Sri Lanka

Sub catchment	**Area (km^2)**	**Land Use**	**Sediment Yield ($t\ ha^{-1}yr^{-1}$)**
Above Peradeniya	1,160	Tea, grassland	4.2
Above Plogolla	1,300	Tea, townships	3.4
Nilembe oya	61	Tea, home gardens	0.6
Victoria	1,800	Tea	3.4
Mahaoya	476	Vegetables	9.4
Uma oya	94	Vegetables	10.6

From this table it can be seen that the Sandy Regosils (Entisols) showed the highest soil erodibility and the Reddish Brown Latasolic soils (Ultisols) the lowest. These erodibility values are related to the fine sand, sand and silt fractions of the soil mineral particles, the organic matter content, slope, soil structural type and permeability (Wischmeier *et al.* 1971).

Table 4. Soil erodibility values for selected stations in Sri Lanka

Station	**Great Soil Group**	**Soil Taxonomic Equivalent**	**Soil Erodibility Factor (K)**
Ratnapura	Red Yellow Podzolic	Rhodudults	0.22
Katugasthota	Reddish Brown Latasolic	Ultisols	0.17
Katunayake	Sandy Regosols	Entisols	0.48
Anuradhapura	Reddish Brown Earths	Rhodustalfs	0.27
Kankasanthurai	Red Yellow Latasols	Oxisols	0.33
Batticaloa	Non Calcic Brown Soils	Haplustalfs	0.35

Control

The soil conservation methods that can be adopted include agronomic and mechanical measures. Agronomic measures are suitable for lands with low slope gradients and are inexpensive. These include growing of cover crops, mulching, selective weeding as well as planting on the contour. Many tea plantations are adopting large scale replanting of vegetatively propagated tea. During this time the land preparation should be done according to acceptable standards, with planting on the contour. The mechanical control measures include contour lock and spill lateral drains connected to leader drains to carry excess water. In addition to these, policy decisions taken by the government include the revision of the Soil Conservation Act of 1951 to accommodate current needs. These include better monitoring of agriculture lands, increase of fines for defaulters and protection of road and building construction sites. In addition, increasing incentives are offered to small farmers for soil conservation, farmers in erosion prone lands are being relocated, and private enterprises operating in erosion prone areas are being required to reinvest an adequate proportion of their profits in adopting erosion control measures.

Conservation farming practices will be introduced to lands under shifting cultivation, while other lands will be allowed to continue with traditional practices which are less harmful for the environment. The lands most degraded due to shifting cultivation will be released for forest rehabilitation projects. Where there is encroachment of hydrologically critical areas, the government plans to conserve 10% of the land area as hydrological reservations. In addition a soil database is being developed by line agencies. This can be used for land use planning at national, provincial and local levels leading to less land degradation in the future.

Fertility Decline

Fertility decline may take place due to reduction of soil depth, depletion of soil nutrients and organic matter. The removal of most fertile topsoil can reduce the yields of crops drastically. It is shown that removal of the first five cm of topsoil reduces the yield from 40% to 50% in many crops. Basnayake (1985) documented that during a five month observation period the N, P and K losses from a tea land on a 30% slope in the up country wet zone were 0.37, 0.87 and 0.045 kg ha^{-1} respectively.

The cation exchange capacity (CEC), organic matter content and available P for the surface layer of selected Sri Lankan soils are shown in Table 5 (Senarath *et al.* 1995). These are all cultivated soils and possess very low CEC values mainly due to their highly weathered nature. Mapa (1996) showed that most of the soils of Sri Lanka have a kaolinite and oxidic clay mineralogy and show low clay activity values. In such soils the only practical way to increase the CEC is by maintaining a higher amount of soil organic matter. The organic matter contents of cultivated soils are low due to its rapid decomposition in these tropical environments (Table 5). In addition the soils in the wet zone are mostly acidic, affecting the availability of essential plant nutrients. Nayakekorala and Prasantha (1996) showed that the nitrogen content of most cultivated soils is within a range of 0.19% to 0.14% while the exchangeable K values vary from 27 to 75 ppm.

The ways to overcome the degradation of soils by fertility decline include application of fertilizers to replenish nutrients lost by plant uptake and leaching, and maintaining a healthy organic matter content, and application of soil amendments and liming material for the acidic soils. Maintaining a higher organic matter level is beneficial in increasing soil physical, chemical and biological properties. While providing a part of plant nutrient requirements, organic matter improves CEC and aggregate stability, reducing erosion by wind and water. Instead of application of organic matter from external sources as straw or compost, agro-forestry systems in which nitrogen fixing trees are grown alongside crops to enrich the soil have become sustainable farming systems in countries as Sri Lanka.

Table 5. The soil organic matter content (OM), cation exchange capacity (CEC) and available P (Av. P) for selected Sri Lankan soils

Soil	CEC (C mol kg^{-1})	OM%	Av. P (ppm)
Rhodustalfs	11.3	1.2	4
Paleudalfs	2.7	0.9	30
Tropothents	4.7	1.4	7
Rhodudults	4.8	2.4	6
Plinthudults	4.2	2.0	31

Salinization

The salinity developed in Sri Lankan soils is due mostly to seawater intrusion in low-lying areas and improper water management. De Alwis and Panabokke (1972) reported that the area affected by salinity is around 18,000 to 45,000 ha. Salinity development is more common in irrigation systems without proper water management and drainage facilities. Electrical conductivity value of 32 ds m^{-1} was reported by

Punyawardena (1990) in Kirindioya irrigation system, while values of 23 to 60 have been reported by many other workers. As all these values exceed 8ds/m, these waters are classed as high in salinity according to FAO classification, and affect soil productivity. The best way to overcome salinity is by proper water management and training farmers not to overuse water, which results in the building of the water table.

Conclusion

The main reasons of agricultural land degradation in Sri Lanka are soil erosion by water, fertility decline, salinization and soil compaction. Soil erosion is the major factor responsible for land degradation where about 33% of the land area is exposed to soil erosion. The inadequate attention paid to soil erosion leads to serious environmental problems such as siltation of reservoirs, pollution of surface and ground water bodies, landslides and threats to bio-diversity. It has been documented that the erosion rates which are high in the mid country intermediate zone with a soil loss of 70 t ha^{-1} yr^{-1}, could be reduced to 0.24 t ha^{-1} yr^{-1} with soil conservation practices. The least soil loss is from the mixed home gardens with a rate of 0.05 t ha^{-1} yr^{-1} where the canopies at different heights intercept rain drops effectively. Most of the agricultural lands show higher soil loss rates than the tolerable soil losses estimated using standard methods.

The major control strategies include introducing agro-forestry systems and conservation farming, building up the organic matter content, and revising the Soil Conservation Act to accommodate the current needs. The Soil Conservation Act, an important piece of legislation in soil conservation strategies, was extended to cover road and building sites in addition to agricultural lands. Many watershed management projects to reduce soil erosion by mechanical and agronomic conservation methods, some funded by foreign donors, are being implemented successfully as pilot projects. In addition, integrated plant nutrient management systems using chemical fertilizers and organic manures in a complementary manner, better water management and improvements in drainage facilities to prevent soil salinization, and reduction in the use of heavy machinery, are being implemented.

In addition to all these management practices a major improvement will be developing the soil database which could be used for better land use planning. For a land use plan to be successful the agro-ecological approach depending on the land location has to be combined with slope classes, soil information and any specific limitation as presence of wetland or rocky areas, existing land use and land tenure as well as constraints to participation in planning and development.

For all these strategies to be successful there needs to be a serious and honest political will.

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Chapter 21

Coastal Land Degradation and Restoration Strategies in the Philippines

M.N. Lavides

Introduction

One-fourth to one-third of the gross domestic product of many coastal countries is produced in coastal and marine areas, through utilization of living and non-living marine resources for their goods and services, especially fish and energy production, transportation, recreation, medicines and other industrial development (Chua and Bermas 1999). The Philippines is one of these coastal countries and being an archipelagic country with more than 7,100 islands and a coastal length of 22,540 km is vulnerable to the stresses of a multiple-use zone. Aside from natural forces, the current pressures in coastal areas are resource depletion and environmental degradation and pollution brought about by population growth, migration, land conversion and development. These problems affect the sustainability of coastal and marine resources, and can further aggravate the social and economic conditions (Carpenter and Maragos 1989 in MPP-EAS 1999).

Currently, the Philippine coastal and marine resources are in a state of degradation, most notable of which are sedimentation and siltation, which subsequently decrease productivity and fish catches. Sedimentation and siltation can be traced back to land-based activities such as clearing of forests, mining, agriculture and other development activities.

Thus, the need for a broad-based coastal management which includes terrestrial based activities such as soil conservation technologies, is imperative.

The Philippine Coastal Environment as Affected by Land-based Activities

The source of threats to the marine environment from land-based activities that must be addressed, according to UNEP Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (Chua and Bermas 1999), are the following:

- i) sewage;
- ii) persistent organic pollutants;
- iii) radioactive substances;
- iv) heavy metals;
- v) oils (hydrocarbons);
- vi) nutrients;
- vii) sediment mobilisation;
- viii) litter;
- ix) physical alteration; including habitat modification and destruction in areas of concern

In the Philippines the important threats to the marine environment from land-based activities in the coastal areas are sewage, persistent organic pollutants, litter, sediment mobilization and physical alteration including habitat modification and destruction in areas of concern.

Sedimentation mobilization and physical alteration including habitat modification and destruction is rooted primarily in the widespread deforestation in the country. Deforestation is estimated to be at 550,000 ha per year or 63 ha of forest cleared per hour (IBON 1997). All in all, forest cover is down to 2.7% of its original state; only a mere 800,000 ha of old growth or primary forest is left. This is well below the estimated 40% forest cover needed to sustain the Philippines' growing population and economic activities (Lepiten-Tabao 2000).

The Philippines today is one of the most severely deforested countries in the world. The effects are felt in terms of erosion, siltation, uncontrolled flooding, wood shortage and water scarcity (Lepiten-Tabao 2000). DENR (1996) cites deforestation and agricultural activities as the traditional anthropogenic sources of siltation. For example, the deterioration of the fringing reefs in Bacuit Bay, Palawan has been attributed mainly to logging activities in the areas surrounding it.

In a 1993 study of the Bureau of Soils and Water Management, approximately 5.2 million ha of the country were classified as severely eroded (17% of the total land area of 30 million ha); 8.5 million ha moderately eroded (28% of the total land area) and 8.8 million ha were slightly eroded (30% of the total land area). Areas with no apparent erosion covered 7.1 million ha or 23.7% while 0.4 million ha or 1.3% were unclassified.

Similarly, a global project called Reefs at Risk, offers a stark warning of the pressure of human activities, including land-based activities, that poses grave danger to reefs on most of the world's oceans. Irreparable damage is occurring rapidly (Bryant *et al.* 1998).

Globally, 36% of all reefs were classified as threatened by overexploitation, 30% by coastal development, 22% by inland pollution and erosion, and 12% by marine pollution. When there threats are combined, 58% of the world's reefs at risk (defined as medium and high risk) (Bryant *et al.* 1998).

Southeast Asia contains one-quarter of the world's mapped reefs. Indonesia and the Philippines account for a major portion of these habitats. Reefs in both countries are noted for extraordinary high levels of diversity, each containing at least 2,500 species of fish. Studies suggest that only 30% of reefs of both countries are in good condition or excellent condition (as measured by live coral cover). Reefs at Risk results indicate that virtually all of Philippine reefs, and 83% of Indonesia's reefs are at risk. Because of the reef area they contain, coastal zone policy and management decisions made by these two countries will have a major impact on the global heritage of coral reef diversity of future generations (Bryant *et al.* 1998).

Sediment mobilisation and physical alteration can also be attributed to mining activities. As of September 1996, more than 100 mining claims (disguised as foreign Financial and Technical Assistance Agreements or FTAAs) cover land areas in the Philippines, not counting the land areas covered by small-scale mining operations (Lepiten-Tabao 2000). Many of the mining claims based on the map of FTAA applications are in the coastal areas.

Integrated Coastal Management

The need for a more comprehensive, coordinated and integrated approach in addressing the problems of multiple use conflicts and environmental degradation cited above, resulted in the development of a new environment and natural resources management mechanism three decades ago. Since the 1970s, this new mechanism has been operational in various forms, such as coastal resources management (CRM), coastal zone management (CZM), integrated coastal zone management (lCZM), coastal area management (CAM), integrated coastal area management (lCAM) and recently, integrated coastal management (lCM) (Chua and Bermas 1999).

Initially, ICM was conceptualized to address obvious multiple resource use problems rising as a result of increasing competition for the limited coastal and marine resources. It began with a conservation focus aiming at conserving the ecosystem and the marine flora and fauna. In recent years, ecosystem management and community-based management became an integral part of the ICM program. The operational modality, however, underwent various transformations and improvement as more resource management and environmental projects were being implemented (Chua and Bermas 1999). In the Philippines alone, more than a hundred community-based coastal management project units in mid-1990s were documented (Lavides 1998). The scope and operation covered by an ICM program has greatly widened as the resource management and environmental issues have become more complicated (Chua and Bermas 1999).

An Example of an Integrated Coastal Management Programme That Considers Land Degradation as an Issue

There are a number of coastal management initiatives in the Philippines that consider land degradation as an issue. The following example in Negros Oriental demonstrates almost equal focus on issues concerning artisanal fishermen and upland farmers, and includes land degradation, i.e., soil erosion.

The following program description was taken from Community-Based Resource Management in the Province of Negros Oriental, Philippines (2000).

A programme of community-based resource management was implemented in 1989-1992 in four provinces of the Philippines, including Negros Oriental, with funding from the World Bank, as part of the Central Visayas Regional Project. In 1993, the Provincial Government of Negros Oriental established a Resource Management Division to continue and expand the programme.

The community-based resource management programme is a priority programme of the said provincial government. It aims at environmental protection and rehabilitation to help improve the living conditions and the income of occupants of marginal forests, small-scale upland farmers and artisanal fishermen. Watersheds and municipal waterways are rehabilitated to turn them into productive resource bases using two technologies: agro-forestry/watershed management and near-shore fisheries. The communities are organized and mobilized as resource managers.

The introduction of agro-forestry/watershed management technology to marginal farmers aims at increasing their income by maximizing crop output and at the same time protecting the environment. Under the programme, each farmer is awarded a farm area and a Certificate of Stewardship renewable every 25 years. Agricultural crops are planted on 70% of he farm area, while 30% is reforested with tree seedlings. On-farm soil conservation structures (such as hedgegrows, contour bunds, rock walls, diversion canals) are built by the farmers to protect their farms against soil erosion, to prevent water run-off and siltation of marine waters and to improve land productivity.

The programme has also introduced artificial reefs, marine reserves, mangrove reforestation and (land-and water-based) micro-enterprise development to be managed by the local communities. These interventions were designed both to benefit the marine ecology and to provide additional income to fishermen. A renewable Certificate of Mangrove Stewardship for 25 years is awarded to fishermen-cooperators who maintain and managed sites for mangrove reforestation.

By August, 1995, the programme had assisted in the establishment and training of 73 small-fishermen's associations and fifteen farmers' associations.

Thus, the resource management programme is being able to address both the landward and the seaward environmental and livelihood concerns of this coastal province. Aside from what has already been mentioned about the soil conservation measures, the following section describes the soil conservation technologies which may be an integral component of coastal management programmes in the Philippines.

Soil Conservation Technologies in the Philippines

There are several approaches to soil conservation management strategies that can be an integral part of an integrated coastal management and whose goal can include the promotion of sustainable agricultural development. By these environmental risks such as flash floods, sedimentation, eutrophication and chemical contamination of adjacent surface water resources such as rivers and bays can be minimised.

The following soil conservation technologies were consolidated from JICA (1994) and Pulhin (2002):

1. Reforestation. This involves replanting of denuded forestlands that have been reduced to perennial grass communities by frequent burning. Although reforestation reduces land degradation, broadscale production forestry may be irrelevant as a land use to some farmers unless alternative economic opportunities can be provided for communities dependent on intensive agriculture.

2. Erosion control technologies. Most erosion control technologies promoted in the Philippines primarily concern the control of overland flow and soil movement and are both structural and vegetative in nature.

a) Structural barriers. These are physical barriers. to soil and water movement. They reduce surface runoff velocity by modifying slope length, slope gradient and trap sediments. The most common structural measures in the Philippines include:

1) Contour bunds. These are embankments (risers or humps) of stones, grasses or hard soil or combination of all these materials which are constructed along the contour of the land and which serve to slow and trap eroded soil. Hedgerows are usually planted on top of the bunds to reinforce them, e.g. guinea grass *(Pennisetum maximum)*, napier *(Pennisetum purpureum)*, vetiver *(Vetiveria zizanoides)* and leguminous shrubs *(Leucaena leucocephala, Leucaena diversifolia, Gliciridia sepium, Flemingia macrophylla, Desmodium rensonii, Calliandra spp., Desmanthus sp.)*. These plants are used as a source of biomass for green manuring and/or forage in a cut-and-carry system for penned livestock. Animal manure may be returned to the field.
2) Contour rockwalls. These are constructed by collecting the rocks lying on or near the soil surface and using them to construct a 0.5 to 1 m rock wall running on the contour. Contour rockwalls are constructed at regular intervals down the slope. Walls may be stabilized by planting grasses, shrubs or trees at the lower base of each wall. These plants are again used as a source of biomass for green manuring and/ or forage in a cut-and-carry system for penned livestock. Animal manure may be returned to the field.
3) Bench terracing. There are several forms of bench terracing, namely, backward sloping, forward-sloping or level bench terraces. Terraces are constructed using the cut and fill method.

b) Vegetative barriers. These involve the management of vegetative cover to protect the soil from erosive rainfall or runoff.

1) Hedgerow intercropping. This is the most common vegetative barrier promoted in the Philippine uplands. Hedgerow intercropping is an agroforestry technique, which, in its conventional form, involves the cultivation of annual crops between contoured hedgerows of perennial shrub or tree species, usually legumes.
2) SALT. Adaptations of hedgerow intercropping have resulted in different variants. The most common is the Sloping Agricultural Land Technology (SALT) which has become the most widely promoted conservation technology. SALT is a modular hedgerow intercropping technology involving the cropping of cereals (corn, rice, sorghum) and legumes (soybean, mungbean,

peanut) and permanent crops (coffee, cacao, citrus and other fruit trees).This forms the basis for soil conservation activities of the Department of Environment and Natural Resources and the Department of Agriculture. Several NGOs likewise initiate SALT and SALT-derived farming systems. Hedgerow intercropping continues to be the focus of most research and extension efforts aimed at promoting soil conservation in the Philippine uplands. Hedgerow intercropping appeals to researchers and extensionists because it provides a method with potential to integrate the benefits of tree cover into intensive agricultural systems.

There are currently four variants of SALT. SALT I -Sloping Agricultural Land Technology. SALT II- Simple Agro-Livestock Technology, SALT III -Sustainable Agroforest Land Technology and SALT IV- Sloping Agro-Fruit Land Technology.

c) Supplementary structural measures. These are structural measures that are implemented in association with the main structural or vegetative soil conservation structures and are usually on localized portions of a farm.

1) Contour canals. They are usually implemented in association with contour bunds or contour hedgerows. Contour canals are used to hold water on fields, increasing the time for water to percolate into the soil and thereby increase soil moisture and ground water supplies. They may also be used to drain excess water from fields.
2) Drainage canals. Contour canals should lead into a drainage canal which is built at the top of a farmer's field and passes down one side to the bottom. These are also implemented with contour bunds or contour hedgerows.
3) Soil traps. They are pits in a gully or drainage canals used to slow runoff and trap eroded soil before it leaves the farm.
4) Check dams. They are physical or vegetative barriers placed in drainage canals and eroded gullies use to slow runoff, prevent erosion and trap eroded soil before it leaves the farm.

d) Agronomic measures and soil fertility management. These involve the management of crop cover and the modification of cultivation practices to protect the soil from raindrop impact and overland flows. In many areas, agronomic measures and soil fertility management technologies are also promoted to supplement the physical and vegetative soil conservation technologies. These include crop rotation, multiple cropping, green manuring, fertilizer management and various methods of composting (trench composting, double digging, basket composting, compost piling and soil reconstitution).

Conclusion

When the main options to maintain or restore the biophysical, parameters of land, including forest areas, agricultural land and river basins are considered in coastal management, the on-site restoration effects move spatially to off-site environments such as the mangroves, sea grass and coral reefs. These main options include reforestation, erosion control technologies such as structural barriers, vegetative barriers and agronomic barriers. Siltation and sedimentation of the marine ecosystem are therefore largely prevented, ensuring sustainability of ecosystem goods (e.g. fish, tree) and ecosystem services or processes including the productivity cycles and hydrological cycles.

Therefore, there are several dimensions of integration that can be included in ICM such as integration among sectors, integration between the land and the water sides of the coastal zone, integration among levels of governance, integration among nations and integration among disciplines.

Land-based resource management activities such as soil conservation technologies are just as important as water-based activities particularly in archipelagic and other coastal countries like the Philippines.

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Chapter 22

The Assessment and Management of Acid Sulfate Soils in Bangladesh in Relation to Crop Production

H.R. Khan, M.M.A. Bhuiyan, S.M. Kabir, F. Ahmed, S.M.A. Syeed and H.P. Blume

Introduction

The majority of acid sulfate soils are located in recent coastal marine sediments of the tropics and subtropics. Among the world distribution of about 24 M ha of acid sulfate soils, about 7 M ha are found to occur in Asia and Far East, about 3 M ha are in the coastal zones of Australia, about 2.3 M ha are in the Mekong Delta of Vietnam (White *et al.* 1996) and about 0.7 M ha are located in the coastal areas of Bangladesh. The areas in Bangladesh were once occupied by dense mangrove forest. Now about 95% have been cleared for agricultural cultivation. As a result, the potential acid sulfate soils have become actual acid sulfate soils with very poor yields. They generate H_2SO_4 that brings their pH from 6-7 to below 4, sometimes to as low as 2. The acid leaks into drainage and floodwaters, corrodes steel and concrete, and attacks clay, liberating soluble Al. Drainage waters may also be enriched in heavy metals and arsenic, a toxic cocktail endangering aquatic life and public health. Soil solutions can be extremely toxic to plants so that extremely low crop production can occur for lengthy periods (Dent 1986). Losses due to fish kill in the coastal plains of Bangladesh were about US$ 3.4 million during 1988-1989 (Callinan *et al.* 1993).

The weathering of sulfidic mine spoils and overburdens present the same problems. Accordingly, descriptions of acid sulfate soils and techniques to manage them have been put forward. However, until now, the reclamation and management of these soils has not been successful. Conventional reclamation of acid sulfate soils through liming and leaching is not sustainable (Khan 1994). Construction of raised beds is important in management practices of the soils, but not always successful, because success depends on several attributes of the soils, especially their position and environmental conditions. Against this background, the objectives of the present investigation were (i) to characterize the acid sulfate soils in relation to acidification; (ii) to identify suitable reclamation measures for the soils; (iii) to screen different crops for tolerance; and (iv) to find alternative land use options.

Materials and Methods

Eight series of acid sulfate soils were studied on the basis of land type, land use and hydrological conditions and having the acid forming jarosite layer at different depths (Table 1). Pits approximately 1.2 m deep were dug, depending on the ground water level. Bulk samples obtained from every 10 cm up to 100 cm were stored under field moist conditions prior to laboratory analysis, when the sub-samples were air-dried and crushed to 2 mm. Water samples were also collected from the nearby ponds and ditches of the sampling sites and analyzed (Table 1) following standard methods. The soils of Cheringa and Badarkhali series were selected for further study using pot and field experiments to find out suitable reclamation and management techniques. Their physicochemical properties are presented in Table 2.

Table 1. The areas studied and selected properties of their soils and waters

Land Description				Soil Analyses						Water Analyses	
Soil Series	Land use	Texture	Jarosite layer (cm)	Depth (cm)	pH (1: 2.5) Field	pH (1: 2.5) $CaCl_2$	EC(1:5) mS/cm	O. M. (g/kg)	Total-S (g/kg)	pH	EC (mS/cm)
Cheringa	Fallow	SiCL	10+	0-10:100	3.1-4.6	2.7-4.0	1.3-2.4	28-48	27-47	2.4	2.8
Badarkhali	Rice-Fallow	SiCL	20+	0-10:100	3.8-4.5	3.3-4.3	1.6-2.7	18-39	21-38	3.8	2.2
Harbang	Rice-Fallow	L	60+	0-10:100	4.6-5.4	4.2-5.0	0.3-1.0	14-27	14-27	6.6	0.3
Noapara	Rice-Fallow	SiC to SiCL	90+	0-10:100	4.4-5.8	4.1-5.5	2.2-6.0	15-33	12-26	5.3	2.8
Chakaria	Rice-Fallow	SiCL	30+	0-10:100	3.6-4.6	3.2-4.1	1.0-2.0	16-42	28-39	4.8	2.8
Kutubdia	Fallow	SiC to SiCL	30+	0-10:100	3.3-4.2	3.0-3.8	1.1-2.8	16-40	28-43	3.3	1.6
Dhurong	Fallow	SiC to SiCL	30+	0-10:100	3.2-4.3	3.0-3.9	1.9-6.6	17-35	27-38	5.5	2.8
Barabakia	Rice-Fallow	SiC to SiCL	80+	0-10:100	3.8-5.4	3.4-4.9	1.1-2.8	11-34	10-33	5.4	2.9

Table 2. Some physico-chemical properties of Badarkhali and Cheringa soils (0-20 cm)

Properties	Values		Unit	Properties	Values		Unit
	Badarkhali series	Cheringa series			Badarkhali series	Cheringa series	
Textural class	Silty clay loam	Silty clay loam		Magnesium saturation	6.6	5.6	%
Bulk density	1.10	1.03	mg m^{-3}	Base saturation percentage	24.9	22.2	%
Soil pH (Field Condition)	4.2	3.9		**Water soluble ions:**			
Soil pH (0.02 M $CaCl_2$=1:2.5)	3.4	3.2		Sodium (Flame photometry)	4.09	4.84	c mol kg^{-1}
EC (1:5 water)	1.6	1.9	mS cm^{-1}	Sodium (Flame photometry)	4.09	4.84	c mol kg^{-1}
Organic matter	31.3	40.3	m kg^{-1}	Potassium (Fla. photometry)	0.18	0.21	c mol kg^{-1}
C/N ratio	15.0	16.5		Calcium (AAS)	0.33	0.27	c mol kg^{-1}
Available N (1.3 M KCL)	3.27	3.65	m mol L^{-1}	Magnesium (AAS)	3.66	3.34	c mol kg^{-1}
Avail. P (0.002N H_2SO_4, pH 3)	0.11	0.11	m mol L^{-1}	Aluminum (AAS)	1.84	2.12	c mol kg^{-1}
CEC (1 M NH_4Cl)	19.6	18.2	c mol kg^{-1}	Iron (AAS)	0.30	0.33	c mol kg^{-1}
Aluminum saturation	43.2	42.4	%	Manganese (AAS)	0.10	0.10	c mol kg^{-1}
Iron saturation	7.8	8.3	%	Copper (AAS)	0.007	0.009	c mol kg^{-1}
Sodium saturation	14.8	13.4	%	Zinc (AAS)	0.008	0.009	c mol kg^{-1}
Potassium saturation	1.5	1.4	%	Chloride (0.05 M $AgNO_3$)	2.60	2.86	c mol kg^{-1}
Calcium saturation	2.0	1.8	%	Sulfate($BaCl_2$:Spectrophot.)	4.12	4.96	c mol kg^{-1}

Bulk samples (top soils of 0-20 followed by the sub-soils of 20-40 and 40-60 cm as in the field) were collected for pot experiments conducted at the premises of the Department of Soil, Water and Environment, University of Dhaka. 130 kg of soil, having aggregate sizes of either <20 or 20-30 mm, were placed in concrete containers (size: 0.6 x 0.6 x 0.6 m). The soils in each concrete container were leached for a week by tap and rain water 10 times to provide initial improvement of pHs from about 3.2 to 4.5 and EC values from about 10.5 to 2.0 mS cm^{-1}. The effects of basic slag (BS_{10} and BS_{20}: basic slag 10 and 20 t ha^{-1}), aggregate size (A_{20} and A_{30}: aggregate size of soil, <20 and 20-30 mm) and groundwater (Gw_0: no influence of groundwater and Gw_{50}: groundwater 50 cm beneath the soil surface) on the growth and yield of rice (BR 3: 3 plant/hill and 9 hills/pot) followed by mustard (10 plants/pot), and then chilli (2 plants/pot) and eggplant (2 plants/pot) grown on these soils in the subsequent seasons, were studied.

The effects of basic slag and aggregate sizes were also investigated in field experiments using three systems, 1) modified Plain (plain land of acid sulfate soil), 2) Ridge (raised bed of 0.6 m from plain land, which had been made by raising different layers of 20 cm of soils through excavation of soils), 3) Ditch (approximately 0.6 m deep ditches constructed to act as drainage disposer or reservoir) using two techniques. In Technique I sulfidic materials were placed on the top 20 cm of the ridges having been slit for application of agricultural lime; and in Technique II sulfidic materials were placed under 20 cm of the top soils on the ridges having the same slit.

The potential and effectiveness of sulfidic materials, in comparison to gypsum and magnesium sulfate, as a source of sulfur for rice, tomato and onion grown on two sulfur deficient soils were evaluated in further pot experiments. The levels of significance of different treatment means were calculated by Duncan's New Multiple Range Test (DMRT).

Results and Discussion

The pHs of the Badarkhali soils in the pot experiment were increased strikingly after one month by the different treatments and continued up to two months in most cases and then gradually decreased up to four months after transplantation of rice (Table 3). The initial pH (dry) of the soil was 3.9. The individual effects of basic slag, aggregate size and groundwater levels raised the soil pHs significantly ($p \leq 0.05$). However, their combined application was more effective. The application of BS_{20} was more effective than that of BS_{10} and a similar effect was also recorded in the presence of Gw. Smaller size of aggregates caused a greater ($p \leq 0.05$) increase in soil pHs than those with the larger aggregates.

The pH increments were all rather less in the Cheringa soil. There was a decreasing tendency of soil pH to be raised after a certain period. This might be due to the change of potential acidity with time into actual acidity in the acid sulfate soils. The desired increments of soil pH are likely be due both to the wash out of sulfidic materials and formation of insoluble sulfate compound like gypsum, gibbsite, allunite, akaganite, etc. with the addition of basic slag (Bigham *et al.* 1990). The significant impact of smaller aggregate size (20 mm) on the increment of soil pH may be attributed to the faster leaching of sulfidic materials as a result of smaller aggregate size and quick formation of insoluble sulfate compounds. Groundwater level (Gw_{50}) 50 cm beneath the soil surface was found to increase the pH values by about 0.2, or in some cases by more than 0.5, suggesting that the maintenance of low Gw, by an open system helps in oxidation and the leaching of resultant acidity.

Table 3. Changes in the pH of Badarkhali soil at different stages of growth of rice as influenced by basic slag, aggregate size and ground water levels

Treatment		Soil pH at different periods of time				
No.	Denotation	O Day	1 month	2 months	3 months	4 months
T_1	$A_{20}Gw_0BS_{10}$	4.1	5.1	6.4	5.1	4.7
T_2	$A_{20}Gw_0BS_{20}$	5.2	6.4	6.6	6.1	5.2
T_3	$A_{20}Gw_{50}BS_{10}$	5.6	6.8	6.7	6.8	4.7
T_4	$A_{20}Gw_{50}BS_{20}$	5.7	7.0	7.2	6.9	4.9
T_5	$A_{30}Gw_0BS_{10}$	4.8	5.6	5.6	5.4	4.8
T_6	$A_{30}Gw_0BS_{20}$	4.6	6.0	6.5	6.3	5.0
T_7	$A_{30}Gw_{50}BS_{10}$	4.6	5.8	5.8	5.5	4.8
T_8	$A_{30}Gw_{50}BS_{20}$	5.2	5.5	5.9	5.7	5.0

A_{20} and A_{30} = Aggregate sizes of <20 and 20-30 mm; Gw_0 = No influence of groundwater, Gw_{50} = Groundwater 50 cm beneath the soil surface; BS_{10} and BS_{20} = Basic slag at the rates of 10 and 20 t ha^{-1}

In the subsequent seasons, in the Cheringa soil the maximum yields of rice, mustard, eggplant and chilli were produced by the combined application of $A_{30}Gw_{50}BS_{20}$ (Table 4). The application of basic slag (BS_{20}) was found to be the best among the individual treatments followed by $BS_{10} > Gw_{50} > A_{30}$. The application of BS_{20} increased the grain yield by 100% at A_{20} and by 122% at A_{30}. But in the presence of Gw_{50}, those increments were 138 and 246% at A_{20} and A_{30}, respectively. The larger aggregate size (30 mm) within the 4 months growing period was found to increase the growth and yield of rice regardless of treatment. The best yields of mustard were attained by the combined application of $A_{30}Gw_{50}BS_{20}$ in both the soils. The application of basic slag was found to be more effective among the individual treatments in increasing the fruit yields of eggplants in both the soils. However the effect of BS_{20} was more than BS_{10} in the Cheringa soil. The maximum fresh weight of eggplant was recorded by the $A_{20}Gw_0BS_{20}$ treatment in Badarkhali soils. In Cheringa soil the maximum fruit yield was obtained by the $A_{30}Gw_{50}BS_{20}$ treatment. The individual application of basic slag, aggregate size and groundwater levels were found to have significant ($p \leq 0.05$) effect on the fruit yield of chilli. The largest yield of chilli was obtained from the $A_{30}Gw_0BS_{20}$

treatment in Badarkhali soils, while in Cheringa soils the maximum was recorded by the $A_{30}Gw_{50}BS_{20}$ treatment

Table 4. The effects of basic slag, aggregate size and ground water levels on rice, mustard, chilli and eggplant grown on pre-leached Baadarkhali acid sulfate soil in the subsequent seasons

Treatment		Rice			Mustard		Chili		Eggplant	
No.	Denotation	Straw (t/ha)	Grain (t/ha)	Grain (% IOEC[a])	Yield (g/pot)	% IOEC	Yield (g/pot)	% IOEC	Yield (g/pot)	% IOEC
T_1	$A_{20}Gw_0BS_{10}$	2.21	1.67	-	1.4	-	102.9	-	853	-
T_2	$A_{20}Gw_0BS_{20}$	3.32	3.33	99.4	4.9	250	135.3	31.48	1178	38.10
T_3	$A_{20}Gw_{50}BS_{10}$	2.78	2.42	44.9	1.8	28.57	61.9	-39.84	697	-18.28
T_4	$A_{20}Gw_{50}BS_{20}$	4.32	3.98	138.3	3.3	135.71	56.3	-42.28	822	-3.63
T_5	$A_{30}Gw_0BS_{10}$	4.46	3.71	122.2	2.8	50	113.0	9.82	637	-25.32
T_6	$A_{30}Gw_0BS_{20}$	5.85	5.41	224.0	3.7	164.28	180.2	75.12	475	-44.31
T_7	$A_{30}Gw_{50}BS_{10}$	4.80	4.18	150.3	3.0	114.28	105.1	2.14	558	-34.58
T_8	$A_{30}Gw_{50}BS_{20}$	7.08	5.78	246.1	5.1	264.28	104.5	1.55	716	-16.06

A_{20} and A_{30} = Aggregate sizes of <20 and 20-30 mm; Gw_0 = No influence of groundwater, Gw_{50} = Groundwater beneath the 50 cm of soil surface; BS_{10} and BS_{20} = Basic slag at the rates of 10 and 20 t ha^{-1}; % IOEC[a] = Percent Increase Over Experimental Control.

The average yields were also higher in Cheringa soil as compared to Badarkhali soil, which might be attributed to the initial high content of organic matter in Cheringa soil.

The application of basic slag was found to be the best among the individual treatments, agreeing with the results of Anderson *et al.* (1987) and Gashcho (1997). They showed that the application of calcium silicate slag substantially increase the yield of sugarcane, rice and rice-sugarcane rotation crops. Moreover, as basic slag contains a large amount of SiO_2, the rice plant may have absorbed a large quantity of Si, which is beneficial for the growth and yield of rice. Khan (1994) reported that basic slag from steel industry is effective in reducing soil acidity and also economic if it is available from local supply, because basic slag was found to increase soil solution pH and optimized the concentration of some elements like Ca, Mg in the growing media as well as containing large amounts of Si, which is beneficial for rice growth and also diminishes the toxicity of Al and Fe. Recently it has been reported that Fe_2O_3 may reduce CH_4 emissions. The application of basic slag is therefore not only effective for the reclamation of acid sulfate soil in relation to crop production but also in lessening global warming.

In the field trials, the land was prepared during November 1998 and exposed to sunlight and natural rain, and the soil pHs were found to increase with time regardless of system, treatment, technique or soil type. Soil pHs (dry) in the Badarkhali fields were increased from 2.7 to 4.8 and 3.3 to 5.0, respectively (Table 5) and similarly in the Cheringa fields (data not shown). Application of basic slag exerted significant increment on the pHs of soils and the effects were more pronounced with time. The BS_{20} treatment was found to be more effective in increasing the pHs of the soils in the later half (6-12 months) of the experiments. The increments of the pHs were more pronounced in both the soils with the technique II than in technique I. The pH of the sediments in the ditches decreased initially and then increased (Table 5). The effects of basic slag in Cheringa soil were similar to those in Badarkhali soil under, but the increments of pHs were not so pronounced. This might be attributed to the initial higher contents of total actual acidity in Cheringa soil than that of Badarkhali soil.

Table 5. Effects of basic slag, aggregate size and length of time on the distribution of soil pH $_{(dry\ 1:2.5)}$ under different techniques in field conditions at the Badarkhali site

Treatment		Depth	Technique – I				Technique – II			
No.	Denotation	(cm)	Initial	6 m	12 m	24 m	Initial	6 m	12 m	24 m
a. Plain system (Flood plain areas of acid sulfate soils):										
T_1	$A_{20}BS_{10}$	0-10:50	3.3-3.5	3.3-3.6	3.7-3.9	3.9-4.2	3.4-3.6	3.4-3.6	3.8-4.0	4.1-4.3
T_2	$A_{20}BS_{20}$	0-10:50	3.3-3.5	3.3-3.7	3.8-4.4	4.2-4.5	3.3-3.5	3.5-3.7	3.9-4.4	4.2-4.7
T_3	$A_{30}BS_{10}$	0-10:50	3.2-3.6	3.5-3.7	3.8-4.1	3.9-4.6	3.3-3.5	3.5-3.8	3.9-4.2	4.1-4.4
T_4	$A_{30}BS_{20}$	0-10:50	3.1-3.6	3.5-3.7	3.9-4.6	3.9-4.9	3.2-3.5	3.5-3.7	3.9-4.7	4.3-4.9
b. Ridge system (Raised beds of 60 cm from flood plain soils):										
T_5	$A_{20}BS_{10}$	0-10:50	3.2-3.4	3.3-3.8	3.8-4.4	4.0-4.6	3.1-3.5	3.5-3.9	3.9-4.5	4.0-4.9
T_6	$A_{20}BS_{20}$	0-10:50	3.2-3.5	3.3-3.8	4.0-5.0	4.1-5.3	3.2-3.5	3.4-3.8	4.0-5.3	4.1-5.5
T_7	$A_{30}BS_{10}$	0-10:50	3.1-3.4	3.4-3.8	4.0-4.5	4.2-4.8	3.2-3.4	3.5-3.9	3.9-4.7	4.0-5.1
T_8	$A_{30}BS_{20}$	0-10:50	3.1-3.5	3.4-3.8	3.7-5.2	4.0-5.4	3.2-3.5	3.5-3.9	4.0-5.4	4.1-5.5
c. Ditch system (Approximately 60 cm deep from the soil surface):										
T_9	Between T_5 and T_7	0-10	3.6	3.0	4.1	4.6	3.7	3.0	4.0	5.1
T_{10}	Between T_7 and T_3	0-10	3.5	3.3	4.0	4.2	3.7	3.4	3.9	5.2
T_{11}	Between T_6 and T_8	0-10	3.5	3.2	4.5	4.9	3.6	3.1	4.3	4.6
T_{12}	Between T_8 and T_4	0-10	3.4	3.4	4.3	4.8	3.6	3.2	4.0	4.8

A_{20} and A_{30} = Aggregate size of <20 and 20-30 mm; BS_{10} and BS_{20} = Basic slag at the rate of 10 and 20 t ha^{-1}.

These acid sulfate soils and associated waters show severe problems not only for crop production but also for human and aquatic life (Table 1). The high amount of organic matter and total sulfur contents in the subsoil suggests that the soils could be used as sufidic fertilizers or acidic materials especially for S-deficient or calcareous soils. About 7 M ha of agricultural lands are S-deficient in Bangladesh. Removal of the subsurface material could not only reclaim the acid soils but also bring benefit to farmers with opposite problems. In a further experiment using two sulfur deficient soils, the best growth and yield performance of rice, tomato and onion were attained by the application of sulfidic materials at the rate of 45 kg S ha^{-1} (SM_{45}) followed by SM_{30} (Table 6). These treatments not only enhanced the sulfur but also the organic matter status of the soils. The equivalent doses of gypsum (30 and 45 kg S ha^{-1}) were ranked 3rd and 4th in obtaining better crop yields in both the soils, though the effects were more pronounced in Gazipur soil. The application of SM had pronounced residual effects not only on crop yields but also on the organic matter and sulfur status of the soils during the subsequent seasons.

Table 6. The effects of sulfidic materials on sulfur and organic matter status of two S-deficient soils during first 4 months, and on yields of rice followed by tomato and onion

Treatment		Yield of rice (g/plant)			Tomato (g/plant)		Onion (g/plant)		Organic matter (%)		Total S (m M kg^{-1})		Available S (m M kg^{-1})	
No.	Denotation	Straw	Grain	Grain IOC(%)	Fresh Wt.	IOC (%)	Fresh Wt.	IOC (%)	30 Days	110 Days	45 Days	110 Days	30 Days	110 Days
Gazipur Soil: *Silty clay loam, pH 5.0, Organic matter 0.66%, Total sulfur 15.5 m M kg^{-1}, Available sulfur 0.31 m M kg^{-1}.*														
T_1	Control	5.21	4.12	-	57.6	-	30.96	-	0.68	0.53	15.51	15.13	0.35	0.21
T_2	$Gypsum_{15}$	5.61	5.00	21.35	58.4	1.49	41.6	34.36	0.71	0.65	18.96	18.73	0.42	0.25
T_3	$Gypsum_{30}$	5.95	5.12	24.27	63.1	9.68	42.22	36.36	0.71	0.69	19.53	19.24	0.47	0.27
T_4	$Gypsum_{45}$	6.48	5.32	29.12	78.1	36.65	46.6	50.51	0.79	0.88	21.23	20.92	0.58	0.36
T_5	SM_{15}	5.64	5.08	23.30	77.1	33.90	45.6	47.28	0.88	0.98	19.24	19.01	0.43	0.28
T_6	SM_{30}	5.84	5.20	26.21	117.0	103.3	54.94	77.45	0.96	1.03	21.17	20.97	0.57	0.37
T_7	SM_{45}	5.97	5.44	32.03	130.3	126.4	65.67	112.1	1.02	1.12	26.41	25.67	0.68	0.49
Sirajgonj Soil: *Silty loam, pH 6.1, Organic matter 1.3%, Total sulfur 13.9 m M kg^{-1}, Available sulfur 0.29 m M kg^{-1}.*														
T_8	Control	5.57	4.24	-	50.3	-	30.1	-	1.12	0.94	13.98	13.77	0.31	0.17
T_9	$Gypsum_{15}$	6.46	5.04	18.86	110.1	9.84	39.10	29.90	1.18	0.98	17.56	17.39	0.35	0.23
T_{10}	$Gypsum_{30}$	6.48	5.12	20.75	135.2	34.83	41.68	38.47	1.06	0.86	18.72	18.54	0.41	0.27
T_{11}	$Gypsum_{45}$	6.5	5.20	22.64	141.3	40.91	51.00	69.43	1.01	0.90	20.63	20.25	0.48	0.31
T_{12}	SM_{15}	6.12	4.84	14.15	122.2	21.89	54.47	80.96	1.21	1.09	19.41	19.11	0.44	0.29
T_{13}	SM_{30}	6.16	5.24	23.58	140.6	40.24	60.40	50.6	1.33	1.23	21.11	20.89	0.53	0.37
T_{14}	SM_{45}	6.48	5.32	25.47	149.7	49.30	62.0	105.9	1.42	1.36	23.42	22.21	0.62	0.46

Conclusions

Application of basic slag to the two acid sulfate, Cheringa and Badarkhali, soils under a modified Plain-Ridge-Ditch system was found to be the best among the treatments tested for the reclamation of acid sulfate soils and for the responses of crops. Basic slag not only increased the soil pH but also optimized the concentration of calcium, magnesium and phosphorus. Aggregate size and groundwater were also found to be effectively improved for better growth and yields of crops.

At the opposite extreme application of sulfidic material as compared to gypsum as a source of sulfur was shown to be potentially valuable for the improvement of fertility and productivity of sulfur deficient soils. But further field research is essential. The high organic matter (1.5-5.5%), total-sulfur (3-5%) and micro-nutrients of these acid sulfate soils deserve attention to use these soil materials for the reclamation of alkaline, calcareous or sulfur deficient soils. The high Mg and Al contents of the soils may be valuable for tea plants and nursery crops.

But since the sulfide layers in acid sulfate soils can exert severe effects on surrounding ecosystems, immediate steps should be taken to consider these soils further.

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Chapter 23

Land Degradation in Suburban Agrarian Environment and Entry of Toxic Metals into Food Chains

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Introduction

Application of urban domestic and industrial effluents to enhance agricultural production but leading to land degradation is a common feature in suburban lands in India. A study conducted in the suburban and contiguous rural areas of Bangalore City, subjected to decades of land application of river water contaminated by urban effluents revealed widespread contamination of water, soil and plants by heavy metals. The high level of metals in water and soils have lead to accumulation of heavy metals by plants even in their edible parts and made them unfit for animal/human consumption. The contaminated lands have to be taken out of agricultural crop production to prevent entry of toxic metals into the food chain.

Land degradation by pollution has at last started to receive public attention in India. Studies reported in scientific literature point to widespread land degradation in urban, suburban and contiguous rural areas caused primarily by land disposal of urban domestic and industrial wastes (Azad *et al.* 1986, Gupta *et al.* 1990, Jeevan Rao and Shantararam 1999, Jeybhaskaran and Sreeramulu 1996, Som and Gupta 1994). Urban conglomerates generate a large volume of waste, both industrial and domestic, solids and effluents. Solids are disposed off as land fills whereas effluents are often discharged into urban drainage systems which in turn finds its way to streams and rivers. The contaminated water is used for irrigating arable lands in suburban and rural areas for production agricultural crops. The contaminated water, though rich in production agricultural crops. The contaminated water, though rich in plant nutrients, contains appreciable amounts of toxic metals, inorganic chemicals and biologically toxic materials.

The following are the results of a study conducted in suburban agrarian lands of Bangalore City, a large urban conglomerate of South India. This can be considered a typical scenario, repeated in almost all suburban lands of India.

Materials And Methods

Bangalore urban, suburban and contiguous rural areas can be conveniently partitioned into three major drainage watersheds. The largest area is covered by Vrishabhavati watershed, drained by the river of the same name and its tributaries originating in the urban area itself. Effluents from two large industrial estates and urban domestic effluents are discharged into the river system. In the suburban and contiguous rural areas the contaminated river water is used for irrigating arable lands to grow food and fodder crops. In the study area lands irrigated with contaminated water were delineated with the help of topographic sheets and multidate satellite images. Water samples collected from the river and wells, soil and plant samples collected from contaminated and uncontaminated lands formed the material for study. All the samples were analysed for their heavy metal contents (Cu, Zn, Pb, Ni and Cr) using standard procedures. To determine metal content of water, the samples were digested with nitric acid and residue extracted in 1:1 HCl (APHA 1975). Plant-available Cu, Zn and Pb in soils were extracted by 0.05 M diethylene triamine penta acetic acid (Lindsay and Norvell 1978). 2 N HNO_3 was used to extract plant available Cr in soils (Reisenaur, 1982). For determination of total metal contents of soil the procedure involved pre-digestion of 1 g of soil followed by multiple treatments with HF and $HClO_4$ at 200 ^{o}C and extraction of the residue with 1:1 HCl (Jackson 1967). The metals brought into solution were estimated using atomic absorption spectrophotometry.

Results And Discussion

Contamination of water: Discharge of urban domestic and industrial effluents have turned the Vrishabhavati river water dark brown with suspended and dissolved organics and a host of inorganic contaminants. The pH of river changed from slightly acid to alkaline and salts added through the effluents resulted in increased electrical conductivity of the river water (Table 1). The metal load of the river water ranged as: Cu 0.10 to 0.25, Zn 0.18 to 0.52, Pb 0.06 to 0.15, Ni 0.05 to 0.80 and Cr 0.02 to 0.07 mg L^{-1}. The metal levels of open well and tube well water located in contaminated lands were also elevated, though much less compared to river water (Fig. 1).

Table 1. Reaction, conductivity and mean metal contents of water samples from polluted lands

Source	pH	EC	Total metal content mg L^{-1}						
	(H_2O)	dSm^{-1}	Fe	Mn	Cu	Zn	Pb	Ni	Cr
River	7.8	1.8	1.81	0.30	0.19	0.33	0.10	0.07	0.04
Tube well	8.2	1.5	1.52	0.35	0.01	0.03	ND*	ND	ND
Open well	7.9	1.3	0.12	0.03	0.01	0.03	ND	ND	ND

* ND – not detected.

Soil Contamination: The land area subjected to continuous irrigation with contaminated water is 1,450 ha mainly along the banks of the river. The major changes in soil brought about by irrigation with contaminated water were the dark grey colours, increase in soil pH, electrical conductivity, organic matter content and development of redoximorphic features. The soils, especially surface horizons have become enriched with organic carbon as a result of addition through contaminated water.

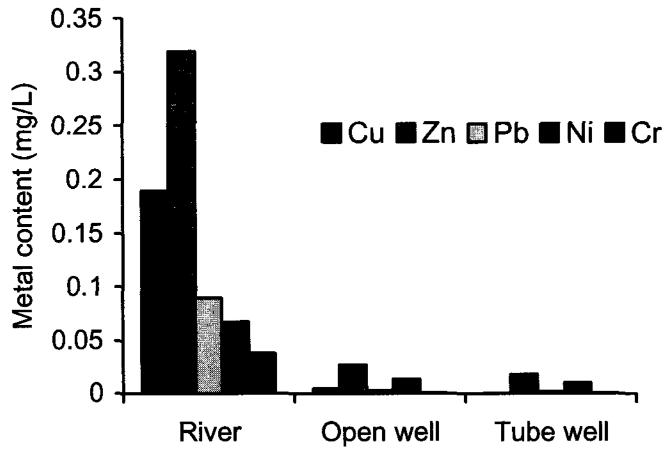

Fig. 1. Metal contents of water samples from three sources in contaminated lands.

Plant-available metals in soil: Plant-available metals in soils exhibited elevated levels in contaminated lands in comparison with samples from uncontaminated sites (Table 2, Fig. 2). Disposal of urban effluents on land has been identified as one of the major anthropogenic sources of toxic metals in soils (Ross 1994, Schirado *et al.* 1996, Som and Gupta 1994, Tiller 1989).

Table 2. Plant-available metals in surface soils (0-25 cm)

Metal	Metal in mg kg^{-1} soil							
	Polluted soil				Unpolluted soil			
	Mean	Max.	Min.	SD	Mean	Max.	Min.	SD
Cu	7.53	42.82	0.12	9.5	1.83	4.0	0.34	1.0
Zn	8.20	24.24	1.01	7.8	1.76	5.30	0.48	0.8
Pb	5.35	38.51	0.68	7.4	1.36	4.36	0.12	0.8
Ni	3.62	13.88	0.48	2.8	1.19	4.18	0.18	0.9
Cr	14.5	162.10	0.52	30.3	1.17	3.10	0.00	0.6

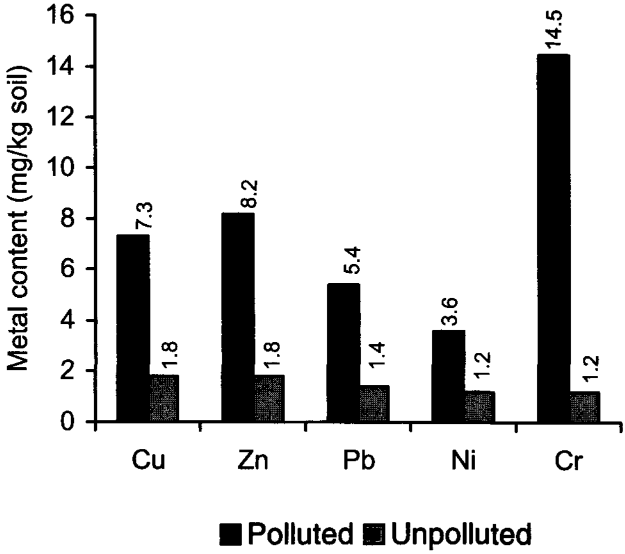

Fig. 2. Mean plant-available metal contents of soils from polluted and unpolluted lands.

Total metal content of soils: Total metal content of soils to a depth of 1.5 m or to the depth of occurrence of bedrock was determined for contaminated lands. The metal content of soil profile from contaminated and uncontaminated sites are presented in Table 3 and Fig. 3. The soils of lands irrigated with contaminated water can be considered toxic with respect to most of the elements investigated. Plants grown in them will accumulate enough metals at toxic levels to make them unfit for animal or human consumption (Alloway 1968, Bohn *et al.* 1985, EEC 1986, Kabata-Pendias and Pendias 1984). Studies of metal content down the soil profile also indicated that metals are not only accumulated in surface horizon but considerable amounts may move down the soil column over a period of time with percolating water.

Metal content of plants: Plants grown in metal contaminated sites tend to accumulate them in their vegetative parts and through edible parts eventually find their way into animal/human food chain. The metal content of edible parts of plants collected from polluted and unpolluted lands is presented in Table 4 and Fig. 4. The metal content recorded for edible parts of many plants from the contaminated sites are beyond the threshold levels suggested by WHO (1993) for human consumption.

Table 3. Total metal contents of soil profiles from contaminated (Hoskerahalli) and uncontaminated (Ramanagaram) sites

Site	Depth	Total metal in mg kg^{-1} soil				
	(cm)	Cu	Zn	Pb	Ni	Cr
Hoskerahalli	0-18	275.0	606.0	503.0	210.0	551.0
	18-36	168.0	156.0	87.0	236.0	460.0
	36-60	171.0	112.0	80.0	240.0	366.0
	60-90	144.0	108.0	34.0	228.0	194.0
	90-125	119.0	113.0	10.0	165.0	191.0
Ramanagaram	0-13	16.0	54.0	29.0	22.0	22.0
	13-33	18.0	60.0	16.0	28.0	37.0
	33-54	26.0	32.0	16.0	28.0	37.0
	54-95	24.0	22.0	8.0	18.0	32.0
	96-126	24.0	21.0	6.0	12.0	26.0

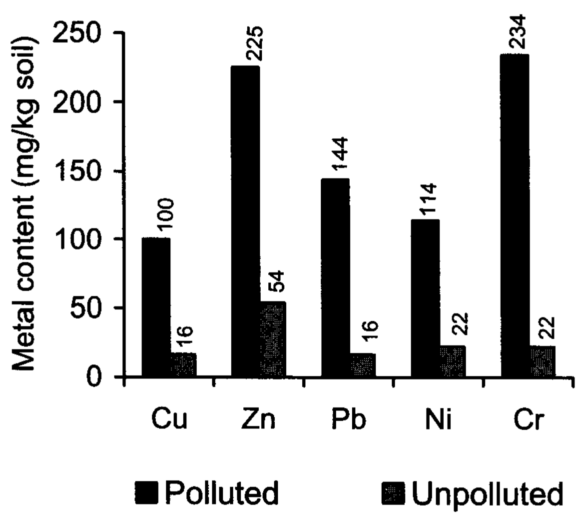

Fig. 3. Total metal contents (mean) of surface soils of contaminated and uncontaminated lands.

Table 4. Metal contents of edible parts of plants grown in contaminated and uncontaminated lands

Plant species	Metal in mg kg^{-1} dry weight				
	Cu	Zn	Pb	Ni	Cr
Amaranthus (*Amaranthus spp.*) leaves	8 (11)*	37 (22)	25 (tr)	22 (1)	11 (tr)
Bhindi (*Abelmoschus esculuntus*) fruit	7 (19)	78 (36)	35 (1)	13 (tr)	2 (tr)
Brinjal (*Solanum melongena*) Fruit	25 (17)	70 (39)	22 (3)	60 (1)	51 (tr)
Coffea (*Coffea robusta*) berry	11 (6)	38 (26)	9 (tr)	10 (tr)	32 (tr)
Maize (*Zea maize*) cob	6 (3)	57 (13)	30 (2)	18 (tr)	2 (tr)
Onion (*Alium sepa*) bulb	7 (21)	110 (29)	2 (tr)	5 (1)	3 (tr)
Pea (*Pisum sativum*) fruit	18 (9)	87 (29)	43 (tr)	45 (tr)	7 (tr)
Tomato (*Lycopersicon esculentum*) fruit	31 (13)	166 (31)	29 (5)	22 (1)	21 (tr)
Ragi (*Elusine corocana*) grain	7 (7)	44 (20)	2 (tr)	10 (tr)	10 (tr)
Rice (*Oryza sativa*) grain	12 (9)	34 (34)	2 (2)	2 (1)	2 (tr)

* Figures in parenthesis indicate metal contents of plants from unpolluted lands; tr-trace.

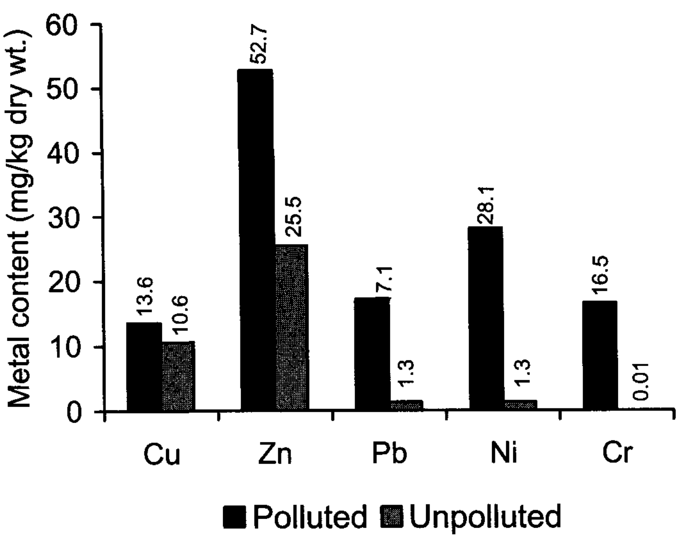

Fig. 4. Metal contents (mean) of edible parts of plants collected from contaminated lands.

Conclusions

The study has shown that disposal of urban effluents to streams and rivers pollute the river system and often make the water unfit for human/animal use in any form. Land application of the contaminated water can lead to metal accumulation in soils and possible transmission to ground water. Crop plants grown in contaminated lands accumulate metals in their edible parts affecting human food chain. Application of untreated urban effluent on cropland should be avoided and lands already contaminated require remediation.

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Chapter 24

Species Tolerance to Acidic Waste Ore Rock of Iron-Mining Areas along Yangtze River, Anhui Province

D. Hu, Z. Xi and Y. Han

Introduction

In China, wasteland reclamation researches in mining areas have made many achievements in recent years (Li 1995, Zhao 1993, Zhou 1995), following a large of pilot researches on restoration and reclamation in mines in other countries (Bradshaw 1997, Dobson *et al.* 1997, Fyson *et al.* 1994, 1998, Kalin *et al.* 1997, Pawlowski 1997). The restoration of vegetation in acidic wasteland of mining areas is a major area of investigation (Bradshaw 1997, Hu *et al.* 1999, Zhao 1993). Applying bioremediation techniques to facilitate the soil maturation on acidic waste ore rock is a key approach to native ecosystem restoration, and the experimental studies of species tolerance on typical acidic ore rock is important and necessary work for developing effective and applicable bioremediation techniques, which become the ecological basis for the improvement of the economic and social value of acidic wasteland in iron mines.

There are typically three basic techniques for the restoration of soil structure on wasteland in mining areas (Hu *et al.* 1999, Li 1995, Yu *et al.* 1996, Zhao 1993, Zhou 1995): (1) complete covering with topsoil, (2) topsoil addition in ridges; (3) topsoil addition in pits. These techniques are typically used in many mines all over the world. Up to the present, it has not been reported that using the direct planting of tolerant species improves the formation of soil in waste rock. It seems that such an application of direct planting is a promising approach to solving ecosystem restoration in waste rock at relatively low cost and satisfactory restorative speed. To make such an approach possible in Chinese iron mines, an understanding of tolerance of alien and native species to extreme acidity is very important.

This experimental study aimed at testing tolerant plant species that survive in acidic waste ore rock. By this a technical basis of bioremediation on acidic waste rock to realize ecosystem restoration in iron-mining areas along Yangtze River, Anhui province, can be developed.

Materials and Methods

Plant Species Selection

According to the characteristics of the native natural vegetation and the physical-chemical features of local natural soil, 26 plant species were selected in 1998. These species belonged to 14 families and included 3 species of herbaceous plants from 3 families. There were a total of 3780 experimental seedlings, of which 3,000 were one-year seedlings, 680 1-3 years seedlings and 100 herbaceous seedlings newly germinated. The seedling transplantation and seed sowing were finished before March 1998. The plant species selected are listed in Table 1.

The waste rock sampling followed site investigation. Samples were taken from Nanshan Iron Mine, Maanshan city, an open pit mining site in which the stripped waste rock had been piled up in a ringed form, and Shunfengshan Mine of Tongling, a deep mine in which waste rock had been piled up in a radiation shape away from the pit mouth.

The classification of samples is based on the original colors of the stripped rock, which were identified as Category I - Blue-gray magnetite rock, Category II – red sulfur rock, Category III – yellow kaolin rock, Category IV – mixed rock of the former three types. There were 4 samples taken in the 4 categories from the sites of Nanshan Mine, and 3 samples in Category I, II and III from Shunfengshan Mine. In addition, one sample was made by mixing the natural topsoil from the two mines. So there were 8 samples in total for the experimental studies. All the rock samples were wind-dried according to rock types, and then sorted using sieves of 20 meshes and 60 meshes.

Table 1. The plant species selected for experimental studies

Experimental number of plant species	Names of species
Evergreen species	
1	*Castanpsis sclerophylla*
2	*Cyclobalanopsis glauca*
3	*Cinnamomum camphora*
4	*Pinus massoniana*
17	*Ulmus parvifolia*
18	*Celtis tetrandra var.sinensis*
Deciduous species	
5	*Quercus acutissima*
6	*Quercus fabri*
7	*Quercus chieaii*
8	*Castanea seguinnii*
9	*Castanea mollissima*
10	*Liquidambar formosana*
11	*Platycarya strobilacea*
12	*Dalbergia hupeana*
13	*Robinia pseudoacacia*
14	*Amorpha fruticose*
15	*Pistacia chinensis*
16	*Choerospondias axillaris*
19	*Ailanthus altissima*
20	*Toona sinensis*
21	*Malia azedarach*
22	*Vitex negundo*
23	*Diospyros kaki var silvestris*

The experimental results showed that the physical-chemical features of the waste rock samples from the two iron mines were very different (Table 2). The samples from the former mine had relatively high content of total sulfur and organic matter, and low values of pH, and the samples from the latter mine had relatively low content of total sulfur and organic matter, and high values of pH. The content of heavy metals in the waste rock from the two mines were not high compared to the local natural soil, and potential toxicity to plant seedlings due to heavy metals was unlikely to be high.

Table 2. The physico-chemical characteristics of waste rock samples from the two iron mines

Sample number	1	2	3	4	5	6	7	8
Waste rock category	I	II	III	IV	I	II	III	
pH	3.2	2.7	5.8	4.0	8.2	7.7	8.0	5.7
Total S (%)	2.01	2.30	0.65	1.76	0.372	0.024	0.023	0.035
Available N (ppm)	29.4	13.6	26.6	3.5	29.7	58.4	20.2	68.8
Available P (ppm)	40.7	8.0	10.6	3.9	10.2	7.4	12.6	8.6
Available K (ppm)	10.0	12.4	62.4	19.6	108	98.4	97.9	101.0
Organic matter (%)	4.9	6.0	3.8	5.6	1.3	0.1	0.2	1.6
Zn (ppm)	48.0	34.0	239.0	111.0	49.0	223.0	69.0	130.0
Cu (ppm)	156.0	49.0	69.0	137.0	26.0	46.0	39.0	21.0
Ni (ppm)	11.7	9.1	13.7	14.6	14.7	29.7	27.1	19.6
Fe (%)	10.8	12.5	11.9	13.3	8.95	10.1	11.3	6.1
Al (%)	9.2	7.8	5.3	6.1	5.3	11.0	9.2	9.8
Ti (%)	0.4	0.4	0.6	0.2	0.3	0.4	0.6	0.5
V(ppm)	91.0	104.0	117.0	49.0	55.0	80.0	108.0	187.0

(1) samples 1, 2, 3, 4 come from the open pit mining site of Nanshan Iron Mine, and samples 5, 6, 7 from the deep-mining site of Shunfengshan Iron Mine

(2) sample 8 is mixed sample of the natural topsoil from the two mines.

Experimental Research Method

The first experiment was to observe survival rates of different seedlings in different categories of waste rock. There were 4 categories of waste rock samples from the sites of two mines from complete waste rock to intact natural topsoil, Group C_0 – local natural topsoil,; Group C_1– stripped primary waste ore rock, Group C_2 – 4/5 in volume of stripped primary waste ore rock + 1/5 natural contrasting topsoil, Group C_3 – 99% primary ore rock + 1% organic fertilizer.

Young seedlings were transplanted into different pots in the greenhouse, one seedling by one pot. After one year, these were moved to the outdoor environment so as to observe growth subject to local microclimate.

The experiment was arranged according to the above 4 experimental groups of C_0, C_1, C_2 and C_3. For each species, there were 5 replications for each category of waste rock and contrast topsoil. So there were 22 experimental subgroups for each plant species for Nanshan Mine and

Shunfengshan Mine (Table 3).

Table 3. The experimental design for the tolerance of plant species to acidic waste rock

The types of sites where samples were taken	The categories of waste rock (samples)	The types of experimental groups	Replication for each subgroup
N and S	natural topsoil	C_0	5
N	I	C_1	5
N		C_2	5
N		C_3	5
N	II	C_1	5
N		C_2	5
N		C_3	5
N	III	C_1	5
N		C_2	5
N		C_3	5
N	IV	C_1	5
N		C_2	5
N		C_3	5
S	I	C_1	5
S		C_2	5
S		C_3	5
S	II	C_1	5
S		C_2	5
S		C_3	5
S	III	C_1	5
S		C_2	5
S		C_3	5

"S" stands for deep--mining site in Shunfengshan Iron Mine, and " N" for open pit mining site Nanshan Iron Mine.

The experiment started at the beginning of March, 1998, In July the survival rate of the seedlings were first investigated; in September, survival rate investigation was repeated. The same investigation was implemented in the second year. Finally, the survival rates of all the plant species were statistically analyzed.

Results and Discussions

Seedling Survival Rate

Over two plant growth cycles, marked differences in survival were found (Table 4).

Table 4. Average seedling survival rate (%) in different groups of waste ore rock in 1998 and 1999

Plant species	Categories of Waste Ore Rock Samples								Natural topsoil
	Category		Category		Category		Category		
	S	N	S	N	S	N	S	N	
1	40	-	33	-	73.3	13.3/10	-	-	42.5/20
2	20	-	20	-	47	-	53	-	52.5/25
3	67	-	80	-	40	20/13.3	80	-	50/35
4	60	-	60	-	60	40/27	40	-	82.5/65
5	100	6.7	6	6.7/ 3.3	-	21	-	20	40/35
6	73	26.7/20	67	6	73	40/33	73	53	95/82
7	100	20/ 13.3	100	-	100	40/27	73	6.7	85/65
8	40	-	27	-	67	13/9	20	67	37.5/30
9	67	-	67	6.7	60	96/67	47	6.7	55/55
10	27	-	27	-	53	70/53	27	6.7	65/60
11	40	-	27	-	53	40/27	13	6.7	65/55
12	27	-	27	-	33	53/27	47	6.7	60/55
13	67	-	47	-	60	60/53	73	33.3	77.5/68
14	93	-	93	-	100	73/67	93	20	100/100
15	40	-	40	6.7/ 3.3	47	40/27	87	-	74/70
16	100	-	80	-	87	93.3/80	73	6.7	65/58
17	73	-	100	20/ 6.7	93	100/93	100	36.5	100/100
18	100	-	93/ 3.3	6.7	100	98.5/87	87	40	97.5/86
19	67	6.7/ 3.3	53	-	67	93.5/80	100	-	90/85
20	67	-	93	-	60	46.7/33.3	93	13	82.5/80
21	47	6.7/ 3.3	20	-	53	40/33.3	67	40	70/55
22	87	-	73	-	67	73/73	87	13	87.5/85
23	6.7	-	13	-	20	73/47	-	6.7	50/40

(1) "S" stands for deep-mining site in Shunfengshan Iron Mine, and "N" for open pit mining site in Nanshan Iron Mine.
(2) the symbol "-" means the death of seedlings.
(3) survival rates in Nanshan Iron Mine in 1999 expressed with "/" plus a black figure are for March to Sept. 1999).
(4) the numbering of plant species is the same as in Table 1.

Analysis of the seedling survival rates in Table 4, shows that, in 1998, the seedling survival rates in Category I and II of waste rock from Nanshan Mine, Maanshan, were only 21.7% and 26%, and there were only a few surviving species namely *Quercus fabri.*, *Quercus chieaii*, *Quercus acutissima*, *Ailanthus altissima* and *Malia azedarach* in Category I, and *Quercus fabri*, *Quercus chieaii*, *Castanea mollissima*, *Pistacia chinensis*, *Ulmus parvifolia* and *Celtis tetrandra var. sinensis* in Category II. Most plant species in Category III and IV of waste ore rock survived. Most of evergreen species did not survive in Category I, II and IV of waste ore rock from Nanshan mining sites. In 1999, there were only few species can survive Category I and II of waste ore rock, which are respectively *Quercus fabri*, *Quercus chieaii*, *Ailanthus altissima* and *Malia azedarach* in Category I, and *Quercus acutissima*, *Pistacia chinensis*, *Ulmus parvifolia* in Category II.

Table 5 shows that the survival rates of plant species in waste rock from the two iron mines were quite different. The total survival rate for each species in Shunfengshan Mine were much higher than that in Nanshan Mine. AcThe species with highest survival rates were respectively *Quercus fabri, Castanea mollissima, Ulmus parvifolia, Celtis tetrandra var. sinensis and Ailanthus altissima* in Nanshan Mine material; *Quercus chieaii, Amorpha fruticose, Choerospondias axillaris , Ulmus parvifolia and Celtis tetrandra var.sinensis* in Shunfengshan Mine. There were two plant species with high survival rates in both Nanshan and Shunfengshan mines, *Celtis tetrandra var.sinensis* and *Ulmus parvifolia*.

There was also a big difference among 4 categories of waste rock and natural topsoil (Table 6). The total trends for the average survival rate in different waste ore rocks were: *Category II < Category I < Category IV < Category III< Natural topsoil.*

Table 5. Total survival rates for different plant species in 2 mining sites in the first experimental year

Plant species	Total survival rate for each species			Ranking in total survival rate	
	S	N	Natural topsoil	S	N
1	36.6	3.3	42.5	16	20
2	35.0	0.0	52.5	17	21
3	66.7	5.0	50.0	10	19
4	55.0	10.0	82.5	13	18
5	26.5	13.6	40.0	21	16
6	71.5	31.4	95.0	9	3
7	93.2	16.7	85.0	3	14
8	38.5	20.0	37.5	15	11
9	60.2	27.3	55.0	12	4
10	33.5	19.2	65.0	18	13
11	33.2	11.7	65.0	19	17
12	33.5	14.9	60.0	18	15
13	61.7	23.3	77.5	11	7
14	94.7	23.2	100.0	2	8
15	53.5	11.7	74.0	14	17
16	85.0	25.0	65.0	5	6
17	91.5	39.1	100.0	4	1
18	95.0	36.3	97.5	1	2
19	71.7	25.0	90.0	8	5
20	78.2	14.9	82.5	7	15
21	46.7	21.7	70.0	15	9
22	78.5	21.5	87.5	6	10
23	9.9	19.9	50.0	20	12

(1) "S" stands for deep-mining site in Shunfengshan Iron Mine, and "N" for open pit mining site in Nanshan Iron Mine.

(2) "Total survival rate" is the average value of survival rates of each species in all the categories of waste ore rock for each iron mine site.

Table 6. Average survival rates for different waste rock categories in 2 mining sites in the first experimental year

Species survival character	Categories of waste ore rock sample								Contrast natural topsoil
	Category I		Category II		Category III		Category IV		
	S	N	S	N	S	N	S	N	
Number of survived species	23	5	23	6	22	22	20	17	23
Average survival rate of all species	61.25	13.36	54.17	9.22	61.45	53.80	57.96	16.64	70.61
Average number of survived species	14.00		14.50		22.00		18.50		23
Average survival rate in total	37.30		31.70		57.62		37.30		70.61

(1) "S" stands for deep-mining site in Shunfengshan Iron Mine, and " N" for open pit mining site in Nanshan Iron Mine.

(2) "Average survival rate in total" is the average value of survival rates of all the species in site S and site N.

(3) "Average number of survived species" is the average value of numbers of survived species in site S and site N.

The Relationships Between pH Value of Waste Ore Rock and Seedling Survival Rates.

Waste ore rock can produce acidity when exposed in the air in wet conditions. This chemical characteristic has a great influence on the plant growth. So pH value of waste rock drainage becomes the most primary factors influencing to the survival of plant species (Bradshaw 1997, Dobson *et al* 1997, Fyson *et al* 1998, Pawlowski 1997). Obviously, the plant survival rate will change with pH value of waste ore rock drainage usually with a parabolic relationship. We mathematically described the relationships of 23 species' survival rate and pH value of waste ore rock drainage by a parabola equation as $\hat{y} = a + bx + cx^2$, using least squares method. There, $\hat{y}$ is the survival rate for each species and x is the pH value of waste ore rock drainage (Table 7). This analysis shows that the individual species show considerable differences in behaviour, and in adaptation to acid conditions.

Table 7. The regression equations of quadratic parabola representing the relationships of pH value in typical waste ore rock drainage and survival rates of plant seedling

Number of plant species	Regression equation	Explanation
1	$\hat{y}=16.5+1.7x+0.73x^2$	$\hat{y}=a+bx+cx^2$ is tested by surplus regression. The equations for No. 7 and 14 trees have great errors beyond the bounds of regressive estimation.
2	$\hat{y}=32.4+9.2x+0.023x^2$	
3	$\hat{y}=-15.0+8.4x+0.092x^2$	
4	$\hat{y}=34.2-2.2x+0.30x^2$	
5	$\hat{y}=-1.03+0.70x+0.47x^2$	
6	$\hat{y}=-3.4+10.5x-0.12x^2$	
7	$\hat{y}=?$	
8	$\hat{y}=-1.8+5.0x+0.08x^2$	
9	$\hat{y}=-43.4+21.1x-0.87x^2$	
10	$\hat{y}=-3.6+3.0x+0.37x^2$	
11	$\hat{y}=-40.2+15.0x-0.60x^2$	
12	$\hat{y}=-15.04+9.4x-0.38x^2$	
13	$\hat{y}=-22.6+13.8x-0.34x^2$	
14	$\hat{y}=?$	
15	$\hat{y}=-19.20+11.4x-0.84x^2$	
16	$\hat{y}=-40.9+16.6x+0.06x^2$	
17	$\hat{y}=-25.1+19.3x-0.49x^2$	
18	$\hat{y}=34.6+18.9x-0.18x^2$	
19	$\hat{y}=-27.5+15.7x-0.33x^2$	
20	$\hat{y}=-32.2+14.8x-0.13x^2$	
21	$\hat{y}=-8.2+10.2x-0.41x^2$	
22	$\hat{y}=35.0+16.2x-0.18x^2$	
23	$\hat{y}=41.6-2.0x-0.42x^2$	

Conclusions

Through the experiment of screening seedlings in different waste ore rock materials, the tolerance of different species to acid waste rock drainage at Nanshan Mine, Maanshan city, and Shunfengshan Mine, Tongling city, has been demonstrated. The survival rates of these species are quite different. Special attention should be given to the tolerance shown by species on in Category I, II of waste ore rock drainage from Nanshan.There are only a few species able to survive in such acidic environment, *Quercus fabri.*, *Quercus chieaii*, *Quercus acutissima*, *Ailanthus altissima* and *Malia azedarach* in Category I, and *Quercus fabri.*, *Quercus chieaii*, *Castanea mollissima*, *Pistacia chinensis*, *Ulmus parvifolia* and *Celtis tetrandra var.sinensis* in Category II..

The relationship of seedling survival rates and the pH value of the waste ore rock drainage can be obtained in the form of $\hat{y} = a + bx + cx^2$, using quadratic regression equations. As the pH of the drainage of waste ore rock decreases, the toxicity of heavy metals in the drainage would increase or decrease. This complicates the interactions among the pH value, the toxicity of heavy metals and seedling growth and their identification. But their individual effects on seedling growth is important for establishing effective bioremediation techniques. Especially, because the availability of Al, Mn and Fe becomes much larger as the pH value of waste ore rock drainage decreases, the toxicity of these elements to seedlings growth will increase and become a leading factor affecting the survival rate of seedlings. So further experimental studies are important to examine the different responses of the plant species to these different metal in order to identify whether these toxicity really exist and what is their intensity.

This experiment is a preliminary work for determining the actual relationships between pH value of the drainage and seedling growth. Further studies need to be focused on the mechanism and intensity of acidity generation on waste ore rock, and how they impair the survival of plant seedlings. With these, we can establish effective ecological engineering techniques for achieving a low cost, relatively fast natural vegetation restoration on acidic waste ore rock.

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Chapter 25

The Role of Legumes in the Reclamation of Metal Mined Land in China

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Introduction

It is commonly recognised that the establishment of a vegetation cover on degraded land can ensure stability, reduce potential pollution, provide amenity, and in many cases produce an economic product. The common characteristic of degraded land is the loss of surface soil containing the organic matter and the store of plant nutrients especially nitrogen (N), the most important macronutrient needed for plant growth. However, degraded land caused by metal mining and smelting has additional problems. The present article attempts to review the general properties of metal mined land and the adverse factors inhibiting plant growth and establishment, and the role of legumes species in natural colonization. The effects of elevated heavy metal concentrations on legume plants, associated rhizobia and their N-fixing capability will also be discussed.

Properties of Metal Mined Land

General Properties

The mine wastes produced from mining and smelting operations commonly contain a mixture of soil, various sizes of gravel and mining wastes, and their weathered products are very different from normal soil (Kent 1982).

Table 1 lists the general physico-chemical properties of 5 Pb/Zn mine tailings located at different sites of South China. The concentrations of potential toxic metals, Pb and Zn are high although they vary according to different mine sites. They all contain low levels of organic matter, N and P, only 20%-30% of mean background values of soils with plant cover in China.

Deficiency of Organic Matter and Nutrients

In general, seeds can geminate on wastelands containing lower bioavailable concentrations of heavy metals. Previous experiments demonstrated that all the tested seeds (including trees, grasses and vegetables) could germinate in Pb/Zn mine tailings with adequate moisture. However, the growth of seedlings of *Acacia confusa* and *Leucaensa leucocephala* on Pb/Zn tailings were seriously inhibited by the lack of essential nutrients resulting in low contents of N, P, and K in the seedlings (Zhang *et al.* 1996). It is well established that a sufficient supply of nutrients is an important aspect of land restoration.

Table 1. General properties of five Pb/Zn mine tailings in South China

	Unit	Fankou (n=15)	Lechang (n=18)	Huangshaping (n=7)	Shuikousha (n=7)	Taolin (n=7)
Sand	%	57	39	52	56	63
Silt	%	15	43	31	30	23
Clay	%	28	18	17	14	14
pH		6.88	5.47	7.71	7.59	8.24
EC	dS m^{-1}	2.09	4.09	1.16	1.10	0.50
Total N	mg kg^{-1}	399	429	228	414	324
Total P	mg kg^{-}	695	552	804	1463	249
Total K	mg kg^{-}	7125	1562	2001	1287	2605
Organic Matter	%	0.54	0.69	0.45	0.43	0.27
Total Pb	mg kg^{-1}	18423	3051	11558	2461	1120
Extractable Pb	mg kg^{-1}	385	196	419	257	113
Total Zn	mg kg^{-1}	16745	3655	10011	1794	833
Extractable Zn	mg kg^{-1}	336	79.29	375	181	24.40
Total Cu	mg kg^{-1}	710	160	204	106	197
Extractable Cu	mg kg^{-1}	31.53	5.04	5.77	10.37	2.94

Fankou and Lechang Tailings at Guangdong Province

Huangshaping, Shukousha and Taolin Tailings at Hunan Province

The Importance of Metal Tolerant Species

Both metal toxicity in soils (Alloway 1990, Lepp 1981), and the phenomenon of metal tolerance in herbaceous plants (Baker 1987, Ernst 1990) have been extensively studied. To survive in contaminated soil, species or populations must possess metal tolerance. This tolerance in plants may be achieved by avoidance or by tolerance. Avoidance is defined as an ability to prevent excessive metal uptake into its body, whereas tolerance is an ability to cope with metals that are excessively accumulated within the plants (Levitt 1980). Advances have been made to revegetate metal-contaminated sites and improve their aesthetic and economic value by chemical and physical amelioration of soils to reduce metal availability (Johnson *et al.* 1977) and by planting metal tolerant species, which are mainly grasses (Bradshaw and McNeilly 1982). However, a combination is often better. The Pb/Zn mine tailings in South China have been successfully restored by applying appropriate organic amendments (such as manure compost and refuse compost) and using tolerant plant species (such as *Cynodon dactyldon*) (Lan *et at.* 1998, Ye *et al.* 1999, 2000). A further approach is to use tolerant plant species that accumulate high concentrations of metals (hyperaccumulators) in their tissues to remediate metal-contaminated soils. By harvesting and removing the plant material, within a few to several harvests soil metal levels can be significantly reduced (McGrath *et al.* 1993).

The Use of Legumes in Revegetation

The Role of Legume Species in Natural Colonization of Mine Wastelands

The restoration of the N cycle within metal-contaminated sites is essential for revegetation and long-term stability of the disturbed ecosystem. Organic matter provides most of the N reserve, and if organic matter is lacking, the N reserve is also poor. If legumes are able to colonise or be sown in and fix N, the N accumulation will be more rapid than otherwise (Ashton *et al.* 1997, Franco and Faria 1997). Therefore, legumes can be used to provide organic matter and N for the reclamation of derelict land (see Chapter 11).

The role of legumes in building up N during the early stages of natural succession has been studied on china clay waste and some natural substrates (Marrs and Bradshaw 1993). However, there is evidence that legumes or other N-fixing higher plants are not important components of the primary succession on colliery spoils, and legumes are rarely colonizers of metalliferous land (Harris *et al.* 1996). This could be due to the low level of P which restricts the growth of N-fixing species or to metal toxicity.

According to our investigations on the natural colonisation of plants on different metal mine tailings in China, a number of legume species were recorded (Table 2). However, although *Medicago lupulina* was a dominant species among the plants growing on the Cu tailings at Tonglin and Mo tailings at Jinduicheng, all other legume species recorded were not important components of tailings vegetation.

Table 2. Legumes found growing on Cu, Mo and Ni mine tailings in China

Species	Baiying Cu tailings	Tonglin Cu tailings	Jinchuan Ni tailings	Jinduicheng Mo tailings	Lechang Pb/Zn Tailings
Amorpha fruticosa	+		+		
Kummerowia striata					+
Kummerowia stipulacea		+		+	
Lespedeza thunbergii					+
Medicago lupulina		+		+	
Medicago minima		+			
Pueraria lobata		+			
Sophora japonica	+		+		
Styphnolobium japonica	+		+		

At least two points can be concluded from this. Firstly, there are some legume species or ecotypes tolerant to the edaphic conditions of these wastelands existing in natural vegetation. Searching, screening and cultivation of these tolerant species or ecotypes would be important for restoration of metal mined land. Secondly, some assistance measures is necessary to improve the role of legume species in N accumulation, such as substrate amelioration (application of P, adjusting pH), and, obviously, planting or sowing legume species to increase their population dominance.

The Use of Annual Legumes and Woody Legumes

It has been suggested that annual pioneer legumes play an important role in the restoration of degraded lands. Part or all an annual legume at the end of the growing season has a low C to N ratio, low enough for microbes to be able to break the organic matters down (Harris *et al.* 1996). Our previous experiment growing *Sesbania rostrata* (annual legume which forms both root as well as stem nodules) in Pb/Zn mine tailings indicated that 90% of seeds of the legume germinated in pure Pb/Zn tailings containing high concentrations of Pb and Zn (34,300 and 36,500 mg kg^{-1} dry weight basis, respectively). Although seedling growth suffered from the adverse environment, they became established on tailings, in the glasshouse, as well as on the actual tailings dam, and completed their life cycle in 4 months. Dry matter production and N accumulation were 3,200 and 69.4kg ha^{-1}, respectively in the actual tailings dam. These legumes are therefore very effective in accelerating the accumulation of N in the nutrient deficient mined land, and modifying the habitat for the subsequent colonization of other plant species.

Woody legumes are useful for revegetation of water-deficient, low-nutrient environments because of their ability to form symbiotic association not only with rhizobial bacteria but also with mycorrhizal fungi, which improve nutrient acquisition and help plants to become established and cope with stress situations (Herrera *et al.* 1993). Six tree legume species, namely *Sesbania grandiflora, Leucaena leucocephala, Acacia nilotica, A. auriculiformis, Prosopis julifora* and *Albizia lebbeck* were planted in Fe mine waste soil and it was found that *L. leucocephala* and *A. nilotica* were the most suitable, as the former had the highest total N content, and the latter better rooting and nodulation capacity with larger nodule size and dry weight per nodule (Thatoi *et al.* 1995). In a field trial with 55 species (including 25 legumes) on tin (Sn) mine tailings, 14 species had both high survival rates and rapid growth. Of these 11 species were legumes, and four *Acacia* spp. (*A. gerrardii, A. nilotica, A. sieberiana,* and *A. tortilis*) (Piha *et al.* 1995). We have recently found that *Leucaena leucocephala* can be successfully established on Pb/Zn mine tailings and completed its life cycle.

Metal Tolerant Legumes in Revegetating Metal Mined Land

In tests of the Pb tolerance of 6 legume species, bengalgram (*Cicer arientinum*), blackgram (*Vigna mungo*), cowpea (*V. unguiculata),* greengram (*V. radiata*), horsegram (*Macrotyloma uniflorum*) and redgram (*Cajanus cajan*) grown on Pb ore tailings, bengalgram and cowpea were found to posess the highest tolerance levels and adaptive growth on Pb rich soils (Sudhakar *et al.* 1992). In another study of selected legume cover crops on acid mine spoils contaminated with Zn, Mn, Pb, Cu, Ni and Al, cowpea and "Bragg" soybean (*Glycine max*) generally produced the highest dry matter yield and accumulating the largest quantities of metals, except Al, from the spoils (Taylor *et al.* 1992).

Copper tolerance has been found in legumes (*Lotus purshianus, Lupinus bicolor* and *Trifolium pratense*) colonizing soils with high concentrations of soil Cu in northern California (Kruckeberg and Wu 1992). It was suggested that the successful colonization of Cu enriched soil by *L. purshianus* is accomplished by the evolution of Cu tolerance in both the legume plant and its symbiont (*Rhizobium loti*), and the Cu tolerance of the plant and rhizobium may have evolved independently (Wu and Lin 1990). There is no doubt, although the legumes are rarely dominant in metal mined land vegetation, some species are able to colonise and grow on it.

Rhizobia-host Symbiotic Association in Metal Mined Land

Under the conditions of mine wastelands, the survival, growth, and reproduction of host plant and rhizobia, the capacity for forming rhizobia-host plant symbiotic association and their N-fixing effectiveness are very important. If one of these are seriously inhibited by the heavy metal toxicity contained in the wasteland, it is impossible for legumes to promote the accumulation of N. Accordingly, the first challenge for using legume species on restoration, besides the tolerance of host plant, is the tolerance of the rhizobia and their symbiotic associations to the edaphic conditions of mine wastelands, especially to the heavy metal toxicity.

The study on the survival of *Rhizobium leguminosarum biover trifolii (R. trifolii)* in plots with a range of metal contamination at Woburn, UK (Giller *et al.* 1989) indicated the original effective population was altered by metal pollution derived from sewage sludge, leading to the survival only of a strain ineffective in N-fixation (McGrath *et al.* 1988). The isolated strains had multiple metal (Zn, Cu, Cd and Ni) tolerance, but they had lost their ability to fix N with *Trifolium repens* (Hirsch *et al.* 1993). It was concluded that the major factor influencing rhizobial numbers was the soil metal concentrations (Chaudri *et al.* 1992).

However, effective *Rhizobium* were always found in soil from sites where the host plant was established, irrespective of the amount of metal contamination. The *Rhizobium* strains had developed tolerance to elevated metal conditions without losing ability to fix N with white clover (Smith and Giller 1992). Other studies also demonstrated metal tolerance by strains of *R. leguminosarum* and *R. meliloti* were effective in N-fixation with their respective host plants (El-Aziz *et al.* 1991).

In a study of a number of disposal sewage sites and highly contaminated samples from abandoned Pb/Zn mine sites, it was found that when the host plant was indigenous to the sward, the rhizobia were found in the nodules and in the soil rhizosphere at all the sites tested, capable of effective symbiosis and N-fixation (Obbard and Jones 1993). A more recent study has indicated that *Rhizobium,* effective in N-fixation, is present in all the soils supporting the host plant, irrespective of metal concentrations in soil which increased to 300 mg Cu kg^{-1} and 2,000 mg Zn kg^{-1}. In contrast, several soil samples with no indigenous host plant failed to nodulate white clover in the infection test (Smith 1997).

A recent experiment, testing the effects of Zn on *Acacia auriculiforimis,* and its associated rhizobia (isolated from the host) indicates that the rhizobia had significantly higher tolerance than the host plant (Zhang *et al.* 1998).

Conclusion

It is clear that the selection of legume plants and their associated N-fixing bacteria for growing on metal contaminated sites having tolerance to the extreme edaphic conditions of the lack of nutrients and elevated metal concentrations is possible and is occurring naturally. The plants should be adapted to local climatic conditions. For this native species would be the best choice. It seems necessary therefore for us to search, screen and propagate tolerant species and ecotypes and their associated

N-fixing bacteria from different parts of China to assist in the restoration of different types of metal mined land across the country, which consists of several climatic belts. Fortunately, our plant resource is rich and there are 1,660 legume species, subspecies and varieties belonging to 172 genera.

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A Framework for the Process of Rehabilitation and Restoration of Degraded Land

From the previous Chapters it is clear that there are many aspects to the restoration and management of derelict and degraded land. Nevertheless it is common practice for operators involved in restoration work to apply certain routine treatments without reference to the site or its problems. Yet individual sites can have their own special problems, both physical and chemical. If these are not recognised, failure of the restoration can occur either immediately or after a few years.

Another possibility is that solutions may be employed which, although they work satisfactorily, can be unnecessarily elaborate and expensive. On many sites, for instance, where an expensive soil cover could be proposed, it may be perfectly possible to treat the material directly. On other sites a treatment may be possible, such as forestry, that yields an economic return later.

It is therefore essential that, for any site, a framework of approach is adopted at the outset, and then followed scrupulously. Although this will involve some expense, it will be justified by the economic savings and reliable performance of the work subsequently carried out.

The Croucher Advanced Study Institute on the Restoration and Management of Derelict Lands brought together approximately 40 scientists with a particular interest in the repair of degraded land. These scientists from many parts of the world represented a considerable collection of multidisciplinary expertise.

This expertise was drawn upon in the final session of the program to develop a generic framework for a process of rehabilitation of degraded land that could be utilised in any country or region. Through small group and plenary discussions, the following framework was developed. This framework is applicable to all restoration projects.

The Steps that Need to be Taken to Ensure Effective Rehabilitation and Restoration of Degraded Land is Achieved

1. Survey the Ecological Potential of the Site

- Components to consider should include –
  - Previous history of the site including land use
  - Land tenure
  - Environmental impacts (on- and off-site)
  - Climate
  - Topography
  - Hydrology (surface and sub-surface)
  - Soil (chemical, physical and microbiological properties)
  - Vegetation (structure, cover and vigour)
  - Fauna
- Methods for sampling and analysis should conform to internationally accepted guidelines

2. Identify Future Land Use

- Consult stakeholders
  - Owners
  - Local community
  - Government
- Consider the ecological potential of site
- Make decision on land use, or uses, to be adopted

3. Conduct Workshop to Plan Research Program

A workshop, involving scientists representing the range of disciplines required to address the rehabilitation of the degraded land, should be held with the objectives of –

- Reviewing data from the survey of the site
- Reviewing relevant data from elsewhere in the world

- Planning the experimental program needed to provide the data for the implementation of large-scale rehabilitation (subsidiary workshops may need to be conducted to complete this component)
- Ensuring appropriate funding is made available for required trials

4. Experimental Phase

This phase would commonly involve laboratory testing, small-scale plant growth experiments and field trials.

4.1 Laboratory tests

- Additional media characterization tests to complement those undertaken in the initial survey of ecological potential of site
- Sufficient sampling intensity across site to allow heterogeneity (laterally and vertically) to be determined as a precursor to selection of the specific site(s) for field trials and for collection of bulk samples for small pot trials
- Provide basis for planning small scale (pot) and field trials to assess remediation approaches

4.2 Small scale (pot) experiments

- Careful selection of bulk samples for study which reflect the heterogeneity of the site
- Cost-effective narrowing down the number of factors which need to be investigated in trials on the site
- Assessment of nutrient status and fertilizer needs by nutrient omission and rate trials, respectively
- Assessment of ameliorative treatments for acidity, alkalinity, metal toxicity, salinity etc.
- Screening of plant species and cultivars for their capacity to grow on degraded, and ameliorated, material.

4.3 Field (site) trials

- The selection of a site which can be studied over the long term
- The placing of replicates to cover the heterogeneity of the site
- Factors to be investigated should include –
  - Erosion control
  - Ameliorative treatments (for physical, chemical and microbiological limitations)
  - Plant species selection
  - Establishment techniques
  - Ecotoxicology (health) issues
- Trials should be monitored for sustainability of ameliorative treatments
- Decision on the technical aspects of land rehabilitation based upon results of the field trials

5. Environmental Impact Assessment (EIA)

- Prior to commencement of the large-scale rehabilitation program, assess the environmental impact of the proposed approach, taking into account environmental, economic and social aspects
- Reassess aspects of the proposed large-scale rehabilitation plan, including proposed land use, as necessary, as result of output of EIA
- Prepare report detailing all preliminary experimentation and analysis and preferred approach to large scale rehabilitation

6. Large-Scale Rehabilitation

- Establish a management program, to cover
  - Technical aspects
  - Communication aspects (all stakeholders including future users of the land)
  - Importance of ensuring quality assurance and control
- Ensure the sustainability of the project with respect to
  - Economics

  - Environment (soil, vegetation, water, animal and human health)
- Ensure continual monitoring of performance, with opportunity for feedback to refine methodology where appropriate

7. Conclusions

Although those confronted with the task of planning the rehabilitation of degraded land may find that some steps in the framework may be omitted in practice, the outline should provide a basic checklist to assist in the planning process.

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Modern Approaches

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The Restoration and Management of Derelict Land serves as an important reference for undergraduate and postgraduate students, professors, decision-makers and engineers in environmental science and management.

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