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Environmental Damage from Extraction Of Road Building Materials: Results and Recommendations from Studies in Southern Africa

Transport Research Laboratory, Crowthorne, Berkshire, United Kingdom

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by C S Gourley and P A K Greening

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ENVIRONMENTAL DAMAGE FROM EXTRACTION OF ROAD BUILDING MATERIALS:

Results and Recommendations from Studies in Southern Africa

Contents

ABBREVIATIONS

ALC	Agricultural Land Classification
DFID	Department for International Development
FAO	Food and Agriculture Organisation
EC	European Commission
EIA	Environmental Impact Assessment
K	Potassium
N	Nitrogen
OM	Organic Matter
P	Phosphorous
pH	Acidity index
SADC	Southern African Development Community
SATCC	Southern African Transport and Communications Commission
SIDA	Swedish International Development Agency
TRL	Transport Research Laboratory

Executive Summary

Aims

This particular project was designed to examine current practice in the development and restoration of gravel borrow pits, assess the effects on the environment and seek possible ways of reducing consequent environmental damage. The project also aimed at increasing the environmental awareness of road engineers in the region to the problems of extracting non-renewable natural resources used for road construction.

The detailed objectives of the project were to:

a) Review current practice in the excavation of materials.
b) Report on the economic and environmental impact of current and revised land restoration strategies.
c) Produce recommendations for future restoration strategies.

Work Done

A review of current gravel extraction practice has been undertaken by surveying a wide variety of borrow areas for roads projects in Malawi, Zimbabwe and Botswana.

Improvements in excavation and back-filling have been researched and trials conducted on both current and improved procedures. These trials have been monitored by detailed visual logging of soil profiles backed-up by relevant scientific testing. A comparison has been made of current, uncontrolled restoration procedures with the quality of the soils in the area prior to excavating the gravel.

Options for best-practice procedures for the excavation and back-filling of gravel pits were discussed with relevant contractors, consultants, and government departments.

Achievements

Current practices and standards adopted for borrow pit development in the region have been reviewed in the light of a survey of restoration practices carried out during the project. The impacts of gravel extraction operations on local communities have been assessed and factors identified which can be mitigated by appropriate good practice.

The survey of as-used borrow areas in conjunction with the review of impacts on local communities revealed valuable information. Key points to arise were:

- Historically, restoration of borrow pits has been the exception rather than the rule. Post excavation inspections are rarely conducted to determine whether borrow pits have been restored correctly; whether landowners are satisfied with the reinstated land; or whether compensation payments have been received.

- The environmental impact caused by improper extraction and rehabilitation practices can extend over a wide area, and may only become apparent after project completion.

Examples include the erosion of the exposed soils causing siltation of natural water courses.

- Environmental damage caused be working borrow pits is often most severe in areas important for subsistence farming. Top-soils, which are often thin and fragile, are organically rich and have characteristics important to agriculture. The fertility of these soils depends on the nutrients available in the soil, which can be destroyed by poor extraction and rehabilitation procedures.

- The extraction of road building materials can have a significant impact on land, and interviews with land owners and subsistence farmers have indicated that they are concerned with and understand the need to limit damage to their local environment.

- Contractors often leave pits open at the request of the land owner, because these are seen as a useful mini-reservoir to provide water for animals, washing and bathing and in rare cases also irrigation. Health risks associated with this option have been highlighted, including the risks to humans caused by exposure to stagnating water and mosquito borne disease. In many cases, it is women and children who are most at risk.

A revised method of working borrow areas has been devised and implemented in a number of borrow pits on new construction projects in Malawi and procedures developed during the current project have been successfully demonstrated. Much of the information, knowledge and experience gained during the project have been synthesised into guidance notes. These can also be applied to some other activities in the road construction process.

The adoption of these procedures could have a significant influence in mitigating potential health and economic problems in rural communities disadvantaged by natural resource extraction.

Recommendations

The impacts of gravel extraction need to be fully recognised by all concerned, and environmental management extended to all borrow area operations on road construction to minimise detrimental influences on the natural, social and economic environment.

All who are involved in the road provision process need to ensure that activities conducted do not diminish the capability to grow food, and that areas disturbed are left safe and secure from hazards. Greater attention should be given to the education of land owners in this area, particularly where they are also subsistence farmers.

Reversal or mixing of the soil profile should be avoided by careful removal, storage and replacement of the soils. Once the road construction materials have been stockpiled, operators can start reshaping and rehabilitation, rather than leaving plant idle in the pit.

Soil fertilisers should be applied as soon as the soils are replaced to encourage vegetation growth prior to on-set of the rains.

It is difficult to avoid disturbance to local drainage patterns and to changes in the topographic profile, but these effects can be reduced if pits are back-filled with spoil. It is, however, recognised that this could incur additional haulage costs.

Procedures need to be developed by contractors for individual borrow areas, and presented as part of their contract proposals for evaluation by the Roads and Environmental Departments. Even if the implementation of environmentally sensitive operations incur additional costs at construction, these are likely to be offset by the longer term benefits.

The guidance notes developed could be incorporated into contract documentation.

Further development and research application work can be usefully undertaken in the following related fields:

- The cost-effective use of redundant borrow areas for waste and spoil disposal.
- The safe modification of borrow areas into rural irrigation schemes as potential small reservoirs.
- The use of back-filled borrow areas as bio-engineering nursery areas for earthwork stabilisation and maintenance.

1. Introduction

1.1 Background

The Transport Research Laboratory has been undertaking a programme of collaborative research with countries in southern Africa. The overall purpose of the research programme was to encourage an integrated approach to the economic and environmental use of natural gravels for roadbase in low-volume road construction and maintenance. This programme evolved from discussions with road administrations in the region and donor agencies, in which subject areas for research were identified that could the assist development in the region. The programme was funded by the Department for International Development (DFID) and the Swedish International Development Agency (SIDA). A TRL team was established in Zimbabwe during 1994-98 to work in collaboration with government departments in the region, other regional organisations, academic institutions and consulting engineers.

The provision of roads is recognised as an important contribution to development. Improved access to and within rural areas, in particular, can help to alleviate poverty and improve livelihoods by accelerating social and economic development. Road provision and the extraction of road building materials can have far reaching impacts on the natural environment. This is becoming an increasingly important issue in the road planning process in many developing countries, including those in southern Africa.

Historically, the damage caused to the environment by winning road construction materials from borrow areas has received little attention. Although many standard contracts for road construction projects include recommendations for borrow area rehabilitation, these are often not enforced. Little guidance is available on the methods to be used or the quality of reinstatement to be achieved. In recent years, however, there has been an increased awareness of the environmental impact of road construction, and most new projects are now subjected to an environmental impact assessment (EIA) as part of the feasibility study.

1.2 Objectives

This particular project was designed to examine current practice in the development and restoration of gravel borrow pits, assess the effects on the environment and seek possible ways of reducing consequent environmental damage. The project also aimed at increasing the environmental awareness of road engineers in the region to the problems of extracting non-renewable natural resources used for road construction.

The objectives set out at project inception were to:

- Review current practice in the excavation of materials
- Report on the economic and environmental impact of current and revised land restoration strategies
- Produce recommendations for future restoration strategies

1.3 Regional emphasis of the overall programme

The research programme was also supported by the Southern African Transport and Communications Commission (SATCC). The need for the work to have a regional impact was recognised. There is a reluctance of many national engineering organisations, both in government and the private sector, to accept and apply the results of research conducted outside their borders. The involvement of SATCC raised awareness of the research, and increased opportunities for the transfer of the technology developed. This also gave member countries in the region an opportunity to influence the project objectives and methodology. Project progress and the results of the research were disseminated to representatives of the Southern Africa Development Community (SADC) countries at SATCC meetings, regional conferences and workshops.

There are also technical benefits of operating regionally. Collaboration with different road administrations enabled the project team to achieve a better appreciation of the range of traditional methods as well as gaining an understanding of the benefits and constraints of the local working environment. By operating in the different countries it has been possible to collate experience from the region and thus extend the conditions to which the results of the research can be applied. Although regional application was not an overall programme objective, the importance of sharing and using the available information and knowledge should be an achievable future aim for the region.

1.4 General project approach

The approach to the borrow areas project was based on the need to quantify the current state of reinstatement practice, to measure the impact of this on land use, and to assess the benefits of revised procedures. A review of current practice was undertaken by visiting and surveying existing borrow areas for roads projects in Malawi, Zimbabwe and Botswana. A range of project roads of varying age and type were investigated to provide sufficient information on reinstatement practices.

Ideally, the methodology to measure the impact of current and revised procedures would have involved a variety of different types of land use. However, within project budget and time constraints this was not possible, and a selected number of borrow areas on roads under construction at the time of the study were targeted. Detailed costing of the different borrow pit management procedures was not possible, principally because the methods used by contractors to cost such works are not currently presented as separate items in bills of quantities

The principle activities of the project were:

- Investigation of the current guidelines and practices
- Survey of redundant borrow areas
- Identification of improvements to current practice
- Field testing of recommendations
- Drafting of recommended procedures for new contracts

2. Environmental impacts of gravel extraction

2.1 Background to the problem

Natural gravel deposits provide a valuable resource as construction materials for road pavement layers. In this region they normally occur in thin seams between 0.3 and 1.2 metres in thickness. Because of the volume of materials required, large tracts of land are often disturbed to provide sufficient material for construction. For example, a ten kilometre road typically requires 30,000m^3 of roadbase material and with a 0.75m thick gravel seam this requires a borrow area of approximately 200m by 200m. An additional area 100m by 100m is generally required to provide space for stockpiling of gravel and the storage of overburden.

Materials are very often excavated from close to the road in order to save on haulage costs, hence many of the environmental impacts relate to areas close to the road. In these cases issues relating to drainage and erosion need to be taken into account at the design stage if they are likely to impact on the road itself.

Often, road development follows existing tracks or roads, which are located close to the populations being served and, in rural areas, close to agricultural activities. This means that local populations and agricultural land are inevitably disturbed. Poor engineering practice in the development and restoration of borrow areas can, therefore, have a direct and detrimental effect on the well-being of rural communities. However, good engineering practice during planning, design and construction can overcome many of these concerns.

When most of the road design and other planning manuals were written in the 1970s and early 1980s, projects did not require environmental assessments, and little if any adequate information or guidance was given on these issues. Now, most donor funded and some internally funded projects require a mandatory environmental impact assessment. This assessment identifies the type of impacts, the future consequences for the environment, and the actions required to mitigate them.

2.2 Impacts

Environmental impacts of extraction of construction materials in general include:

- Material resources
  - permanent loss of natural resources
- Morphological damage
  - modification of the natural drainage
  - increased soil erosion and siltation of waterways by disturbance of soil
  - destabilisation of slopes
  - compaction of soil surrounding the borrow area by plant or soil bunds
- Ecology
  - loss of wilderness and forest
  - displacement of species and habitats
  - loss of potential productivity of agricultural land
- Pollution
  - contamination of water and soil by fuel and oil spillage

  - generation of dust during the processing, loading and transporting of materials
  - increased dust generated by vehicles along access tracks
  - littering
- Social and health impacts
  - creation of habitats for disease
  - landscape alteration and interference with natural beauty
  - bisection of communities or farms
  - loss of land legacy
  - loss of antiquities, cultural heritage, areas of cultural concern, such as graves
  - hazards to pedestrians and animals, including open or unmarked trial pits, demarcation beacons, etc
  - safety risks to local population by exposure to heavy plant and traffic
  - noise of blasting, traffic, plant and drilling

The majority of these impacts can be associated directly with the extraction of natural gravels from borrow pits. Some of these impacts are illustrated in Plate 2-1 to Plate 2-6.

Plate 2-1 Typical condition of an un-reinstated borrow pit
This shows gravelly layer at the surface and little re-growth of vegetation

Plate 2-2 15 year old lateritic gravel borrow pit in Malawi
This shows little re-growth of vegetation

Plate 2-3 Borrow area providing local washing facilities
Continued use is degrading the quality of water available and increasing the health risk to humans and animals

Plate 2-4 Children exposed to risk of drowning and poor quality water
Ponding increases the level of mosquito-borne disease

Plate 2-5 Loss of productive agricultural land for subsistence farming
The undisturbed land to the left is still productive whilst that of the borrow on the right has been sterile for 12 years

Plate 2-6 Eroded sub-soils on borrow floor
Susceptibility to erosion leads to siltation problems in water courses

It should also be recognised, however, that there are also some benefits to be derived from gravel extraction and that these should be taken into account. These benefits include, for example:

- Provision of tracks to borrow pits can benefit local populations be improving access
- Pits can act as small reservoirs, if properly constructed and managed
- Short term work may be available at site
- Land owners may receive financial compensation
- Pits may provide areas for the controlled dumping of spoil or waste.

2.3 Issues to be addressed

Site clearance
Normal practice in gravel excavation is to clear vegetation and remove the full depth of overburden to expose the gravel seam. Overburden consists of top-soil and sub-soil above the seam, and is normally stock-piled for reinstatement. Bush clearing is often achieved by burning. This practice removes organic matter when plants are destroyed and also removes useful bacteria, which help to produce additional nutrients that enrich the soil. The removal of overburden is generally carried out generally as one operation. This results in mixing together of the top-soil and sub-soil, and complete destruction of the fragile top-soil. The overburden is normally bulldozed back into the borrow area. This practice can result in unused gravel, rocks and boulders being strewn across the surface. This practice is detrimental to agricultural

use of the land, especially where farming is by subsistence methods and the land is worked with basic tools.

Plant operation

The use of heavy tracked plant to open-up borrow pits can destroy the natural structure of soil. It can reduce water infiltration, reduce aeration of the soil and decrease the moisture retention capacity by clay particles blocking the macro and micro porous structure. Rapid soil degradation can result, with a resulting reduction in the capacity of the soil to sustain crops. Compaction also makes soils difficult to work and can lead to considerable soil erosion. Farmers must then re-work the soil continually until the density in the growing layer is similar to that before excavation. The adverse impact of compaction plant can be reduced by giving consideration to the type of plant used, and to the effect of tyre width, tread pattern and contact area on compaction. Plant movement over the fragile top-soil and sub-soils should be kept to a minimum. Carrying out as much of the initial clearing as possible when the soil is relatively dry reduces soil compaction.

Stockpiling

Careful stockpiling of overburden soils will preserve soil quality by reducing exposure of the soluble minerals and organic matter in the soil to oxidation. The longer the soil is stockpiled, the greater will be the change in soil structure and nutrient availability due to rapid decline in the soil organic matter. The length of time that the soil is stockpiled should be minimised to prevent leaching and loss of nutrients and soluble minerals. There will be benefits in restoring borrow pits from stockpiles towards the end of the dry season since a wet soil will compact more than a dry one.

Erosion

Heavy rain can cause soil erosion on the exposed soils and in restored borrow pits. There are particular problems in areas of steep terrain, with slopes greater than 5 per cent.

3. Current guidelines and practices

3.1 Practice in the United Kingdom

In the United Kingdom, around 300 million tonnes of aggregates are produced each year, a third of which are used for roads. Issues of environmental impact are close to the public eye. Planned surface mineral workings in quarries and gravel pits are required to embrace a wide range of environmental measures to meet the EC Directive on Environmental Assessment (Council of the European Communities 1985) and related legislation and procedures in the United Kingdom. Adherence to good practice is enforced by the regulatory authorities. Old pits and gravel workings must be reinstated, reclaimed or turned into community assets. Similar environmental controls are in place in other European Countries, in Australasia and North America.

Most aggregates are now produced from commercial pit and quarry operations, and suppliers need to comply with strict working procedures designed to mitigate negative environmental impacts. In wet workings, where water tables are high, operators back-fill pits with clean, inert waste materials prior to replacement of sub-soil and top-soil. In some cases additional drainage is provided and, in others, piping for sub-soil irrigation or drainage is placed within the soil at the same time as refilling. In dry workings, other domestic, trade and industrial wastes materials are permitted as fills. Pit operators make a charge for dumping these waste materials and, in most cases, this contributes a substantial proportion to the profitability of the pit. Top-soil and sub-soils are replaced by spreading from an excavator with an extended boom to avoid recompaction.

An agricultural land classification (ALC) is used to assess the quality of land for agricultural use. Bransden (1991) has shown that ALC grades have been improved in the course of land restoration through improved drainage, by evening out soil depth variations, and by incorporating sub-soil irrigation methods.

3.2 Regional practice

Malawi
The specifications for road and bridge works in Malawi states that:

> "…borrow pits shall be excavated to regular width and shape and shall be cleared upon completion so that the sides are neatly trimmed, top-soil replaced and the bottom levelled and drained in such a manner that no water will collect or stand in them."

Botswana
The Botswana specification for Road Bridge works, states that:

> "…on completion of his operations in a borrow area, the contractor shall reinstate the entire area so that it blends with the surrounding area and is suitable for re-establishment of vegetation."

The specification offers five paragraphs explaining requirements on shaping, dumping spoil and excess materials, replacement of 'soft' materials, scarification of haul roads, drainage, fencing and grassing. The contractor needs to submit to the engineer a signed certificate from the landowner or the Land Board if tribal lands have been excavated, stating that he is fully satisfied with the finishing off of any borrow.

Zambia
In Zambia, similar guidance is given in the section on quarries and borrow pits in the 1973 *Standard specification for roads and Bridges*.

Zimbabwe
The Zimbabwe *Road Design Manual* (Part F, Section 8.5) gives guidance on the reinstatement of material deposit areas. It requires that, after the removal of pavement gravels and fill materials for use in the road, the working area:

> "… must be reinstated so that it will not prove a hazard to man or beast, or a source of erosion. The sides of the excavation must be sloped and the overburden and topsoil previously removed before stockpiling the gravel, must be replaced over the entire area in order to assist in re-establishing grass cover......the rehabilitation of both gravel areas and access roads must be carried out to the satisfaction of the engineer.....the rate per hectare will include full compensation for clearing and rehabilitation of the defined area as specified."

These statements are typical of the instructions for rehabilitation contained in regional specifications.

4. Survey of borrow areas

A visual survey method was developed to assess the level of compliance with the guidance given in existing manuals. The survey sheets incorporated in this method are included in Appendix A. A range of borrow areas was selected from project records or the available materials inventories, and the sites visited by project staff. Typical sites are shown in Plate 4-1 and Plate 4-2.

Plate 4-1 Un-reinstated borrow area in an area of natural beauty; Zimbabwe

Plate 4-2 Un-reinstated borrow area in northern Botswana
Typical of many borrow pits in the region

Results obtained from pits surveyed in Malawi and Zimbabwe are summarised in Table 4-1. In only 12 per cent of the pits was there any attempt at restoration. The extent of the land degradation is demonstrated by the number of areas previously used for farming activities, and which are now non-productive. The problem of abandoned borrow pits without restoration was particularly serious in the communal lands in Zimbabwe, and in parts of Malawi where intensive subsistence farming is common.

Table 4-1 Summary of borrow pit survey results

	Per cent of pits reinstated	Per cent with high visual impact	Per cent used previously for farming	Per cent used currently for farming	Per cent of sites eroded	Per cent for which compensation has been received
Zimbabwe	0	0	50	0	12	0
Malawi	17	86	56	4	60	0
Average	12	65	55	3	48	0

In many cases, these areas are also prone to further degradation by soil erosion. Top-soil and overburden were not removed and stockpiled separately, thus preventing in the correct order after working.

The results suggest that there is a significant problem in the region of contractors not complying with regulations and guidelines, even to the extent of replacing overburden in the borrow area. In the past, supervising consultants and some roads departments have given little emphasis to ensuring that this particular contractual obligation has been met. All too frequently, the contractor is allowed to move the plant to other jobs without completing borrow pit reinstatement.

During the study, many of the effected farmers raised the issue of compensation. Land owners have a statutory obligation to part with their land if it is required by the state for public works and, in this case, a claim for compensation can be made to government. Compensation is calculated on the basis of one year of lost production. Houses, out-buildings, fruit trees, and the like, are valued and then compensated separately. However, evidence from the survey suggests that compensation is rarely paid to farmers renting or owning land that is lost.

5. Improvements to current practice

5.1 Current practice

It was clear that from the survey of working borrow pits, and discussions with various personnel responsible for these, that there was no systematic plan or work procedure to develop and manage borrow areas. Often it was the responsibility of a single bulldozer operator to open the pit, initially by bush clearing, grubbing, moving soft materials to the edge of the borrow area, ripping and stockpiling the seam. In general, the shape of the pit was pre-determined, but there was no attempt to separate the soil profile layers, even though this information was often available from the pit plans.

After stockpiling and removal of the gravel to the road site, plant is usually moved quickly to undertake other operations, such as bush clearing on the road, or to open another borrow pit. Little or no attempt is made to reinstate by pushing back the overburden soil.

5.2 Proposed procedures

Revised working procedures need to be easy to operate, flexible, practical and cost-effective, if contractors are to be persuaded to adopt them. New procedures were developed under the project in close consultation with personnel from several roads departments, and based on information provided by experienced contractors and supervisors. The new procedures developed for opening, working and rehabilitation of the borrow pits are as follows:

1. During borrow pit investigations obtain information necessary to plan operations on:
2. soil profile (thickness of top-soil and sub-soils)
3. areas to be designated for storage of top-soil and sub-soil materials
4. amount of scrub and vegetation to be removed.
5. Scrape off the thin organic layer (usually 100 to 150mm); this can usually be distinguished by a change in soil colour; care must be taken to minimise contamination with the underlying material
6. Stockpile the top-soil material in shaped berms
7. Remove the sub-soil layers in sequence, and stockpile separately from the top-soil in shaped berms
8. Rip, stockpile, load and remove the seam material
9. Grade, contour and rip the floor of the borrow area if required
10. Spread excess or spoil material evenly to level the floor of the borrow pit
11. Spoil and waste construction materials may be dumped and levelled in the pit
12. Spread the sub-soils in the reverse sequence to that in which they were removed to reinstate the layers in the correct order, restricting plant movements to the minimum necessary
13. Spread the top-soil evenly over the surface, restricting heavy plant movements to the minimum
14. Fertilise and seed, as required, or as agreed with the land owner

Figure 5-1 shows a sketch of the recommended working procedure for stockpiling soils and materials. The top-soil should only be used for borrow area restoration, and should not be used to supplement materials required for side-slope cover or other road project purposes.

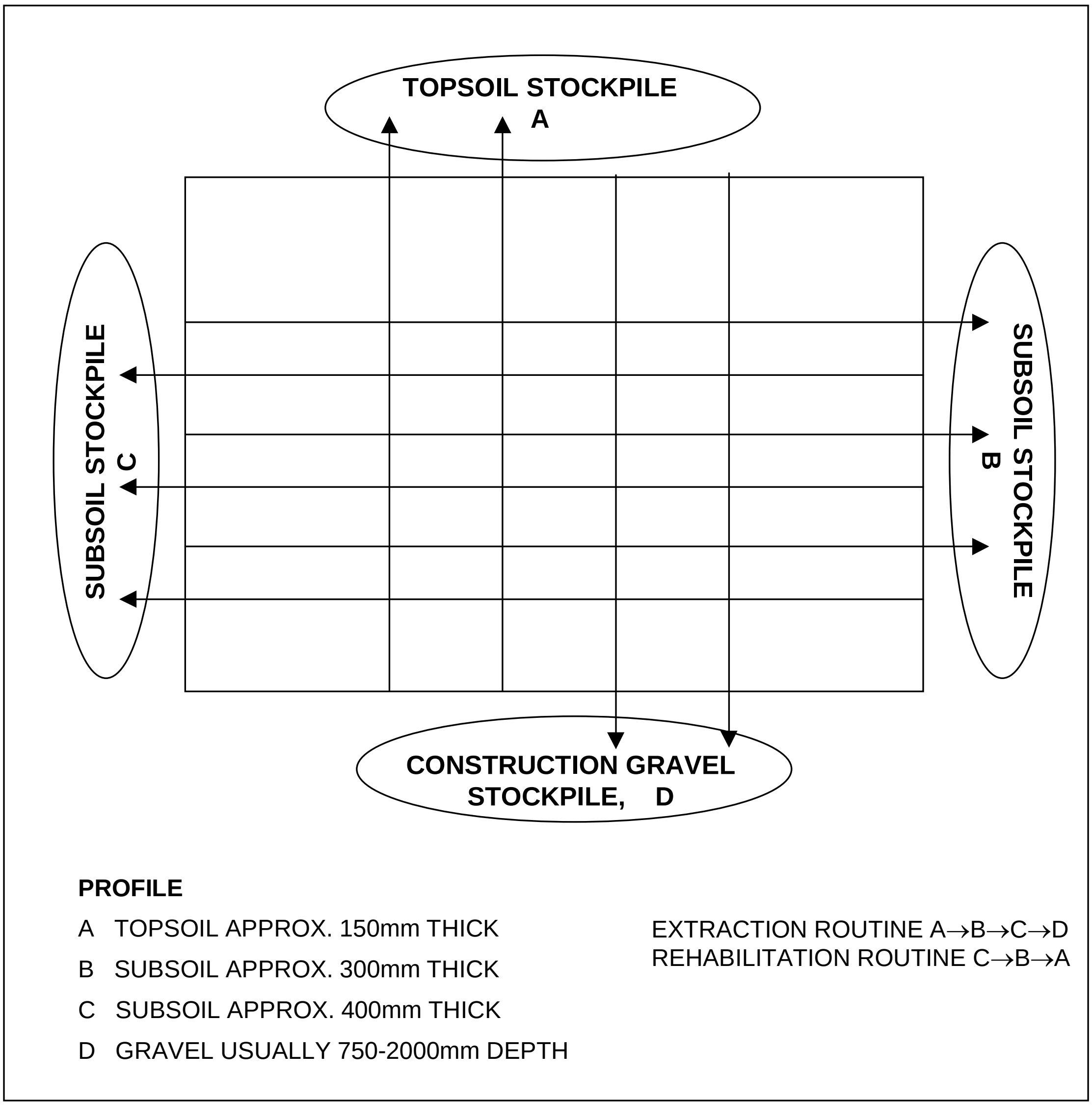

Figure 5-1 Recommended working procedure

6. Field testing programme

6.1 Basic approach

The field work on the project was conducted mainly in Malawi where the environmental impact of road construction projects is high, particularly in areas of intensive subsistence farming. Borrow areas for roadbase and sub-base materials in Malawi were identified for detailed investigation at Muhura, Khululira and Namale on the Limbe-Muloza road project in the south of the country. Six further pits were identified on the Kasungu-Mchinji road. An initial investigation of the area was conducted without involving the contractors so that the normal method of excavating borrow-pits could be monitored. Some of the borrow areas identified for materials extraction and subjected to site investigation and soil sampling were not subsequently used by the contractor.

Pits were identified where the effectiveness of the contractors normal working procedures could be evaluated, and revised procedures could be implemented and monitored. The pits at Muhura, Khululira and Matutu were used to observe current practice, and the revised operating and rehabilitation procedure implemented at Bongera, Kochilira, and Ncholonjo.

Visual surveys, site investigations and laboratory testing were carried out to determine soil quality before extraction of road building materials started. Information from samples collected was used to classify the land quality prior to opening and working the gravel seam. A follow-up programme of surveys and soil testing was conducted on the selected borrow areas reinstated within the project time-frame

6.2 Soil-science background

In situ soils are primarily characterised by their morphological properties. These, however, are complemented by chemical properties to give a more complete characterisation of the soil. One of the definitive morphological properties is the variation in the character of soil with depth. This variation is indicated by changes in properties such as colour, texture, structure and gravel content. Soil profile descriptions are the basic field records for this type of information and constitute the primary means of characterisation.

The potential of a soil for agricultural use is a function both of its morphological and nutritional chemical properties. In this respect, the relevant morphological properties are the effective soil depth, soil structure and soil gravel content. The key nutritional chemical properties are the nitrogen (N), phosphorous (P) and potassium (K) contents. The organic matter (OM) content and pH also influence the nutritional status of the soil, although they themselves have no direct nutritional value to plants.

Morphological properties are the primary criteria used by subsistence farmers to assess land for agricultural purposes, and useable soil depth, grading and texture are particularly important in this context.

6.3 Field monitoring and testing

Expert personnel were provided by the Soil Survey Unit of the Ministry of Agriculture and Water Development in Malawi to carry out the field investigations and soil analysis. Road

Department staff monitored the opening of the pits, the excavation, stock-piling of the materials and final reinstatement. These staff also supervised implementation of the revised working procedures where these were adopted.

At each of the prospective borrow areas, the soil investigation included:

- Collection of data on the characteristics of the soil profile
- Collection of samples for determination of soil chemistry for the individual layers in the profile
- Analysis of the data with respect to the quality and agricultural use

Information was also collected on the environment in and around the borrow area, including vegetation, land use, hydrology, topography, climate, watershed and drainage.

Typically six soil pits were excavated at each site to expose the layered profile of a soil, as shown in Plate 6-1. These pits were normally at least 1.5 metres deep or were dug to a limiting layer which was usually the gravel. The horizons of each profile, as shown in Plate 6-2, were then described according to the Food and Agriculture Organisation (FAO) guidelines (FAO 1977). Among the main morphological properties examined were horizon thickness, soil colour (see Plate 6-3), soil structure, soil consistency and gravel content. The pH of the soil was also recorded as illustrated in Plate 6-4.

Soil samples were taken from profiles, using recognised methods, for chemical analysis by the soil laboratories at the Chitedze Agricultural Research Station (Plate 6-2). The basic analyses carried out were for pH, organic matter, nitrogen, phosphorous and exchangeable cations. The soil bulk densities, both unheated and heated at 105^{o}C, were determined from small undisturbed cores, as in Plate 6-5. These soil-science based tests were carried out at the Bvumbwe Agricultural Research Station.

Plate 6.1 Trial pit dug through dense borrow area showing soil profile
1 is top-soil
2 and 3 are sub-soils
4 is laterite gravel seam

Plate 6.2 Soil description procedure

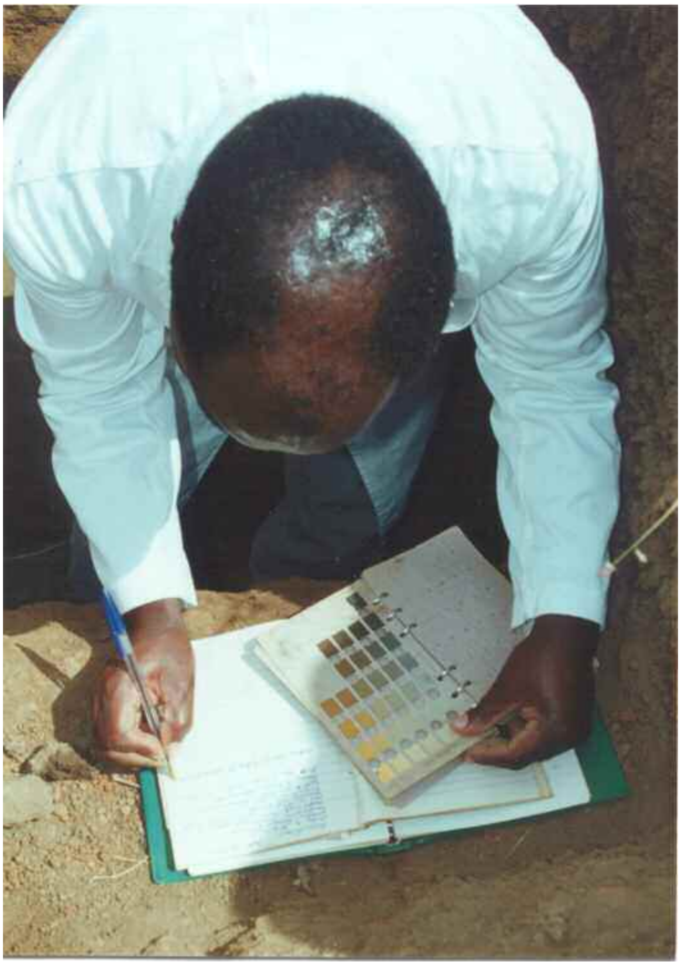

Plate 6-3 Soil colour determination using FAO guidelines

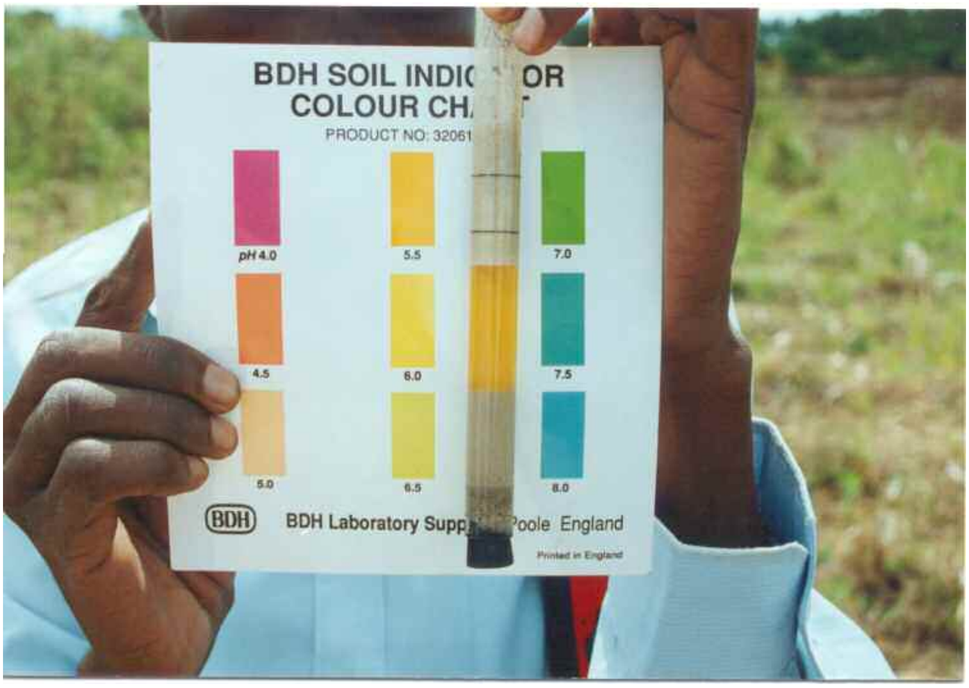

Plate 6-4 Determination of soil pH

Plate 6-5 Extraction of undisturbed soil cores for in situ soil density testing

6.4 Results

The results of the investigations prior to the excavation of soil are presented in Appendix B, and in Appendix C for the soils after reinstatement.

6.5 Discussion of results

6.5.1 Investigation prior to excavation

In general, the effective depth of the soils at the gravel pits ranges from 0.2m to 1.0m. The depth is limited by the cemented gravelly layers of the potential construction material. The texture of soils ranges from sandy to sandy loam or sandy clay loam. The soil structure can be classified as “fairly good” where the texture is sandy loam, sandy clay loam or sandy clay. Where the soils are sandy, the soil structure is “poor” and the soils are acidic. The organic matter and nitrogen contents are consistently low across the study sites with a marked trend to decrease with depth. The extractable phosphorous is variable, ranging from very low to high levels (eg at Muhura). The exchangeable potassium is mostly low or marginally adequate.

The amounts of organic matter and all plant nutrients are highest in the top-soil, and then decrease sharply with depth. However, because plant nutrients are concentrated in the top-soil, some yield is possible under subsistence farming. The results suggest that the sites are valuable agricultural lands for subsistence farmers.

6.5.2 Investigation after reinstatement

The comparisons concentrate on the working procedures monitored at Khululira and Muhura. In addition, results are reported from two borrow areas on the Kasungu-Mchinji road. The opening and restoration at Matutu was uncontrolled, whilst those at Ncholonjo complied fully with the proposed working procedures.

Sites where conventional procedures were adopted

In the Khululira, Muhura and Matutu borrow areas, the top-soil and sub-soil were removed, stockpiled and replaced in an uncontrolled sequence of movements. The general properties of the soil profile and its variation with depth suggest that soil layers have not been reinstated in their original order. The operational processes used at these sites inevitably result in disturbance of the soil profile, and in the mixing of the top-soil and sub-soil layers, as in Plate 6-6. Comparison of the soils before and after restoration indicate that there have been changes in soil colour, soil texture, clay content, organic matter content and nitrogen content. An almost unavoidable result of any borrow area working is that the natural slope, hydrology and normal geomorphological processes are disturbed.

In the natural state, the land at the Khululira and Muhura gravel pit sites sloped almost imperceptibly towards natural drainage lines beyond the gravel pit sites. After gravel extraction and the subsequent restoration, local basins were created. The land now slopes towards these basins at an increased gradient, and there is now an increased risk of soil erosion, particularly since the soil has been loosened. The land surface is now so uneven at the sites that normal subsistence farming operations, particularly ploughing, will be very difficult. These negative impacts were most pronounced at the Khululira gravel pit site, as shown in Plate 6-7, although in some areas, where top-soils were repositioned correctly, crops were being planted, as shown in Plate 6-8.

Plate 6-6 Disturbance to soil profile by mixing top-soil and sub-soil during overburden stripping operations

Plate 6-7 Environmental impacts at the Khululira gravel pit March 1999

Plate 6-8 Agricultural activity commencing at Khululira gravel pit March 1999

Nitrogen is the nutrient that crops use in the largest amounts. In subsistence farming, the main source of this nutrient is the organic matter in the top-soil. The data showed that, on the whole, the soil profile has been reversed because the organic matter content is higher in the sub-soils than in the top-soils of restored sites. This is more evident at the Muhura site where the original level of organic matter was quite high. Reversal of the soil profile would cause considerable difficulties for traditional subsistence farmer because, in general, fertilisers are seldom applied in Malawi because of their cost.

The soil colour also indicates that the soil profile has been reversed. Normally, top-soils are darker than sub-soils, due to the higher organic matter content. In the Munsell Colour Chart, the hue of regional sub-tropical top-soils is generally 10YR, while that of the sub-soils is 7.5YR, 5YR or 2YR. The data showed that in the restored state, the dominant hues of the top-soil are 7.5YR or 5YR whereas that of the sub-soil is 10YR. The colour reversal implies that the nitrogen-rich material is deeper in the soil and beyond the crop rooting zone. The clay content has been more or less homogenised through the new soil profile whereas, in their original state, it was much higher in the top-soil than in the sub-soil. This will increase the capacity of the soil to retain moisture for crop use and, in this respect, is advantageous.

These observations are illustrated in Figure 6-1 for the Matutu Borrow area. Here it can be seen that the percentage of clay increases in the top-soil, but reduces in the sub-soil after reinstatement. More importantly, nitrogen in the top-soil has been lost after the soils have been replaced.

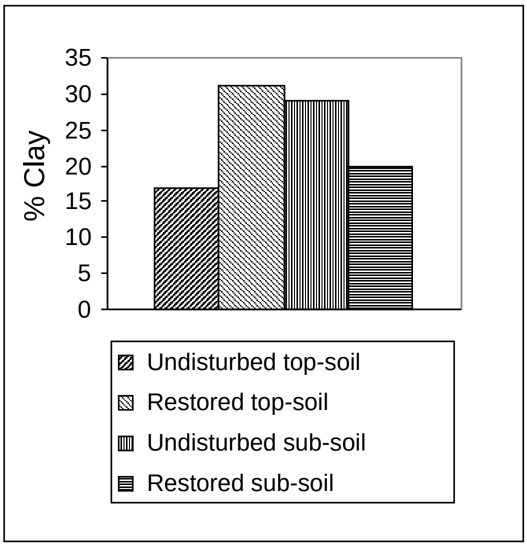

Figure 6-1 Increases in clay content for the Matutu borrow area

It is clear that a decline in yield can be expected if a soil is stripped of its top-soil, or if the top-soil is buried below the sub-soil. The sites comprised soils with favourable morphological properties for subsistence agriculture, so represented valuable land for smallholder farmers. It remains to be seen whether the local farmers will be able to generate reasonable yields from the restored sites at Muhura, Khululira and Matutu. It is likely to take a number of years for the soils to reconstitute. There is a case for compensation to be paid for a period extending beyond the end of the roads project. However, three months after the pits were rehabilitated, there was evidence that the natural vegetation was already beginning to establish itself. By March 1999, some areas of the borrow pit had been planted with maize, although disturbance to the natural slope had led to the formation of many ponds within the borrow area.

Sites where new working procedures were adopted

The new borrow area opening and restoration procedures, outlined earlier, were adopted at Ncholonjo. The contractor reported no difficulties in implementing the procedures, and the restoration was carried out using the same equipment that worked the seam. Although, inevitably there is some disturbance to the soil profile, the mixing of top-soil and sub-soil is much less than when using the existing working practices.

Figure 6-2 shows that again the clay content increases both in the restored top-soil and sub-soil. Although the Nitrogen levels have dropped by about half, the top-soil still retains the higher proportion. The soil colour was retained at its original levels reflecting that the organic content has remained high and within the correct layers.

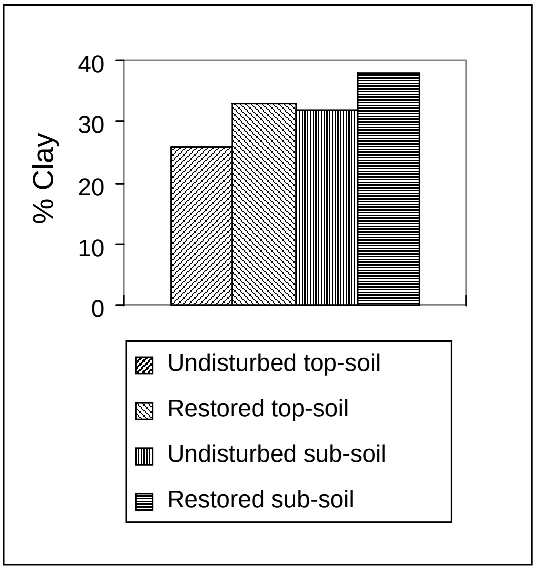

Figure 6-2 Increases in clay content for the Ncholonjo borrow area

The revised working procedures appear to offer significant improvements over the normal practice. The land stands a much greater chance of recovering at an earlier stage than any of the other sites. By March 1999, the reinstated area at Ncholonjo was producing maize and, even with the heavy rains in the area, no ponding had occurred at the borrow pit (see Plate 6-9).

Plate 6-9 Reworking land one year after rehabilitation using new procedures

7. Recommended procedures

7.1 Standard documentation

It was the intention that the results of this project could be presented in such a manner that they could be incorporated directly into new project documentation such as EIAs, contract documents, feasibility study documents or standard specifications for road and bridge works. The following guidance notes are provided in the form of standard paragraphs that can be incorporated directly.

7.2 Borrow area management

7.2.1 Planning

When determining size of the borrow area, allowance should be made for separate stockpiling of top-soil, overburden and borrow materials. Separate areas outside the borrow pit (but within the borrow area) should be allocated for storage of maintenance stockpiles. The borrow pit should be excavated to a regular width and shape. As far as possible, all existing trees, hedges, fences, and other features as set out in the contract, should be protected from damage.

7.2.2 Access

If it is necessary to construct access tracks to the borrow area, these should be provided in such a manner as to minimise disturbance to the local population and environment. Access tracks should be located at a safe distance from permanent dwellings and, if necessary, fencing should be provided for dwellings to protect local people and livestock. Access tracks, if close to dwellings or cultivated land, should be watered on a regular basis to prevent unnecessary health, environmental and vegetation damage caused by dust. Where access roads are constructed, adequate provision should be made for drainage at stream and water crossings to prevent flooding or diversion of water courses. If the access track is to be retained after rehabilitation of the borrow area, it should be shaped and graded to a suitable standard as directed by the resident engineer.

7.2.3 Top-soil removal and stockpiling

The average and range of thickness of the top-soil should be recorded on the pit plans. If differentiation between the top-soil and the overburden is not possible, the surface layer to a maximum depth of 150mm should be removed and stockpiled separately from the underlying layers in such as way that this does not interfere with the drainage of the adjacent land area. The top-soil stripping operation should be carried out in tandem with removal of vegetation, bush and grass. Conservation of the top-soil is of primary importance, and the choice of civil engineering plant used is crucial to the success of this operation. Using earth-scrapers, which operate more quickly, effectively and economically than dozers, can most effectively control top-soil stripping. The tracks of dozers tend to compact the upper soil layers and destroy the soil fabric. Earth-scrapers are also more effective at moving material over the relatively large distances required. In the absence of earth-scrapers, a combination of dozer and grader may be effective. The position and volume of the top-soil stockpile should be marked on the pit plans, and the stockpile should be demarcated with permanent markers. Top-soil stockpiles should be protected from contamination from overburden and borrow materials. They should, therefore, be located separately from these stockpiles, the borrow material loading areas and the haul routes. The top-soil stockpiles may have to stand for some time and can be subject to erosion, and the washing out of nutrients and fines. Their slopes should be shaped to minimise this, and they should be constructed in such a manner to be safe for both people and animals.

The use of stockpiled top-soil to make up deficits on other parts of the construction site should be avoided wherever possible. A maximum of 30 per cent of the available top-soil may be removed from the borrow area for this purpose, but only in exceptional circumstances.

7.2.4 Overburden removal and stockpiling

The average and range of thickness of the overburden soil should be recorded on the pit plans. In the absence of information to enable differentiation between top-soil and overburden, the latter is assumed to occupy the layer from a depth of 0.15m to the top of the gravel seam. The overburden is an important component of the soil profile and should be removed and stockpiled separately from the top-soil. It should be left in a condition that will not interfere with the drainage of the adjacent land area. The stripping operation can be carried out using any suitable plant. The position and volume of overburden soil stockpiled should be marked on the pit plans. The stockpile of overburden should be demarcated using permanent markers wherever necessary. The stockpiles should be located in a suitable area away from the top-soil stockpile to minimise the danger of contamination of the top-soil and borrow material. The over-burden stockpiles may have to stand for some time and can be subject to erosion. Their slopes should be shaped to minimise this, and they should be constructed in such a manner to be safe for both people and animals.

The use of stockpiled over-burden may be needed to make up deficits on other parts of the construction site. A maximum of 70 per cent of the available over-burden may be removed from the borrow area for this purpose. Where rocks and core-stones are encountered in the excavation, these should be stockpiled separately from the soft material. They should be placed in a safe condition.

7.3 Rehabilitation procedures

7.3.1 Replacement of overburden

It is crucial that materials are reinstated in the correct soil profile order, and landscaped to prevent unnecessary soil erosion or water ponding. On completing removal of the borrow material, any excess material in stockpiles should be spread evenly over the floor of the borrow area. Large boulders and core-stones should be placed separately, if necessary. If spoiled material is available from other parts of the construction works, this should be dumped and spread evenly over the borrow pit to a thickness not exceeding that of the seam material which was removed. Compaction of this material can be left to the action of the tyres or tracks of plant working in the pit. The overburden can then be placed at a thickness which reflects, as far as possible, the original thickness and topographic profile. If no spoil material is available for the borrow pit, the level at which the overburden is replaced will be below that of the surrounding land. In such circumstances, the provision of adequate drainage is essential, and it may be necessary to provide horizontal sand drains or other suitable drainage layers within the replaced overburden. Over-compaction of this layer by plant tyres should be avoided. On some occasions, it may be necessary to rip the top of the replaced layer lightly before replacing the top-soil.

7.3.2 Replacement of top-soil

Replacing the top-soil is a sensitive operation and should be arranged on a programme that enables work to be undertaken in an appropriate season of the year. This operation is best achieved with earth-scrapers, front-end loaders or back-actors. The top-soil should be replaced uniformly and, as far as possible, to the original top-soil thickness. Compaction of the top-soil should be avoided to prevent de-structuring, and areas, which have been compacted by tracks or tyres, should be lightly ripped. Trees, grass or shrubs should be planted as directed in the contract. Removal, stockpiling and replacement of the top-soil will result inevitably in the loss of nutrients and the degradation of the material. This should be made good. After replacing the top-soil, the layer should be reduced to a tilth and any stones, larger than about half of the layer thickness, should be removed. The planting of grass or other vegetation shall be carried out just prior to the on-set of the rainy season. Phosphate should be applied evenly and worked into the soil at a rate of about 200kg per hectare. Runners of designated grasses should be planted as directed in the contract, usually in rows 300mm apart with 300mm between individual plants. A top dressing of nitrogen should be applied after the runners have started to take. Any subsequent applications of nitrogen should be as directed in the contract. Replanting and the application of further nutrients should be considered in areas which do not germinate. Where replacement of trees is stipulated in the contract, these should be well rooted and well grown before being transplanted in the proper season. Ties to stakes with creosoted ends shall support each tree. A facility should be established with the land owner to ensure that new trees are well maintained by watering and the addition of required nutrients.

7.3.3 Disposal of surplus material and spoil

It is desirable that the borrow pit is reinstated as closely as possible to the original level. One way of achieving this is to use the borrow pit for disposal of excess materials and spoil derived from the construction works. This might include excess cut, expansive or dispersive soils, or unsuitable materials such as ant hills and screenings. Materials used to back-fill the borrow pit should be chemically inert and be approved by the resident engineer. These materials should be dumped, spread and levelled in the same way as the overburden. Compaction of these materials is not required unless directed by the resident engineer. The level at which these materials are placed should be recorded on the pit plans, giving due consideration to the volume of over-burden and top-soil to be placed at the final stage.

7.4 Additional requirements

7.4.1 Safety considerations

Temporary warning signs should be placed to alert local pedestrians and traffic to the presence of heavy plant and machinery within the borrow area and along the access routes. Adequate provision of passing places on access routes should be provided.

No hazardous waste or materials should be left in or buried within the borrow area without the prior consent of relevant local authorities.

Where it has not been possible to reinstate the borrow area to the original level, slopes should be cut so as to pose no threat or danger to people or animals. Fencing should be provided if steep slopes are unavoidable.

Where the land is reinstated to a level that is lower than that of the original, adequate drainage should be provided throughout the area to reduce the risk of water ponding. In some cases, it may be necessary to provide cut off-drains within the borrow area.

7.4.2 Other damage

Any refuelling or other plant maintenance operations carried out at the borrow pit should be strictly controlled to avoid spills, and contamination of soil and water by fuel, oil, grease, and the like. Any accidental spills should be cleaned up.

Littering and use of the borrow pit for dumping should be avoided, unless agreed previously with the local authorities.

Fencing displaced during the borrow operations should be replaced and made good to the satisfaction of the land owner.

7.4.3 Stockpiling for maintenance

If a proportion of the borrow area is to be retained for storage of maintenance materials, stockpiles should be located in suitable areas outside of the original borrow pit. This will allow the above rehabilitation procedures to be carried out fully. These stockpiles may stand for several years and should be kept to a uniform symmetrical shape. Side-slopes should be designed to prevent erosion, and should be at a safe slope and height. These smaller reserved areas should be fenced.

7.4.4 Completion

On completion of works the side-slopes of the borrow area should be stable and safe for pedestrians and animals to negotiate.

7.5 Special considerations

7.5.1 Antiquities

Due consideration should be given to avoiding areas of local historical or cultural interest. Borrow areas should not be located within 25 metres of grave sites.

7.5.2 Flora

The felling of mature trees and the burning of vegetation on the site should be avoided, unless otherwise directed by the resident engineer.

8. Conclusions and recommendations

8.1 Review current practice

The survey and observations made in the region show that, in the past, restoration of borrow pits has been the exception rather than the rule.

Post excavation inspections are rarely conducted to determine whether borrow pits have been restored correctly, that landowners are satisfied with the reinstated land, and that compensation payments have been received.

8.2 Impact of current and proposed restoration strategies

The environmental impact caused by improper extraction and rehabilitation practices can extend over a wide area, and may only become apparent after project completion. Examples include the erosion of the exposed soils causing siltation of natural water courses.

The causes and effects of these impacts needs to be recognised, and environmental management needs to be extended to all borrow area operations on road construction, rehabilitation and maintenance projects to minimise damage to the natural, social and economic environment in the surrounding area.

Environmental damage caused be working borrow pits is often most severe in areas important for subsistence farming. Top-soils, which are often thin and fragile, are organically rich and have characteristics important to agriculture. The fertility of these soils depends on the nutrients available in the soil, which can be destroyed by poor extraction and rehabilitation procedures. All who are involved in the road provision process need to ensure that activities conducted do not diminish the capability to grow food, and that areas disturbed are left safe and secure from hazards.

The extraction of road building materials can have a significant impact on land, and interviews with land owners and subsistence farmers have indicated that they are concerned with and understand the need to limit damage to their local environment. Greater attention should be given to the education of land owners in this area, particularly where they are also subsistence farmers.

Contractors often leave pits open at the request of the land owner, because these are seen as a useful mini-reservoir to provide water for animals, washing and bathing and in rare cases also irrigation. The health risks associated with this option should be highlighted, including the risks to humans caused by exposure to stagnating water and mosquito borne disease. In many cases, it is women and children who are most at risk.

In Canada, a levy based on the tonnes of material extracted is placed on the operators of borrow pits. This is held in a security account or against a contract value, and only returned when the restoration works have been carried out properly and in good time. Other methods available to ensure restoration procedures are carried out include the imposition of penalty and retention clauses in the contract documentation.

8.3 Future restoration strategies

A revised working procedure for borrow areas has been developed which could reduce the impact of materials extraction on top-soil quality.

Reversal or mixing of the soil profile should be avoided by careful removal, storage and replacement of the soils.

Once the road construction materials have been stockpiled, operators can start reshaping and rehabilitation, rather than leaving plant idle in the pit.

Soil fertilisers should be applied as soon as the soils are replaced to encourage vegetation growth prior to on-set of the rains.

It is difficult to avoid disturbance to local drainage patterns and to changes in the topographic profile, but these effects can be reduced if pits are back-filled with spoil. It is, however, recognised that this could incur additional haulage costs.

Procedures need to be developed by contractors for individual borrow areas, and presented as part of their contract proposals for evaluation by the Roads and Environmental Departments. Even if the implementation of environmentally sensitive operations incur additional costs at construction, these are likely to be offset by the longer term benefits.

Procedures developed during the current project have been demonstrated.

The guidance notes developed could incorporated into contract documentation.

8.4 Further work

Further development and research application work can be usefully undertaken in the following related fields:

- The cost-effective use of redundant borrow areas for waste and spoil disposal.
- The safe modification of borrow areas into rural irrigation schemes as potential small reservoirs.
- The use of back-filled borrow areas as bio-engineering nursery areas for earthwork stabilisation and maintenance.

9. References

Bransden, B E, 1991. Soil protection as a component of gravel raising. Soil Use and Management. 7, (3).

Council of the European Communities, 1985. The assessment of the effects of certain public and private projects on the environment. Council Directive 85/337/EEC. Brussels: European Commission.

Department of the Environment and the Welsh Office, 1989. Environmental assessment: A guide to procedures. London: H M Stationery Office.

FAO, 1977. Guidelines for soil profile description. Soil Resources Development and Conservation Service. Rome: United Nations Food and Agriculture Organisation, second edition.

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Appendix A: Survey method for the borrow pits

Road: ....

Pit name: ....

Location: .... Chainage: .... Offset: ....

Notes

1. GENERAL

A Date worked [ ][ ]

B Reinstated Yes/No 1B
Level [ ]

C Photo Yes/No
Ref [ ][ ][ ]

D Fenced Yes/No
Level [ ]

E Evidence of standing water Yes/No
If wet Yes/No

F Size [ ]

G Owner:...

....

....

H Compensation information:...

....

....

2. ECONOMIC ACTIVITIES

A Previous use:..
(cf adjacent area)
2A,2B,2C

B Current use:..
2A,2B,2C

/continued

C	Potential future use:... 2A,2B,2C					
D	Vegetation in borrow		Y/N	Type:....................		2D
E	Vegetation:	Planted	Y/N	Type:....................		
		Natural	Y/N	Type:....................		
		Saved trees	Y/N	Alive	Y/N	
F	Population density	Level	[ ]			2F
G	Demolished buildings	Y/N				

3. ENGINEERING INFORMATION

A	Seam type:..		(see list)	
B	Seam use:...			3B
C	Thickness.:..		(cm)	
D	Side slopes:	Height:...................................	(m)	
		Angle:....................................		3D
		Shape:....................................		
E	Erosion:	Edge slopes:.............................		3E
		Berms:....................................		3E
		Borrow floor:............................		3E
		Adjacent area:...........................		3E
F	Drainage:	Direction:................................		
		Type:.....................................		
		Shape:....................................		
		Level [ ]		3F
G	Access roads:	Type:......................................		3G1
		Use:.......................................		3G2

/continued

4. SOIL FEATURES

A	Organic layer:	Type:....................................	
		Thickness:..............................	(cm)
		Particle size:...........................	
		Grading:................................	
		Fabric:..................................	
		Porosity:................................	
		Strength:................................	
		Moisture condition:....................	
		Colour:..................................	
		Texture:................................	
B	Overburden	Type:....................................	
		Thickness:..............................	(cm)
		Particle size:............................	
		Grading:................................	
		Plasticity:...............................	
		Fabric:..................................	
		Porosity:................................	
		Strength:................................	
		Moisture condition:.....................	
		Colour:..................................	
		Texture:................................	

5. OTHER INFORMATION

A Visual impact Level [ ] 5A

B Other information:..

....

....

....

....

....

....

....

C Water quality risks Y/N

Mineral type:............................

D Cultural:... Type:.....................

E Risks to population/livestock/animals

Type:....................................

NOTES

1B REINSTATED LEVEL:

Very good (i.e. very productive)	= 4
Adequate (i.e. productive)	= 3
Poor (poor yields)	= 2
Natural vegetation (bush)	= 1
Barren	= 0

1D FENCING:

Very good (safe)	= 3
Adequate	= 2
Poor/none	= 1
None & dangerous	= 0

2A, 2B, 2C

ECONOMIC USE:

Arable land	type?
Ranching	type?
Forestry	type?
Commercial farming (Estate)	type?

2D VEGETATION:

Forested	F
Natural woodland	NW
Scrub/bush	S
Crops	C
Grassland	G
Other (type?)	O

2F POPULATION DENSITY (within 100m of Borrow):

None	= 0
1 house per $100m^2$	= 1
1-3 houses per $100m^2$	= 2
3-5 houses per $100m^2$	= 3
>5 houses per $100m^2$	= 4

3B	SEAM USE:		
		Base	
		Sub-base	
		Fill	
		Other	(what)
3D	SLOPES:		
		ANGLE: Steep	
			Gentle
			Shallow
3E	EROSION:		
		None	= 0
		Runnels	= 1
		Gullies	= 2
		Severe	= 3
		Very severe (sheet)	= 4
3F	DRAINAGE:		
		Free drainage soil	= 0
		Inhibited (likely erosion)	= 2
		Ponded	= 4
3G	ACCESS ROADS:		
	3G1	TYPE:	Bush track
			Earth track
			Gravel road
			Other (type?)
	3G2	USE:	No use
			Used by local population
			Used by vehicles
5A	VISUAL IMPACT:		
		Hidden	= 1
		Seen from 200m	= 2
		Seen from 500m	= 3
		Seen from 1000m	= 4

Appendix B: Results of investigations prior to soil excavation

Box B.1 Abbreviations used in Appendices B and C

Ca	Calcium
Ex	Exchangeable
Extr	Extractable
g	Gravelly
K	Exchangeable potassium
LS	Loamy sand
Mg	Magnesium
N	Nitrogen
Na	Sodium
O	Original
OM	Organic matter
P	Extractable phosphorus
R	Restored
SC	Sandy clay
SCL	Sandy clay loam
SL	Sandy loam

B1 Soils of the Muhura gravel pit site in Thyolo

The physical environment

The Muhura gravel pit site is on an interfluve, which slopes eastward at slope gradients of 2 per cent or less. Obvious signs of soil erosion were not observed at the site. The site is in an area with a mean annual rainfall of 1375mm. Most of this amount falls from November to May. The natural vegetation has long been cleared and the land is used for arable cropping by subsistence farmers. Maize is the main crop being grown but it is inter-cropped with minor crops such as pigeon peas, groundnuts and cassava.

Soils

At the Muhura gravel pit site, the five soil profiles give an idea about the nature and range of soils. Table B-1 gives a summary of the main morphological properties contained in the soil profile descriptions, focusing on the soil over gravelly layers. The table contains the corresponding summarised chemical data also. Soil profile descriptions were prepared for five such test sites and these are presented in Table B-2, together with the corresponding analytical data.

Morphological properties

The depth of the soil overlying gravelly layers is 20cm at least, but ranges from 20 to 95 cm. The top-soil on its own is at least 19cm thick. At most test sites, cementation of the gravelly layers starts at the depths shown in Table B-1; detrimental hindrance to vertical plant root extension is expected at these depths. The brown colour of the soil is indicative of good soil drainage. The texture of the soil above the gravelly layers ranges from loamy sand to sandy clay. The top-soil texture is either sandy loam or loamy sand; the sub-soil is generally sandy loam but is as fine-textured as sandy clay at some test sites. The soil structure is generally good in the top-soil but deteriorates as the gravelly layer is approached. Considering that the soil has been under continuous cultivation, probably under minimal management, the soil structure of the top-soil seems to be fairly stable.

Table B-1 Properties of soils at the Muhura gravel pit site

Profile no.	Depth to gravelly layer (cm)	Soil texture over gravelly layer	Soil structure over gravelly layer	pH	OM (%)	N (%)	P (Fgg^{-1})	K (cmolkg^{-1})	Bulk density (gcm^{-3})	
									105°C	Unheated
1	41	SCL-SC	Good	5.0-5.3	2.1-3.5	0.10-0.18	29-78	0.18-0.45	1.54	1.65
2	32	SL-SCL	fair to good	5.4-5.6	1.6-1.7	0.08-0.09	8-44	0.22-0.31	1.56	1.67
3	20	SL-SCL	good	5.0	1.7	0.09	43	0.28	1.41	1.47
4	95	LS-SCL	fair to good	6.4-6.9	0.3-1.1	0.02-0.06	80-108	0.09-0.17	1.42	1.43
5	65	LS-SL	poor to fair	5.5-5.8	0.3-1.0	0.02-0.03	66-74	0.08-0.22	1.65	1.67

Table B-2 Soil profile descriptions and corresponding analytical data for Muhura

Profile no.	MUHURA 1	MUHURA 2	MUHURA 3	MUHURA 4	MUHURA 5
Location	Muhura gravel pit, Thyolo District	Muhura gravel pit, Thyolo District	Muhura gravel pit, Thyolo District	Muhura gravel pit, Thyolo District	Muhura gravel pit, Thyolo District
Slope	gently sloping, 4%	almost flat, 2%	almost flat, 2%	flat, <2%	flat, <2%
Land-use	maize garden	maize garden	maize garden	maize garden	maize garden
Drainage	well-drained	well-drained	well-drained	well-drained	well-drained
Surface moisture condition	dry	dry	dry	dry	dry
Depth to groundwater table	unknown, but more than 150cm	unknown, but more than 160cm	unknown, but more than 140cm	unknown, but below 123cm	unknown, but more than 65cm
surface stones	none	none	none	none	none
Evidence of erosion	none	none	none	soil deposited by water	soil deposited by water
Presence of salt or alkali	none	none	none	none	none
Human influence	cultivation	cultivation	cultivation	cultivation	cultivation
PROFILE DESCRIPTION	0-20cm Dark brown (7.5YR 3.2) dry, and very dark greyish brown (10YR 3/2) moist; sandy clay loam; strong, medium, sub-angular blocky; hard, firm, slightly sticky; common, very fine tubular pores; no mineral nodules; common very fine roots; abrupt smooth boundary.	0-19cm Brown/dark brown (10YR 4/3) dry and dark brown (7.5YR 3/2) moist; sandy clay loam; moderate, medium sub-angular blocky; slightly hard, slightly sticky; common fine tubular pores; no mineral nodules; few ant nests; common very fine roots; abrupt smooth boundary.	0-20cm Dark brown (10YR 3/3) dry and dark brown (7.5YR 3/2) moist; sandy loam/medium sand clay loam; moderate, medium sub-angular blocky; slightly hard, friable, slightly sticky; common tubular pores, common very fine roots; very few mineral nodules; abrupt smooth boundary.	0-12cm Brown/dark brown (10YR 4/3) dry and moist; loamy sand/medium sandy loam; strong, thin platy soil structure; slightly hard, very friable, non-sticky; many fine roots; porous; abrupt smooth boundary.	0-10cm Brown (10YR 5/3) dry and dark brown (7.5YR 3/2) moist; loamy medium sand; strong thin platy soil structure; slightly hard, very friable, non-sticky; very porous; common fine roots; abrupt smooth boundary.
	20-41cm Reddish brown (5YR 4/4) dry and dark reddish brown (5YR 3/3) moist; sandy clay/clay; moderate, coarse sub-angular blocky; hard, friable, sticky, no cementation; common, fine tubular pores; no nodules; common very fine roots; abrupt wavy boundary.	19-32cm Brown/dark brown (7.5YR 4/4) dry and dark reddish brown (5YR ¾) moist; sandy clay loam; weak, medium sub-angular blocky; hard, friable, sticky; no cementation; common fine tubular pores; very few mineral nodules; some ant nests; common very fine roots; abrupt wavy boundary.	20-110cm Cemented, nodular petroferric horizon; abrupt wavy boundary.	12-22cm Dark brown (10YR 3/5) dry and moist; loamy sand/sandy loam; moderate medium sub-angular blocky; slightly hard, friable; very porous; common fine roots; abrupt wavy boundary.	10-35cm Brown/dark brown (10YR 4/2) dry and moist; loamy medium sand; structureless (massive); slightly hard; very friable; non-sticky; very porous; common fine roots; clear smooth boundary.
	41-93cm Hard mineral nodules (small and large) very frequent to dominant; soil material occurs as filling; no cementation of nodules; abrupt wavy boundary.	32-71cm Horizon dominated by hard, yellowish, large nodules; partially cemented horizon but penetrable by roots; clear, wavy boundary.	110-140cm Yellowish-red (5YR 4/6) dry and moist; sandy clay loam/sandy clay; weak, medium angular blocky; hard, friable, sticky; many weatherable rock materials.	22-50cm Dark yellowish brown (10YR 4/4) dry and moist; medium sandy loam; weak angular blocky; hard, friable; slightly sticky; few fine roots; diffuse boundary.	35-65cm Brown (10YR 5/4) dry and dark brown (7.5YR 3/2) moist; medium sandy loam; structureless (massive); hard, friable, slightly sticky; porous; few fine roots; abrupt smooth boundary.
	93-150cm Yellowish-red (5YR 4/8) dry and moist; sandy clay loam; strong, medium angular blocky structure; hard, friable, sticky; very few mineral nodules; weathering biotitic rock; many mica flakes.	71-100cm Reddish brown (5YR 4/4) dry and moist; sandy clay loam; strong, medium angular blocky; hard, brittle, slightly sticky; distinct cutans; incipient dark cementing materials; weathering rock minerals; clear wavy boundary.		50-95cm Dark yellowish brown (10YR 4/4) dry and brown/dark brown (7.5YR 4/4) moist; sandy loam/sandy clay loam; weak, coarse, angular blocky; hard, non-sticky; common fine pores; ant nests filled with materials of the overlying horizons; abrupt smooth boundary.	65cm+ Hard, reddish nodules, strongly cemented below 70cm.

continued

Profile no.	MUHURA 1			MUHURA 2				MUHURA 3			MUHURA 4			MUHURA 5		
PROFILE DESCRIPTION				100-160cm Mostly very weathered rock; many biotite minerals mixed with a little soil material.							95-123cm Cemented horizon of reddish laterite.					
DEPTH (cm)	0-20	20-41	93-150	0-19	19-32	71-100	100-160	0-20	110-140		0-22	22-50	50-95	0-10	10-35	35-65
Clay (%)	30	45	34	20	30	35	33	20	42		10	14	20	10	12	14
Silt (%)	10	10	10	10	12	12	14	4	10		4	4	4	4	4	4
Texture class	SCL	SC-C	SCL	SL-SCL	SCL	SCL	SCL	SL-SCL	SCL		LS	SL	SL-SCL	LS	LS-SL	SL
pH (H_2O)	5.3	5.0	5.3	5.6	5.4	6.8	5.5	5.0	7.1		6.4	6.9	6.8	5.5	5.8	5.6
OM (%)	3.5	2.1	0.3	1.7	1.6	0.5	0.7	1.7	0.5		1.1	0.3	0.4	1.0	0.6	0.3
N (%)	0.18	0.10	0.02	0.09	0.08	0.02	0.03	0.09	0.02		0.06	0.02	0.02	0.02	0.03	0.02
Ex Ca (cmol(+)kg^{-1})	4.13	1.93	2.80	2.43	2.00	2.37	3.07	1.27	0.78		4.20	2.92	3.26	1.29	1.54	0.92
Ex Mg (cmol(+)kg^{-1})	1.66	1.28	1.97	0.91	1.05	1.61	2.28	0.49	0.65		0.51	0.39	0.64	0.29	0.45	0.45
Ex K (cmol(+)kg^{-1})	0.45	0.18	0.22	0.31	0.22	0.24	0.28	0.28	0.53		0.17	0.09	0.11	0.22	0.11	0.08
CEC (cmol(+)kg^{-1})	6.24	3.39	4.99	3.65	3.27	4.22	5.63	2.04	1.96		4.88	3.4	4.01	1.80	2.10	1.45
Extr. P (Fgg^{-1})	78	29	0	44	8	0	0	43	1		108	80	69	72	66	74
E/C	20.80	7.53	14.68	18.25	10.90	12.06	17.06	10.20	4.67		48.80	24.29	20.05	18.00	17.50	10.36
Bulk density (g/cm^3)																
Depth (mm)	0-100	100-150	150-200	0-100	100-150	150-200		0-100	100-150	150-200	0-100	100-150	150-200	0-100	100-150	150-200
Unheated	1.65	1.68	1.75	1.67	1.64	1.72		1.47	1.77	1.68	1.43	1.41	1.65	1.67	1.52	1.62
At 105°C	1.54	1.55	1.57	1.56	1.54	1.58		1.41	1.69	1.60	1.42	1.38	1.61	1.65	1.47	1.58

The bulk densities are rather high, being 1.46g/cm^3 or higher. For further details on the morphology of the soils at the Muhura gravel pit site, refer to the soil profile descriptions presented above.

Chemical properties

The soil above gravelly layers has a pH of 5.0-6.9 with no definite trend with depth. The pH values indicate that the soil is acid to neutral in reaction. The top-soil only is acid or moderately acid, with a pH of 5.6 or less at most test sites. The organic matter content is low, being 1.7 per cent or less at most test sites. The nitrogen content is low, being 0.09 per cent or less. Both organic matter and nitrogen are highest in top-soils and decrease markedly with depth. The extractable phosphorous level of the soil above the gravelly layers ranges from 8 to 108 Fgg^{-1}; but at most test sites it is 29 Fgg^{-1} or higher. The level is highest in the top-soil and then decreases markedly with depth. The exchangeable potassium level ranges from 0.08 to 0.45 $cmolkg^{-1}$ above the gravelly layers; thus the nutrient ranges from very low to medium. In the top-soil the level is mostly within the medium range, but there is a significant decrease with depth. For more details on the chemical properties, reference should be made to the analytical data accompanying the soil profile descriptions in Table B-2.

Soil potential for agricultural use

The effective soil depth is limited by the cementation of the gravelly layer at relatively shallow depths. Consequently, deep-rooted plants may not do very well on these soils. However, there should be no problems with shallow-rooted crops. At most sites the top-soil texture and structure are not limiting. The low levels of the organic matter and nitrogen reduce the inherent potential of these soils since the nitrogen is utilised in large quantities by crops; and the organic matter is the main reservoir and source of nitrogen in the soil under natural conditions. Both phosphorous and potassium contents are within fairly reasonable ranges. No problems of acidity are expected. The morphological data indicate that the soils at Muhura are fairly good. The nutritional data, however, indicate the soils are deficient in some nutrients. However, this does not diminish the value local subsistence farmers attach to the land. The primary consideration in assessing a soil are the morphological properties such as soil depth, texture and gravelliness of the top-soil. On this basis, the soils are cultivable and are thus very valuable, particularly in this area where there is an acute land shortage problem.

B2 Soils of the Khululira gravel pit site

The physical environment

The Khululira gravel pit site is on the lower slope position on an interfluve which slopes to the west. The slope gradients are invariably less than 2 per cent. The site is in an area with a mean annual rainfall of 1375mm. Most of the rain falls from November to May. There is no natural vegetation at the site as it has long been cleared for cultivation. The main crops grown are maize, pigeon pea and cassava.

Soils

Six soil profiles were studied at the Khululira gravel pit site to determine the morphological (stable) properties of the soil. The morphological and chemical properties of the soil over gravelly layers are summarised in Table B-3. Soil profile descriptions, which are records of the basic morphological information, are presented in Table B-4. Corresponding selected chemical data have also been included. The six profiles examined give a good idea of the nature and range of soil types at Khululira.

Morphological properties

The depth of the soil to gravelly layers is at least 45cm, but the gravelly layers are not indurated until a depth of at least 70cm. The thickness of the top-soil proper is 18 to 28 cm. The texture of the soil over the gravelly layers is loamy or sandy loam with a rather coarse sand fraction. The sub-soil of profile 2 only has a texture of sandy clay. The top-soil proper is almost invariably loamy sand in texture. The soil structure tends to be poor in the top-soil due to the sandy nature of the top-soil. The structure improves with depth where the texture is sandy loam or finer. More details on morphological properties are in the soil profile descriptions presented in Table B-4.

Chemical properties

The soil above the gravelly layers is acid or moderately acid with pH values of 4.7 to 5.6. Only at one test site did the pH rise to 6.9. The organic matter content is very low, being 0.1 to 1.1 per cent in the top-soil. The nitrogen levels, too, are very low, being 0.06 per cent or less in the top-soil. The extractable phosphorous is very low at all depths; except for one test site, it is 10 Fgg^{-1} or less. The lowest levels occur in the sub-soils. The exchangeable potassium is low in the top-soil, being 0.19 $cmol(+)kg^{-1}$ or less. More details on the chemical properties are presented with the corresponding soil profile descriptions.

Soil potential for agricultural use

The soils at Khululira gravel pit site have a rather low inherent agricultural potential. Of the morphological properties, the soil texture is the most unfavourable because it is coarse. It is therefore expected to have low nutrient and moisture holding capacity. All the chemical nutrients are low so that fertiliser application would be necessary for good yields. Despite the low inherent fertility, locally the soils are valued for cultivation because they are gravel-free to a depth of 45cm at least. As a management practice smallholders either apply fertilisers and/or grow crops adapted to sandy soils.

Table B-3 Properties of soils at the Khululira gravel pit site

Profile no.	Depth to gravelly layer (cm)	Soil texture over gravelly layer	Soil structure over gravelly layer	pH	OM (%)	N (%)	P (Fgg^{-1})	K (cmolkg^{-1})	Bulk density (gcm^{-3})	
									105°C	Unheated
1	45	LS-SL	poor to good	5.7-6.9	0.2-1.1	0.01-0.07	1-16	0.11-0.29	1.62	1.69
2	113	SL-SC	fair to good	4.9-5.6	0.3-0.5	0.02-0.03	1-10	0.11-0.25	1.57	1.67
3	70	LS-SL	poor to good	5.1-5.4	0.1	0.03	2-3	0.07-0.19	1.43	1.50
4	56	LS-SL	poor to good	5.2-5.6	0.3-0.7	0.02-0.04	0-2	0.05-0.12	1.47	1.56
5	82	LS-SL	fair	4.8-5.3	0.2-0.6	0.01-0.04	1-3	0.07-0.10	1.38	1.43
6	52	LS-SL	poor	4.7-5.2	0.6-1.1	0.03-0.06	2-3	0.09-0.10	1.56	1.58

Table B-4 Soil profile description and corresponding analytical data for Khululira

Profile no.	KHULULIRA 1 (26/04/96)	KHULULIRA 2 (26/04/96)	KHULULIRA 3 (26/04/96)	KHULULIRA 4 (26/04/96)	KHULULIRA 5 (27/04/96)	KHULULIRA 6 (27/04/96)
Location	Khululira gravel pit site	Khululira gravel pit site	Khululira gravel pit site	Khululira gravel pit site	Khululira gravel pit site	Khululira gravel pit site
Slope	flat, 1%	flat, 1%	flat, 1%	flat, 1%	flat, 1%	flat, <1%
Land-use	maize and pigeon pea garden	maize and pigeon pea and cassava garden	maize pigeon pea and cassava garden	maize, pigeon pea and cassava	maize, pigeon pea and cassava	none, but regenerating bush and young blue gum trees.
Drainage	well-drained	well-drained	well-drained	well-drained	well-drained	well-drained
Surface moisture condition	moist due to rain	moist due to rain	moist due to rain	moist	ridge soil dry, but moist below 22cm	dry
Depth to groundwater table	unknown, but >200cm	unknown, but >200cm	unknown, but >150cm	Unknown, but >165cm; water seepage at 160cm.	unknown, but >150cm	unknown, but >155cm
Surface stones	none	none	none	none	none	none
Evidence of erosion	none	none	none	none	none	none
Presence of salt or alkali	none	none	none	none	none	none
Human influence	cultivation	cultivation	cultivation	cultivation	cultivation	none for quite some time
PROFILE DESCRIPTION	0-18cm Ridge layer; dark brown (10YR ¾) moist; loamy coarse sand; weak, medium, sub-angular blocky structure; soft, friable, non-sticky; no cementation; few tubular pores and very porous; no mineral nodules; abundant fine roots; abrupt smooth boundary.	0-28cm Ridge layer; yellowish brown (10YR 5/4) dry and dark yellowish brown (10YR ¾) moist; sandy loam; weak medium sub-angular blocky structure; soft, very friable, non-sticky; no cementation; many tubular pores and very porous; no mineral nodules/concretions; abundant fine roots; abrupt smooth boundary.	0-28cm Ridge layer; brown (10YR 5/3) dry and dark yellowish brown (10YR ¾) moist; loamy coarse sand; weak fine sub-angular blocky structure, soft, very friable, non-sticky; numerous micro-pores; abundant fine roots; abrupt smooth boundary.	0-22cm Ridge layer; brown (7.5YR 5/2) dry and dark yellowish brown (10YR ¾) moist; loamy medium sand; weak fine granular; soft, non-sticky; abundant fine roots and very fine roots; abrupt smooth boundary.	0-23cm Ridge layer; brown (10YR 5/3) dry and dark yellowish brown (10YR ¾) moist; loamy sand/medium sandy loam; weak fine granular and weak medium sub-angular blocky; slightly hard, friable, non-sticky; very porous; abundant fine roots; abrupt smooth boundary.	0-20cm Grey (5YR 5/1) dry and dark brown (7.5YR 3/2) moist; loamy sand/sand, structureless (massive); slightly hard, very friable, non-sticky; porous; frequent fine roots; diffuse smooth boundary.

/continued

Profile no.	KHULULIRA 1 (26/04/96)	KHULULIRA 2 (26/04/96)	KHULULIRA 3 (26/04/96)	KHULULIRA 4 (26/04/96)	KHULULIRA 5 (27/04/96)	KHULULIRA 6 (27/04/96)
PROFILE DESCRIPTION	18-45cm Dark yellowish brown (10YR ¾) moist; medium sandy loam; moderate, medium sub-angular blocky structure; soft, friable; no cementation; many medium tubular pores, porous; no mineral nodules; few ant rests; common very fine roots; abrupt wavy boundary.	28-55cm Dark yellowish brown (10YR ¾) moist; strong medium sub-angular blocky structure; slightly hard, slightly firm, slightly sticky; no cementation; many tubular pores and micro-pores; no nodules; common ant nests and channels; clear smooth boundary.	28-40cm Dark brown (7.5YR 3/2) moist; coarse sandy loam/ loamy sand; moderate, medium sub-angular blocky structure; very friable, non-sticky; very porous; some ant nests and channels; common very fine roots; abrupt wavy boundary.	22-56cm Dark yellowish brown (10YR ¾) moist; sandy loam/medium sandy clay loam; friable, slightly sticky; very porous; no nodules; few ant nests and channels; frequent fine roots abrupt wavy boundary.	23-53cm Dark brown (10YR 4/3) dry and dark yellowish brown (10YR ¾) moist; heavy coarse sandy loam; weak, coarse sub-angular blocky structure; hard, very friable, non-sticky; common tubular pores, very porous; ant nests and channels; frequent fine roots; clear smooth boundary.	20-52cm Dark brown (10YR ¾) moist; loamy coarse sand; structureless (massive); slightly hard, very friable, non-sticky; no cementation; very porous; no nodules; common fine roots; abrupt wavy boundary.
	45-90cm Hard, black concretions dominant; very little soil material (coarse sandy loam) in between gravels; *in-situ* rock boulder occupies a large volume; clear, smooth boundary.	55-113m Brown (7.5YR 4/4) and olive brown (2.5Y 4/4) mixed, colour variegation due to localised reduction and oxidation as a result of weathering; sandy clay; moderate, medium angular blocky structure; firm, sticky; no cementation; many tubular pores; very few, small, soft black nodules; some ant nests and channels; common very fine roots; abrupt wavy boundary.	40-70cm Dark yellowish-red (10YR ¾) moist; coarse sandy loam; weak fine sub-angular blocky structure; very friable, non-sticky; very porous; some ant nests and channels; common very fine roots; abrupt wavy boundary.	56-165cm Hard, large concretions dominant; not cemented; medium sandy loam soil, material between concretions is greyish brown (10YR 5/2) below 155cm due to wetness.	53-82cm Dark yellowish brown (10YR 4/4) moist; heavy sandy loam/heavy coarse sandy clay loam; weak angular blocky structure; friable, slightly sticky, plastic, no cementation; common medium tubular pores; no nodules; few fine roots; abrupt wavy boundary.	52-90cm Gravels dominant; hard, large irregular nodules not cemented; very little soil material (loamy sand/sandy loam); abrupt wavy boundary.
	90-175cm Red, hard, small and medium concretions dominant; very little, brittle, reddish brown soil material (coarse sandy loam) in between concretions; *in-situ* rock boulder occupies large volume; incipient cementation of concretions.	113-165cm Nodules dominant, weakly cemented but becoming strongly cemented with depth; layer composed of small and large irregular black and red nodules/concretions; sandy clay loam soil material occurs as fillings.	70-150cm Cemented horizon; large, hard, black and reddish concretions dominant, horizon has reddish colour; some tubular pores occur in the horizon.		82-150cm Hard, large, irregular nodules dominant, have black interiors and red exteriors; cemented horizon.	90-150cm Cemented gravelly horizon; large brown concretions dominant.

Profile no.	KHULULIRA 1 (26/04/96)				KHULULIRA 2 (26/04/96)				KHULULIRA 3 (26/04/96)			KHULULIRA 4 (26/04/96)			KHULULIRA 5 (27/04/96)			KHULULIRA 6 (27/04/96)		
DEPTH (cm)	0-18	18-45	45-90	90-175	0-28	28-55	55-113	113-165	0-28	28-40	40-70	0-22	22-56	56-165	0-23	23-53	53-82	0-20	20-52	52-90
Clay (%)	10	14	16	32	12	18	38	34	8	12	12	10	16	12	10	12	18	12	3	12
Silt (%)	4	6	2	6	6	10	8	8	6	6	4	6	6	6	6	6	4	2	4	4
Texture class	LS	SL	SL	SCL	SL	SL	SC	SCL	LS	SL	LS/SL	LS	SL	SL	LS	SL	SL	LS	LS	LS/SL
pH (H_2O)	6.9	6.1	6.3	5.7	4.9	5.3	5.6	5.5	5.4	5.1	5.1	5.3	5.2	5.6	4.9	4.8	5.3	4.7	4.7	5.2
OM (%)	0.5	0.5	0.2	1.1	0.3	0.5	0.3	0.3	0.1	0.1	0.1	0.3	0.7	0.6	0.6	0.6	0.2	1.1	0.1	0.6
N (%)	0.03	0.03	0.01	0.07	0.02	0.03	0.02	0.02	0.03	0.03	0.03	0.02	0.04	0.03	0.04	0.03	0.01	0.06	0.03	0.03
Ex Ca (cmol(+)kg^{-1})	3.63	4.47	4.25	7.22	3.31	6.09	10.16	10.06	3.50	3.53	2.75	3.25	4.50	2.03	3.53	2.53	5.19	1.94	2.41	2.22
Ex Mg (cmol(+)kg^{-1})	0.47	0.62	0.57	1.72	0.52	0.83	3.28	3.64	0.42	0.31	0.21	0.36	0.52	0.88	0.42	0.36	0.94	0.16	0.16	0.16
Ex K (cmol(+)kg^{-1})	0.16	0.13	0.11	0.29	0.17	0.11	0.17	0.25	0.19	0.10	0.07	0.12	0.09	0.05	0.10	0.07	0.07	0.09	0.09	0.10
Ex Na (cmol(+)kg^{-1})	0.44	0.36	0.27	0.49	0.31	0.36	0.40	0.58	0.44	0.23	0.40	0.36	0.27	0.23	0.40	0.36	0.36	0.36	0.31	0.36
CEC (cmol(+)kg^{-1})	4.70	5.58	5.20	9.72	4.31	7.39	14.01	14.53	4.55	4.17	3.43	4.09	5.38	3.19	4.45	3.32	6.56	2.55	2.97	2.84
Extr. P (Fgg^{-1})	16	6	2	1	10	2	2	1	7	3	2	2	0	1	3	2	1	3	2	2
Bulk density (g/cm^3)																				
Depth (mm)	180-230	230-280			280-330	560-610			280-330	330-380		220-270	270-320		230-280	530-580		50-100	230-280	
Unheated	1.69	1.53			1.67	1.81			1.50	1.65		1.56	1.60		1.43	1.61		1.58	1.57	
At 105°C	1.62	1.46			1.57	1.60			1.43	1.54		1.47	1.50		1.38	1.55		1.56	1.52	

B3 Soils of the Nam'male gravel pit site in Mulanje

The physical environment

The Nam'male gravel pit site is on an interfluve with slope gradients of less than 2 per cent. Soil erosion is not evident at the site. The area is within an area with a mean annual rainfall of 1325 mm. Most of this amount falls from November to May. The natural vegetation has long been cleared and the land is used for arable cropping by subsistence farmers. The crops grown are groundnuts, maize, pigeon peas and sorghum.

Soils

Three soil profiles were studied at the Nam'male gravel pit site. Morphological and chemical properties of the soils over the gravelly layers are summarised in Table B-5. Soil profile descriptions were prepared and are presented here in Table B-6, together with the corresponding analytical data. The three profiles give an indication of the nature and range of soils at Nam'male.

Morphological properties

The depth of the soil overlying the gravelly layer is 30cm or more. The top-soil is 10 to 15cm thick. Although gravelly layers start at a depth of about 30cm, the layers are not cemented until a depth of at least about 75cm. Thus the vertical downward extension of plant roots is expected to be significantly hampered from this depth. The texture of the soil overlying the gravelly layers is sand, loamy sand or coarse sandy loam. But that of the top-soil proper is loamy sand or sand. The soil structure is somewhat poor. This is consistent with the sandy textures of the soils. Most of bulk densities are over 1.5g/cm^3 and are thus quite high. They reflect the dominance of the coarse sand fraction in the soil.

Chemical properties

The soil overlying the gravelly layers is moderately acid, with a pH or 5.4 to 6.1. The pH tends to decrease with depth at most test sites. The organic matter content is very low, being 0.04 to 0.8 per cent in the top-soil. The nitrogen levels are correspondingly very low, being 0.01 to 0.03 per cent. The extractable phosphorous is 2 Fgg^{-1} or less; these are extremely low levels. The exchangeable potassium ranges from 0.07 to 0.12 cmol(+)/kg and tends to decrease with depth.

Soil potential for agricultural use

The soils at the Nam'male gravel pit site have low inherent potential. Among the morphological properties, the soil texture is the most unfavourable because it is so coarse that its capacity to retain nutrients and moisture is certainly quite low. All the chemical nutrients are very low. A decent crop yield would require a high dosage of inorganic fertilisers. Despite the low inherent potential, locally the soils are still valued by the subsistence farmers since the soils are gravel-free to a sufficient depth. The subsistence farmers grow groundnuts, pigeon peas and maize on these soils.

Table B-5 Properties of soils at the Nam'male gravel pit site

Profile no.	Depth to gravelly layer (cm)	Soil texture over gravelly layer	Soil structure over gravelly layer	pH	OM (%)	N (%)	P (Fgg^{-1})	K (cmol/kg^{-1})	Bulk density (gm^{-3})	
									105°C	Unheated
1	34	LS-SL	poor to fair	5.8-6.0	0.6-0.8	0.03-0.04	1-2	0.08-0.09	1.61	1.64
2	30	LS-SL	poor to fair	5.6-6.1	0.4-0.6	0.02-0.03	2	0.08-0.11	1.41	1.46
3	79	S-SCL	poor to fair	5.4-5.9	0.3-0.6	0.01-0.03	1-2	0.07-0.12	1.57	1.63

Table B-6 Soil profile descriptions and corresponding analytical data for Nam'male

	NAM'MALE 1			NAM'MALE 2			NAM'MALE 3		
Location	Nam'male gravel pit, Mulanje District			Nam'male gravel pit, Mulanje District			Nam'male gravel pit, Mulanje District		
Slope	Flat, <2%			flat, <2%			flat, <2%		
Land-use	groundnuts and maize garden			groundnuts and maize garden			groundnuts and maize garden		
Drainage	well-drained			well-drained			well-drained		
Surface ,moisture condition	dry			dry			dry		
Depth to groundwater table	unknown, but more than 150cm			unknown, but more than 160cm			unknown, but more than 100cm		
surface stones	none			none			none		
Evidence of erosion	none			none			none		
Presence of salt or alkali	none			none			none		
Human influence	cultivation			cultivation			cultivation		
PROFILE DESCRIPTION	0-7cm Brown (7.5YR 5/4) dry and dark reddish brown (5YR ¾) moist; loamy coarse sand; strong, thin platy soil structure; slightly hard, very friable, non-sticky; very porous; common fine roots; abrupt smooth boundary.			0-10cm Brown (7.5YR 5/4) dry and dark reddish brown (5YR ¾) moist; sand/loamy medium sand; strong thin platy structure; upper 3cm soft, and lower 7cm slightly hard, very friable, non-sticky; porous, many fine and medium tubular pores; common very fine roots; abrupt smooth boundary.			0-10cm Brown (7.5YR 4/5) dry and dark reddish brown (5YR 3/42) moist; sand/loamy coarse sand; strong thin platy structure; soft, very friable, non-sticky, very porous; common fine roots; abrupt smooth boundary.		
	7-15cm Dark reddish grey (5YR 4/2) dry and dark reddish brown (5YR ¾) moist; loamy sand; structureless (massive); slightly hard, very friable, non-sticky; very porous; common fine roots; abrupt smooth boundary.			10-30/38cm Brown/dark brown (7.5YR 4/4) dry and dark reddish brown (5YR 3/3) moist; coarse sandy loam; structureless (massive); porous; many tubular pores; few fine roots; abrupt wavy boundary.			10-35cm Dark yellowish brown (10YR 4/4) dry and brown/dark brown (7.5YR 4/4) moist; sandy loam/heavy sandy clay loam with medium sand grains; weak angular blocky; hard, very friable, slightly sticky; many tubular pores and numerous micro-pores; common fine roots; clear smooth boundary.		
	15-34cm Dark reddish brown (5YR ¾) dry and moist; coarse-sandy loam; structureless (massive); hard, very friable, slightly sticky; porous; few to common fine roots; ant nests; abrupt smooth boundary.			30/38-81cm Horizon dominated by fine, hard, reddish gravels not cemented together; abrupt smooth boundary by roots; clear, wavy boundary.			35-79cm Yellowish-brown (10YR 5/6) dry and brown/dark brown (7.5YR 4/4) moist; sandy clay loam/sandy clay; weak angular blocky; very hard, very friable, sticky; common tubular pores and numerous micro-pores; few fine roots; ant nests; clear wavy boundary.		
	34-76cm Horizon dominated by hard, black and reddish mineral nodules which are not cemented together.			81-160cm Cemented horizon; hard materials of greenish colour.			79-92cm Horizon dominated by hard, small, mineral nodules; incipient cementation of nodules observed.		
	76-150cm Horizon with no mineral nodules but composed of cemented soil materials; olive yellow (2.5YR 6/6) cementing material; brittle.						92-100cm Cemented horizon; very hard.		
DEPTH (cm)	0-15	15-34		0-10	10-30/38		0-10	10-35	35-79
Clay (%)	10	10		6	10		6	14	30
Silt (%)	6	6		6	6		6	8	6
Texture class	LS	LS-SL		S	LS-SL		S-LS	SL	SCL
pH(H_2O)	5.8	6.0		6.1	5.6		5.9	5.4	5.7

/continued

	NAM'MALE 1			NAM'MALE 2			NAM'MALE 3		
OM (%)	0.8	0.6		0.4	0.6		0.6	0.6	0.3
N(%)	0.04	0.03		0.02	0.03		0.03	0.03	0.01
Ex Ca (cmol(+)kg^{-1})	1.08	1.05		0.91	1.03		0.55	1.15	1.79
Ex Mg (cmol(+)kg^{-1})	0.13	0.10		0.08	1.15		0.28	0.22	0.07
Ex K (cmol(+)kg^{-1})	0.09	0.08		0.11	0.08		0.12	0.11	0.07
CEC (cmol(+)kg^{-1})	1.3	1.23		1.10	1.26		0.95	1.48	1.93
Extr. P (Fgg^{-1})	2	1		2	2		2	1	0
E/C	13.00	12.30		18.33	12.06		15.83	10.57	6.43
Bulk density (g/cm^3)									
Depth (mm)	0-100	100-150	150-200	0-100	100-150	150-200	0-100	100-150	150-200
Unheated	1.64	1.43	1.63	too loose to sample	1.46	1.66	1.63	1.59	1.64
At 105^{o}C	1.61	1.43	1.51		1.41	1.61	1.57	1.53	1.61

B4 Soils of the Matutu gravel pit site in Mchinji District

The physical environment

The Matutu gravel pit site is on an interfluve which slopes westwards imperceptibly at slope gradients of one per cent or less. At the time of the study, most of the site was fallow. Short shrubs were the main vegetation. The cultivated parts of the site were under burley tobacco grown by the smallholder.

Soils

At the Matutu gravel pit site, soils were studied at five test sites. Table B-7 gives a summary of the main morphological properties conveyed by the profile descriptions; the focus is on that part of the soil above the gravelly layer where it exists. The table contains summarised chemical data also. Soil profile descriptions were developed for each test site and these are presented in Table B-8, together with corresponding chemical data. Profile descriptions give an idea of the horizontal and vertical variability of the soil profiles.

Morphological properties

The depth of the soil overlying gravelly layers ranges from 60-65cm with the exception of the depth at one test site where the depth was more than 185cm. The top-soil which is darkish, is 10-14cm thick where the soil is under fallow but is thicker where the soil is being cultivated. The sub-soils are strong brown or yellowish-red which is indicative of good soil drainage. The texture of the top-soil ranges from loamy sand to sandy clay loam. That of the sub-soil ranges from loamy sand to sandy clay. The soil structure is generally good except where the soil is loamy sand.

Table B-7 Properties of soils at the Matutu village gravel pit site

Profile no.	Depth (cm) to cemented gravelly layer	Texture over gravelly layer	Top-soil Texture	Soil structure over gravelly layer	TOP-SOIL				
					pH (H_2O)	OM (%)	N (%)	P (Fgg[1])	K (cmol/kg)
1	>188	SCL-SC	SCL	moderate	5.0	1.8	0.09	5	0.35
2	61	SL-SCL	SL	moderate	5.9	1.3	0.07	21	0.33
3	60	LS	LS	poor	5.8	0.9	0.04	34	0.25
4	65	LS	LS	poor	6.1	1.2	0.06	57	0.34
5	65	SL-SCL	SL	good	6.1	2.0	0.10	6	0.57

Table B-8 Soil properties at the Matutu village gravel pit site

Profile no.	GP6/1 (02/08/96)	GP6/2 (02/08/96)	GP6/3 (02/08/96)	GP6/4 (02/08/96)	GP6/5
Location	Matutu Village, Mchinji District	Matutu Village, Mchinji District	Matutu Village, Mchinji District	Matutu Village, Mchinji District	Matutu Village, Mchinji District
Slope gradient	almost flat, 1%	almost flat, 1%, Slope position: middle	almost flat, 1%, Slope position: middle	almost flat, 1%, Slope position: middle	almost flat, 1%, Slope position: middle
Slope position	middle	middle	middle	middle	middle
Vegetation and land-use	fallow	fallow, scattered shrubs	barley tobacco garden	fallow with shrubs	fallow with shrubs
Drainage	well-drained	well-drained	ball-drained	well-drained	well-drained
Surface moisture condition	dry	dry	dry	dry	dry
Depth to groundwater table	unknown, but >188m	unknown, but >150cm	unknown, but >70cm	unknown, but >65cm	unknown, but >65cm
Evidence of erosion	none	none	none	none	none
Human influence	previously cultivated to crops	relict crops ridges	tillage	none currently	none currently
PROFILE DESCRIPTION	0-11cm Dark brown/brown (10YR 4/4) dry, and dark yellowish brown (10YR ¾) moist; sandy loam; weak, medium sub-angular blocky structure; slightly hard, very friable, non-sticky, non-plastic; very porous; abundant fine roots; abrupt smooth boundary.	0-11 Dark-brown/brown (7.5YR 4/4) dry, and dark-brown (7.5YR 3/2) moist; fine sandy loam; medium sub-angular blocky structure; hard, friable, non-sticky, non-plastic; common tubular pores; abundant fine roots; abrupt smooth boundary.	0-12cm (Ridge soil). Dark brown (10YR 3/3) dry and moist; loamy sand; structureless (massive); soft, very friable, non-sticky, non-plastic; very porous; abundant fine roots; abrupt smooth boundary.	0-14cm Dark brown (10YR 3/3) dry, and very dark greyish brown (10YR 3/2) moist; loamy fine sand; weak fine sub-angular blocky structure; slightly hard, friable, non-sticky, porous; abundant fine roots; abrupt smooth boundary.	0-10 Dark brown/brown (7.5YR 4/4) dry, and dark brown (7.5YR 3/2) moist; heavy sandy loam; moderate fine sub-angular blocky structure; slightly hard, friable, slightly sticky; many tubular pores; abundant fine roots; abrupt smooth boundary.
	11-23cm Brown/dark brown (7.5YR 4/4) dry and moist; very fine sandy clay loam/fine sandy clay; strong, medium sub-angular blocky structure; hard, firm, sticky; common tubular pores; some ant nests; very frequent fine roots; clear smooth boundary.	11-23/30cm Yellowish-red (5YR 4/8) dry and moist; fine sandy clay loam; moderate, medium sub-angular blocky structure; hard, friable, sticky, slightly plastic; common tubular pores; frequent, large olive-brown hard nodules; abundant fine roots; abrupt smooth boundary.	12-25cm (Ridge soil). Dark yellowish brown (10YR 4/4); dry and moist; loamy sand; structureless (massive); slightly hard, very friable, non-sticky, non-plastic; very porous; abundant fine roots, abrupt smooth boundary.	14-32cm Strong brown (7.5YR 5/6) dry, and brown/dark brown (7.5YR 4/4) moist; sandy loam; weak medium sub-angular blocky structure; hard, friable; non-sticky, non-plastic, porous; few small, hard reddish gravels; common fine roots; abrupt smooth boundary.	10-30/60cm Yellowish red (5YR 4/8) dry and moist; gravelly sandy clay loam; moderate medium sub-angular blocky structure; slightly sticky; common tubular pores; few to frequent small, hard nodules, and few large hard nodules; abundant fine roots; abrupt smooth boundary.
	23-53cm Yellowish-red (5YR 5/8) dry and moist; very fine sandy clay loam; fine sandy clay; strong, medium sub-angular blocky structure; hard, friable, sticky, plastic; common tubular pores, some ant nests; common fine roots; clear smooth boundary.	23/30-61cm Many irregularly shaped olive brown hard nodules; soil matrix is yellowish-red (5YR 4/8) dry and moist; fine sandy clay loam; few to common fine roots; clear smooth boundary.	25-60cm Strong brown (7.5YR 5/6) dry, and brown/dark brown (7.5YR 4/4) moist; medium sandy loam/loamy sand; structureless (massive); hard, very friable, non-sticky, non-plastic; very porous; common fine roots; abrupt smooth boundary.	32-65cm Gravels dominant; many small, very hard nodules and few large hard nodules; gravels not cemented together..	30/60-65cm Moderately cemented gravelly layer; clear, wavy boundary.
	53-107cm Yellowish-red (5YR 5/8) dry and moist; very fine sandy clay loam; weak, coarse sub-angular blocky structure; hard, very friable, slightly sticky/sticky; very porous; few fine roots; clear, smooth boundary.	61-150cm Nodules dominant; large, irregularly shaped, hard nodules; weakly cemented together; very few fine roots between nodules.	>60cm Strongly cemented gravelly horizon.	>65cm Strongly cement gravelly horizon.	>65cm Strongly cemented gravelly layer.

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Profile no.	GP6/1 (02/08/96)					GP6/2 (02/08/96)		GP6/3 (02/08/96)		GP6/4 (02/08/96)		GP6/5	
	107-188cm Yellowish-red (5YR 5/8) dry and moist with olive brown stains; very fine sandy clay loam; structureless (massive); slightly hard, very friable, slightly sticky; very porous; few, large slightly soft olive brown nodules; very few fine roots.												
DEPTH (cm)	0-11	11-23	23-53	53-107	107-188	0-11	11-30	0-25	25-60	0-14	14-32	0-10	10-30
Clay (%)	28	32	38	28	28	16	22	10	10	12	14	18	28
Silt (%)	2	4	2	10	6	4	2	2	4	2	2	2	10
Texture class	SCL	SCL	SC	SCL	SCL	SL	SCL	LS	LS	LS	LS	SL	SCL
pH (H_2O)	5.0	4.8	4.8	5.4	5.4	5.9	5.9	5.8	6.2	6.1	5.9	6.1	5.9
OM (%)	1.8	1.6	1.7	0.4	0.3	1.3	0.7	0.9	0.5	1.2	0.6	2.0	2.4
N (%)	0.09	0.08	0.08	0.02	0.02	0.07	0.03	0.04	0.03	0.06	0.03	0.10	0.12
Ex K (cmol kg^{-1})	0.35	0.36	0.41	0.60	0.39	0.33	0.45	0.25	0.27	0.34	0.43	0.57	0.66
Extr. P (Fgg^{-1})	5	4	11	3	1	21	4	34	9	57	43	6	48

Chemical properties

The top-soil pH ranges from 5.8 to 6.1, except for one test site where the pH was 5.0. This means the top-soil is either moderately or slightly acid. The organic matter content ranges from 0.9 to 2.0 per cent; only at two test sites was the organic matter higher than 1.5 per cent. The nitrogen content is generally low in relation to the top-soil textures; the levels range from 0.05 to 0.10 per cent. The extractable phosphorous is very variable in the top-soil, being 5 to 57 Fg/g. This range is from extremely low to high levels. The exchangeable potassium level ranges from 0.25 to 0.57 cmol/kg in the top-soil. These levels are within the medium range.

Soil potential for agricultural use

The effective soil depth of soils at Matutu is adequate for annual crops which are the main crops grown within the area. The sandy textures observed at some test sites are unfavourable for most crops. However, these soils are good for burley tobacco. The sandy loam of finer textures are suitable for most crops. No problems are expected from the soil reaction (pH) since it is within favourable ranges. Except for one test site, the organic matter is generally low. Nitrogen levels are also low for most crops. The phosphorus is generally adequate, although it was very low at two test sites. The exchangeable potassium is adequate for most crops. Morphological properties are the most difficult to correct through soil management practices. However, at Matutu these properties are fairly favourable. Those that are unfavourable, such as sandy textures, are suitable for burley tobacco. The low levels of nutrients can be rectified by application of inorganic fertilisers. On the whole, the soils at Matutu are cultivable and are therefore valuable to smallholder.

B5 Soils of the Gandali gravel pit site in Mchinji

The physical environment

The Gandali gravel pit site is on a flat interfluve with slope gradients of less than 2 per cent. There are no signs of soil erosion at the site. The site is in an area with a mean annual rainfall of about 900mm. Most of it falls from November to March. The natural vegetation has been cleared for arable farming. Currently the land is farmed commercially; burley tobacco is the main crop.

Soils

Six soil profiles were studied at the Gandali gravel pit site to determine the morphological properties of the soils. The morphological and chemical properties of the soil over the gravelly layers are summarised in Table B-9. Soil profile descriptions were prepared and are presented in Table B-10. Also included are chemical data corresponding to the soil profile descriptions. The six soil profiles give an indication of the nature and range of soils at Gandali.

Morphological properties

The depth of the soil to gravelly layers is at least 20cm, but the cemented part of the gravelly layers starts at a depth of 40cm at least. The top-soil on its own is at least 17cm thick. The texture of the soil over the gravelly layers ranges from sandy loam to sandy clay. The texture of the top-soil alone is invariably sandy loam. The soil has a good blocky structure which is apparently stable. For more details on the morphological properties, the soil profile descriptions should be consulted.

Chemical properties

The soil overlying gravelly layers is slightly to moderately acid, with pH levels mostly of 5.2 to 6.4. In most cases the pH tends to increase slightly with depth. The organic matter in the top-soil ranges from 1.0 to 2.1 per cent; thus it ranges from low to medium. The nitrogen levels are generally low, ranging from 0.05 to 0.10 per cent. Both the organic matter and nitrogen levels decrease with depth. The extractable phosphorous levels range from medium to high in the top-soils, being 26 to 59 Fgg^{-1}. However, the levels decrease markedly below the top-soil to values as low as 2 Fgg^{-1}. The exchangeable potassium is generally medium in the top-soil, being at least 0.25 cmol(+)kg^{-1}. The levels remain in the medium range in the sub-soil. The bulk densities tend to be high, being 1.5gcm^{-3} or higher.

Soil potential for agricultural use

The soils at the Gandali gravel pit site have favourable properties. Although at a few test sites the soil depth to gravelly layers is only 20cm, the depth to the cemented part of the gravelly layers is 40cm at least. It is at this depth that hindrance to roots can be expected. The loamy textures and the good soil structure make the soils favourable as a medium for plant growth. Among the chemical nutrients (N, P, K) it is only nitrogen which is explicitly deficient. However, nitrogen deficiency can easily be redressed by applying inorganic fertilisers. Of major concern, however, is the low content of organic matter. On the whole the soils at the Gandali gravel pit site have quite a good potential for agricultural use.

Table B-9 Properties of soils at the Gandali gravel pit site

Profile no.	Depth to gravelly layer (cm)	Soil texture over gravelly layer	Soil structure over gravelly layer	pH	OM (%)	N (%)	P (Fgg^{-1})	K ($cmol/kg^{-1}$)	Bulk density (gcm^{-1})	
									105°C	Unheated
1	56	SL-SC	good	5.9-6.4	0.7-1.3	0.03-0.05	3-28	0.25-0.41	1.54	1.65
2	20	SL	good	5.5	1.3	0.07	40	0.34	1.50	1.58
3	20	SL	good	6.0	1.4	0.07	59	0.16	1.65	1.71
4	41	SL-SC	good	5.2-5.7	1.1-1.7	0.06-0.08	2-33	0.45	1.46	1.54
5	36	SL-SC	good	5.7-6.9	1.4-2.1	0.07-0.10	2-26	0.26-0.41	1.48	1.61
6	110	SL-SC	good	5.4-6.1	0.7-1.8	0.03-0.09	1-25	0.19-0.25	1.57	1.66

Table B-10 Soil profile descriptions and corresponding analytical data for Gandali

	GANDALI 1 (20/10/95)	GANDALI 2 (21/10/95)	GANDALI 3 (21/10/95)	GANDALI 4 (20/10/95)	GANDALI 5 (21/10/96)	GANDALI 6 (21/10/95)
Location	Gandali gravel pit, Mchinji District	Gandali gravel pit, Mchinji District	Gandali gravel pit, Mchinji District	Gandali gravel pit, Mchinji District	Gandali gravel pit, Mchinji District	Gandali gravel pit, Mchinji District
Slope	flat, <2%	flat, <2%	flat, <2%	flat, <2%	flat, <2%	flat, <2%
land-use	burley tobacco farm	burley tobacco farm	burley tobacco farm	burley tobacco farm	burley tobacco	burley tobacco
Drainage	well-drained	well-drained	well-drained	well-drained	well-drained	well-drained
Surface moisture condition	dry	dry	dry	dry	dry	dry
Depth to groundwater table	unknown, but >160cm	unknown, but >160cm	unknown, but >175cm	unknown, but <135cm	unknown, but >145cm	unknown, but >143cm
surface stones	none	none	none	none	none	none
Evidence of erosion	none	none	none	soil deposited by water	none	soil deposited by water
Presence of salt or alkali	none	none	none	none	none	none
Human influence	cultivation	cultivation	cultivation	cultivation	cultivation	cultivation
PROFILE DESCRIPTION	0-23cm Brown (7.5YR 5/4) dry and dark reddish brown (5YR ¾) moist; loamy sand; moderate, medium sub-angular blocky; very friable, slightly sticky; porous; many tubular pores; abundant very fine roots; abrupt smooth boundary.	0-20cm Brown (7.5YR 5/4) moist; moderate, medium sub-angular blocky; slightly hard, non-sticky; porous and many tubular pores; many fine roots; abrupt smooth boundary.	0-20cm Brown (7.5YR 5/4) dry and dark reddish brown (5YR ¾) moist; sandy loam; moderate, medium, sub-angular blocky; slightly hard, non-sticky; many tubular pores; many fine roots; abrupt smooth boundary.	0-20cm Brown (7.5YR 5/4) dry and dark reddish brown (5YR ¾) moist; medium sandy loam; moderate medium sub-angular blocky; slightly hard, friable, non-sticky; porous; common tubular pores; abundant fine roots; abrupt smooth boundary.	0-17cm Brown/dark brown (7.5YR 4/4) dry and dark brown (7.5YR 3/2) moist; fine sandy loam; moderate medium sub-angular blocky; slightly hard, friable, non-sticky; common fine tubular pores; common fine roots; abrupt smooth boundary.	0-18cm Brown (7.5YR 5/4) dry and dark reddish brown (5YR ¾) moist; sandy loam; moderate, medium sub-angular blocky; slightly hard, friable, slightly sticky; many tubular pores; common fine roots; abrupt smooth boundary.
	23-56cm Yellowish red (5YR 4/6) dry and dark red (2.5YR 3/6) moist; sandy clay; strong, medium sub-angular blocky; common tubular pores; many very fine roots; clear smooth boundary.	20-55cm Yellowish-red (5YR 4/8) dry and moist; gravelly sandy clay/clay; structureless (massive); slightly hard, friable, sticky; porous; many small and large mineral nodules, not cemented together; common fine roots; clear smooth boundary.	20-50cm Yellowish-red (5YR 4/6) dry and moist; gravelly sandy clay; structureless (massive); slightly hard, friable, sticky; porous; many small, hard, black mineral nodules, not cemented together; common fine roots; ant nests; clear wavy boundary.	20-41cm Red (2.5YR 4/6) dry and moist; sandy clay; strong, medium sub-angular blocky; hard, firm, sticky; common tubular pores, porous; some ant nests, some dark materials from overlying horizon in ant nests; common fine roots; clear wavy boundary.	17-36cm Yellowish red (5YR 4/8) dry and moist; sandy clay; strong medium sub-angular blocky; hard, firm sticky; small cutans observed; many tubular pores filled with dark materials from overlying horizon; common fine roots; few, small, hard mineral nodules; some quartz stones along the bottom of the horizon; clear, wavy boundary.	18-43cm Yellowish-red (5YR 4/6) dry and moist; sandy clay loam; moderate, medium sub-angular blocky; hard, slightly firm, sticky; few small cutans; many tubular pores; common fine roots; some ant nests; clear smooth boundary.
	56-105cm Yellowish-red (5YR 5/8) dry and moist; sandy clay/clay; structureless (massive); slightly hard, very friable, sticky; porous; common, small, black and hard mineral nodules; no cementation; clear smooth boundary.	55-105cm Yellowish-red (5YR 4/6) dry and moist, earthy materials of weathering rock; very little soil, occurs as filling; clear, wavy boundary.	50-131cm Brittle earthy material composed of about 50% of soil materials and about 50% of weathered rock; greenish in colour; abrupt smooth boundary.	41-135cm Large, hard mineral nodules dominant, greenish weathering pieces of rock.	36-105cm Small, hard, black mineral nodules dominant, not cemented; abrupt wavy boundary.	43-110cm Yellowish-red (5YR 5/6) dry and (5YR 4/6) moist; sandy clay loam/sandy clay; weak medium sub-angular blocky; hard, friable, sticky; porous; few fine roots; gradual smooth boundary.

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	GANDALI 1 (20/10/95)				GANDALI 2 (21/10/95)				GANDALI 3 (21/10/95)			GANDALI 4 (20/10/95)		GANDALI 5 (21/10/96)		GANDALI 6 (21/10/95)			
	105-160cm Yellowish-red (5YR 5/8) dry and moist; sandy clay loam/sandy clay; structureless (massive); slightly hard, very friable, sticky; porous; much fewer mineral nodules than in above.				105-160cm Brittle, red (2.5YR 4/8) earthy materials showing distinct rock structure; weathering horizon.				131-175cm Weathering biotitic gneiss rock dominant; very little soil material.					105-145cm Brittle earthy materials dominated by weathering rock; yellowish brown in colour.		110-143cm Strong brown (7.5YR 5/8) dry and yellowish-red (5YR 4/8) moist; sandy clay; loam/sandy clay; structureless (massive); slightly hard, friable, slightly sticky; few, hard, black mineral nodules; few very fine roots.			
DEPTH (cm)	0-23	23-56	56-105	105-160	0-20	20-55	55-105	105-160	0-20	20-50	50-131	0-20	20-41	0-17	17-36	0-18	18-43	43-110	110-143
Clay (%)	10	40	44	32	16	40	16	16	16	44	26	16	42	16	38	16	32	30	34
Silt (%)	6	8	8	10	4	10	8	6	2	4	8	10	8	6	10	8	6	6	4
Texture class	LS-SL	SC	SC	SCL	SL	SC-C	SL	SL	SL	SC	SCL	SL	SC	SL	SC	SL	SCL	SCL	SCL
pH(H_2O)	6.4	5.9	6.1	6.1	5.5	6.0	6.1	6.1	6.0	6.1	6.0	5.7	5.2	6.9	5.7	5.4	5.7	6.1	6.5
OM (%)	1.0	0.7	0.7	0.7	1.3	1.2	0.3	0.3	1.4	0.8	0.4	1.7	1.1	2.1	1.4	1.8	1.2	0.7	0.8
N(%)	0.05	0.03	0.03	0.03	0.07	0.06	0.02	0.01	0.07	0.04	0.02	0.08	0.06	0.10	0.07	0.09	0.06	0.03	0.04
Ex Ca (cmol(+)kg^{-1})	1.85	2.42	2.31	2.30	1.32	1.32	2.14	2.34	1.01	1.99	1.94	2.05	1.92	2.26	2.10	1.53	1.70	1.30	1.29
Ex Mg (cmol(+)kg^{-1})	0.51	0.86	0.71	0.87	0.48	0.50	1.12	1.28	0.40	1.56	1.10	0.73	1.04	0.60	0.78	0.50	0.72	0.55	0.54
Ex K (cmol(+)kg^{-1})	0.41	0.25	0.38	0.27	0.34	0.35	0.34	0.27	0.16	0.35	0.56	0.45	0.45	0.41	0.26	0.25	0.19	0.24	0.24
CEC (cmol(+)kg^{-1})	2.77	3.53	3.40	3.44	2.14	2.17	3.60	3.89	1.57	3.90	3.60	3.23	3.41	3.27	3.14	2.28	2.61	2.09	2.07
Extr. P (Fgg^{-1})	28	3	1	0	40	40	1	0	59	3	0	33	2	26	2	35	2	1	0
E/C	27.70	8.83	7.73	110.75	13.38	5.43	22.50	24.31	9.81	8.86	13.85	20.19	8.12	20.44	8.26	14.25	8.16	6.97	6.09
Bulk density (g/cm^3)																			
Depth (mm)	230-330	330-400			200-300				250-300			200-300	300-400	180-230	290-390	200-300	320-420		
Unheated	1.65	1.64			1.58				1.71			1.54	1.60	1.61	1.61	1.66	1.70		
At 105^{o}C	1.54	1.50			1.50				1.65			1.46	1.44	1.48	1.49	1.57	1.55		

B6 Soils of the Bongela gravel pit site in Mchinji

The physical environment

The Bongela gravel pit site is on an interfluve with slope gradients of 2 per cent or less. There are no signs of soil erosion at the site. The site is in an area with a mean annual rainfall of about 900mm. Most of the rain falls from November to March. The natural vegetation has long been cleared and the land is being used for subsistence farming. The main crop is maize and is inter-cropped with groundnuts and pulses.

Soils

Three soil profiles were studied at the Bongela gravel pit site to determine the morphological properties of the soils. The morphological and chemical properties of soils overlying gravelly layers are summarised in Table B-11. Soil profile descriptions were prepared and are presented in Table B-12. Corresponding chemical data also have been included. The three soil profiles examined give a good idea about the nature and range of soils at Bongela.

Morphological properties

The depth of the soil to gravelly layers is at least 32 cm; but the gravelly layer is not cemented until a depth of at least 45 cm. The thickness of the top-soil alone is 15 cm or more. The texture of the soil overlying the gravelly layers ranges from loamy sand to sandy clay loam. The texture of the top-soil only is loamy sand mostly. The soil structure is good where the texture is sandy loam but rather poor where the texture is loamy sand.

Chemical properties

The soil overlying the gravelly layers is slightly to moderately acid with pH values of 5.4 to 6.3. The organic matter content is low, being 1.1 to 1.8 per cent in the top-soil. The nitrogen levels too are very low, being 0.09 per cent or less in the top-soil. Both the levels decrease markedly from the top-soil to the immediate sub-soil. The extractable phosphorous levels are high in the top-soil, being 59 Fgg^{-1} or higher. The levels decrease with depth. The exchangeable potassium is variable in the top-soil. It ranges from low to medium, being 0.14 to 0.34 $cmol(+)kg^{-1}$.

Soil potential for agricultural use

The morphological and chemical data indicate that the soils at the Bongela gravel pit site have a low inherent potential. Since the textures are somewhat coarse, the soils are expected to have a low nutrient and moisture retention capacity. Except for phosphorous, nutrients levels are low and would need supplementing in order to get good yields. Despite the limitations observed, the soils are valuable to local subsistence farmers so long as the soils are not gravelly to a reasonable depth.

Table B-11 Properties of soils at the Bongela gravel pit site

Profile no.	Depth to gravelly layer (cm)	Soil texture over gravelly layer	Soil structure over gravelly layer	pH	OM (%)	N (%)	P (Fgg^{-1})	K ($cmol/kg^{-1}$)	Bulk density (gm^{-3})	
									105°C	Unheated
1	105	SL-SCL	Fair to good	5.6-6.2	0.8-1.8	0.04-0.09	2-59	0.08-0.14	1.42	1.48
2	32	LS-SL	fair to good	6.1-6.3	1.0-1.8	0.06-0.09	32-73	0.21-0.34	1.59	1.64
3	34	LS-SL	fair	5.4-5.6	0.8-1.1	0.04-0.06	54-96	0.19-0.24	1.52	1.57

Table B-12 Soil profile descriptions and corresponding analytical data for Bongela

	BONGELA 1 (22/10/95)	BONGELA 2 (22/10/95	BONGELA 3 (22/10/95)
Location	Bongela gravel pit, Mchinji District	Bongela gravel pit, Mchinji District	Bongela gravel pit, Mchinji District
Slope	flat, 2%	almost flat, 2%	almost flat, <2%
Land-use	maize garden	maize garden	maize garden
Drainage	well-drained	well-drained	well-drained
Surface moisture condition	dry	dry	dry
Depth to groundwater table	unknown, but more than 160cm	unknown, but more than 135cm	unknown, but more than 150cm
surface stones	none	none	none
Evidence of erosion	none	none	none
Presence of salt or alkali	none	none	none
Human influence	cultivation	cultivation	cultivation
PROFILE DESCRIPTION	0-18cm Reddish brown (5YR 4/3) dry and dark reddish brown (5YR 3/3) moist; sandy loam; moderate, medium sub-angular blocky; slightly hard, friable, non-sticky; porous; many fine roots; abrupt smooth boundary.	0-17cm Brown/dark brown (7.5YR 4/4) dry and dark reddish brown (5YR 3/3) moist; loamy sand/sandy loam; moderate, medium sub-angular blocky; slightly hard, friable, non-sticky; many tubular pores; many fine roots, abrupt smooth boundary.	0-15cm Brown/dark brown (7.5YR 4/4) dry and dark reddish brown (5YR 3/3) moist; loamy sand; weak, medium sub-angular blocky; slightly hard, friable, non-sticky; many tubular pores; many fine roots; abrupt smooth boundary.
	18-35cm Yellowish red (5YR 4/8) dry and (5YR 4/6) moist; sandy clay loam; moderate, medium sub-angular blocky; hard, friable, slightly sticky; porous, many fine tubular pores, common medium pores filled with materials from overlying horizon; common fine roots; clear smooth boundary.	17-32cm Yellowish red (5YR 4/6) dry and dark reddish brown (5YR ¾) moist; sandy loam; weak, medium sub-angular blocky; slightly hard, very friable, non-sticky; common tubular pores; common very fine roots; abrupt smooth boundary.	15-34cm Yellowish red (5YR 4/6) dry and dark reddish brown (5YR ¾) moist; sandy loam; weak, medium sub-angular blocky; slightly hard, very friable, non-sticky; common tubular pores; common very fine roots; abrupt, wavy boundary.
	35-61cm Yellowish red (5YR 4/8) dry and (5YR 4/6) moist; heavy sandy clay loam; weak, medium sub-angular blocky; slightly hard, very friable, slightly sticky; very porous, common tubular pores; diffuse boundary.	32-77cm Yellowish red (5YR 5/8) moist; loamy sand; but small, hard mineral nodules dominant in the horizon; nodules with greening exteriors and brown interiors; not cemented; abrupt wavy boundary.	34-45/70cm Small, hard mineral nodules dominant; red (2.5YR 4/6) soil occurs as filling; not cemented. Abrupt irregular boundary.
	61-105cm Yellowish-red (5YR 4/8) dry and (5YR 4/6) moist; heavy sandy clay loam; structureless (massive; slightly hard, very friable; porous; few fine roots; abrupt smooth boundary.	77-135cm Strongly cemented horizon.	45/70-150cm Strong cemented horizon.
	105-160cm Small, hard mineral nodules dominant; exteriors of nodules are greenish but interiors are brown.		

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	BONGELA 1 (22/10/95)					BONGELA 2 (22/10/95			BONGELA 3 (22/10/95)			
DEPTH (cm)	0-18	18-35	35-61	61-105	105-160	0-17	17-32	32-77	0-15	15-34	34-45/70	45/70-150
Clay (%)	14	22	28	26	20	10	12	10	10	18	40	8
Silt (%)	4	4	6	6	8	6	4	6	4	6	6	8
Texture class	SL	SCL	SCL	SCL	SL	LS-SL	SL	LS	LS	SL	SC	LS
pH(H_2O)	5.6	5.8	5.9	6.2	6.2	6.3	6.1	5.7	5.6	5.4	5.9	6.2
OM (%)	1.8	1.0	0.8	0.8	0.5	1.8	1.0	0.3	1.1	0.8	1.4	0.3
N(%)	0.09	0.05	0.04	0.04	0.02	0.09	0.06	0.02	0.06	0.04	0.07	0.01
Ex Ca (cmol(+)kg^{-1})	1.20	1.38	1.56	1.24	1.05	1.72	0.87	1.55	1.42	0.70	1.83	1.29
Ex Mg (cmol(+)kg^{-1})	0.32	0.30	0.35	0.52	0.53	0.89	0.42	1.34	0.46	0.41	0.70	0.65
Ex K (cmol(+)kg^{-1})	0.14	0.10	0.10	0.08	0.08	0.34	0.21	0.41	0.24	0.19	0.20	0.34
CEC (cmol(+)kg^{-1})	1.66	1.78	2.01	1.84	1.66	2.95	1.50	3.30	2.12	1.30	2.73	2.28
Extr. P (Fgg^{-1})	59	43	13	2	0	73	32	18	96	54	65	0
E/C	11.86	8.09	7.18	7.08	8.30	29.50	12.50	33.00	21.20	7.22	6.80	28.50
Bulk density (g/cm^3)												
Depth (mm)	200-300	320-420				200-300	310-410		170-270	270-280		
Unheated	1.48	1.47				1.64	1.61		1.57	1.54		
At 105°C	1.42	1.45				1.59	1.53		1.52	1.46		

B7 Soils of the Kochilira gravel pit site in Mchinji District

The physical environment

The Kochilira gravel pit site (GP3) is on an almost flat interfluve with slope gradients of less than one per cent. Most of this site was under regenerating bush at the time of the study.

Soils

Soils were studied at five test sites. The morphological and chemical data are summarised in Table B-13 on which the following discussion is based. Soil profile descriptions were prepared for each test site (Table B-14) but chemical data were determined for only three representative test sites (1, 2 and 5).

Morphological properties

The depth of the soils at Kochilira ranges from 75 to about 100 cm. However, in places the soil is very gravelly from a depth of 25cm. The thickness of the top-soil proper ranges from 15 to 25 cm. The top-soil texture ranges from sandy loam to sandy clay loam and is free of gravels. In the sub-soil the texture ranges from sandy loam to sandy clay. The soil structure in the top-soil is good. However, it becomes poor in the sub-soil where the soil is gravelly.

Chemical properties

The pH of the top-soil ranges from 4.9 to 6.8. Thus, the top-soil ranges from strongly acid to neutral in reaction. The organic matter is within the medium range at all test sites. The nitrogen ranges from 0.09 to 0.14 per cent which means it is low. The extractable phosphorous is very low being less than 11 Fg/g. The exchangeable potassium is marginal at most sites.

Soil potential for agricultural use

Part of this gravel pit site has low agricultural potential because of abundant gravels at shallow depth. The top-soil is generally acid. The organic matter level is quite good but the nitrogen is low. The phosphorus is also low. The exchangeable potassium is marginal. The potential of this site for agricultural use is rather low in terms of the soils' ability to supply nutrients. However, this can be rectified by applying inorganic fertilisers. The morphological properties which are more difficult to manage, are all favourable for annual crops. Therefore on the whole, the site is favourable for the cultivation of annual crops.

Table B-13 Properties of soils at the Kochilira gravel pit site

<table>
<tr><th rowspan="2">Profile no.</th><th rowspan="2">Depth to cemented gravelly layer</th><th rowspan="2">Texture over gravelly layer</th><th rowspan="2">Top-soil Texture</th><th rowspan="2">Soil structure over gravelly layer</th><th colspan="5">TOP-SOIL</th></tr>
<tr><th>pH (H_2O)</th><th>OM (%)</th><th>N (%)</th><th>P (Fgg)</th><th>K (cmol/kg)</th></tr>
<tr><td>1</td><td>75</td><td>SL-SCL</td><td>SL/SCL</td><td>good</td><td>6.8</td><td>2.8</td><td>0.14</td><td>11</td><td>0.30</td></tr>
<tr><td>2</td><td>98</td><td>SCL</td><td>SCL</td><td>good</td><td>4.9</td><td>1.9</td><td>0.09</td><td>5</td><td>0.14</td></tr>
<tr><td>5</td><td>100</td><td>SCL-SC</td><td>SCL</td><td>good</td><td>5.1</td><td>2.1</td><td>0.10</td><td>4</td><td>0.13</td></tr>
</table>

Table B-14 Soil profile descriptions and corresponding analytical data for Kochilira site

	GP3/1 (04/08/96)	GP3/2 (04/08/96)	GP3/3 (04/08/96)	GP3/4 (04/08/96)	GP3/5 (04/08/96)
Location	Kochilira, Mchinji District	Kochilira, Mchinji District	Kochilira, Mchinji District	Kochilira, Mchinji District	Kochilira, Mchinji District
Slope gradient	flat, <1%, Slope position: Upper	flat, <1%, Slope position: Upper	flat, <1%, Slope position: Upper	flat, <1%, Slope position: Upper	flat, <1%, Slope position: Upper
Vegetation and land-use	regenerating bush	regenerating bush	regenerating bush	regenerating bush	regenerating bush
Drainage	well-drained	well-drained	well-drained	well-drained	well-drained
Surface moisture condition	dry	dry	dry	dry	dry
Depth to groundwater table	unknown, but >75cm	unknown, but >98cm	unknown, but >100cm	unknown, but >118cm	unknown, but >100cm
Human influence	none	none	cultivation (relict ridges)	none	none currently
PROFILE DESCRIPTION	0-25cm Dark brown (10YR 3/3) dry, and very dark greyish brown (10YR 3/2) moist; sandy loam; moderate, fine granular structure; slightly hard, friable, sticky, plastic; many tubular pores, porous; very few small hard nodules, very abundant fine roots; abrupt smooth boundary.	0-25cm Dark yellowish brown (10YR 4/4) dry and moist; fine sandy clay loam/sandy clay; moderate, medium angular blocky structure; slightly hard, friable; common tubular pores; abundant fine roots; clear smooth boundary.	0-22cm Dark-brown/brown (10YR 4/3) dry, and dark brown (7.5YR 3/2) moist; heavy sandy loam/sandy clay loam; moderate, medium, sub-angular blocky structure; slightly hard, slightly sticky; porous; abundant fine roots; clear smooth boundary.	0-20cm Brown (10YR 5/3) dry, and dark brown (7.5YR 3/2) moist; heavy sandy loam; strong medium sub-angular blocky structure; soft, friable, slightly sticky; porous; common fine roots; clear wavy boundary.	0-15cm Dark brown (10YR 3/3) dry, and very dark greyish brown (10YR 3/2) moist; sandy clay loam; strong fine granular structure; slightly hard, friable, sticky; common tubular pores; porous; abundant fine roots; abrupt smooth boundary.
	25-51cm Gravels dominant; small, hard nodules and quartz gravels; common quartz stones; not cemented; clear wavy boundary.	25-60cm Brown (7.5YR 5/4) dry and moist; sandy clay/sandy clay loam; weak medium, sub-angular blocky structure; slightly hard, friable, sticky, plastic; porous; very few nodules; very frequent fine roots; abrupt smooth boundary.	22-60cm Dark/dark-brown (7.5YR 4/4) dry and moist; gravelly sandy clay loam; structureless (massive); slightly hard, friable, slightly sticky; frequent, small, hard nodules; not cemented; very frequent fine roots; clear wavy boundary.	20-60cm Brown (7.5YR 5/4) dry, and brown (7.5YR 4/4) moist; sandy clay loam; moderate medium, angular blocky structure; slightly hard, friable, sticky, plastic; common tubular pores, porous; few fine roots; diffuse boundary.	15-50cm Dark yellowish brown (10YR 4/4) dry, and dark yellowish brown (10YR ¾) moist; heavy sandy clay loam/sandy clay; moderate, medium sub-angular blocky; hard, slightly firm; common tubular pores; abundant fine roots; clear smooth boundary.

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	GP3/1 (04/08/96)	GP3/2 (04/08/96)		GP3/3 (04/08/96)	GP3/4 (04/08/96)	GP3/5 (04/08/96)	
	51-75cm Gravels dominant; small, brown hard gravels dominant; horizon not cemented; abrupt wavy boundary.	60-98cm Gravels dominant; small, hard yellowish gravels, not cemented; abrupt wavy boundary.		60-100cm Gravelly horizon; small, hard, brownish gravels dominant, not cemented; common fine roots; abrupt smooth boundary.	60-74cm Strong brown (7.5YR 5/6) dry and moist; sandy clay; weak, coarse sub-angular blocky structure; slightly hard, very friable, sticky, plastic; porous; few fine roots; abrupt wavy boundary.	50-77cm Brown (7.5YR 5/4) dry, and dark brown (7.5YR 4/4) moist; heavy sandy clay loam/sandy clay; weak, medium sub-angular blocky structure; slightly hard, friable, sticky, porous; common fine roots; abrupt smooth boundary.	
	>75cm Strongly cemented gravelly horizon.	>98cm Strongly cemented gravelly horizon.		>100cm Strongly cemented gravelly horizon.	74-93cm Yellowish brown (10YR 5/4) dry, and dark yellowish brown (10YR ¾) moist; sandy clay; strong medium sub-angular blocky structure; soft, very friable, sticky, porous; very few fine roots, abrupt wavy boundary.	77-100cm Gravelly horizon; not cemented; abrupt smooth boundary.	
					93-118cm Brownish-yellow (7.5YR 6/6) dry, and strong brown (7.5YR 5/6) moist; fine sandy clay loam/sandy clay; structureless (massive) slightly hard, very friable; very porous; very few fine roots; abrupt smooth boundary.	>100cm Cemented gravelly horizon.	
					>118cm Gravelly horizon but not cemented.		
DEPTH (cm)	0-25	0-25	25-60			0-15	15-50
Clay (%)	20	28	32			24	28
Silt (%)	6	4	4			2	6
Texture class	SL/SCL	SCL	SCL			SCL	SCL
pH(H_2O)	6.8	4.9	4.6			5.1	4.8
OM (%)	2.8	1.9	1.0			2.1	1.3
N(%)	0.14	0.09	0.05			0.10	0.07
Ex K (cmol(+)kg^{-1})	0.30	0.14	0.14			0.13	0.13
Extr. P (Fgg^{-1})	11	5	2			4	3

B8 Soils of the Bongela gravel pit site (GP4A) in Mchinji District

The physical environment

The Bongela gravel pit site (GP4A) is on an interfluve which slopes southwards at gradients of about 2 per cent. At the time of the study, part of the site was under cultivation but the other part was under fallow. Shrubs were the main vegetation on the fallow part.

Soils

Soils were studied at five test sites. These data are summarised in Table B-15, on which the following discussion is based. Soil profiles were prepared for each site and are included in this report, and are given in Table B-16; also included are corresponding chemical data.

Morphological properties

The effective depth of the soil where the site is under cultivation is 60cm or more. However, the fallow part has soils with an effective depth of 36cm at maximum. The thickness of the top-soil proper ranges from 15 to 22 cm. The top-soil texture ranges from loamy sand to sandy clay loam; but it is sandy loam or sandy clay loam at most test sites. The sub-soils are invariably sandy clay loam or sandy clay. The soil structure of the soil overlying the gravelly layers is good. The structure of the top-soil, at one test site with loamy sand texture, was somewhat poor.

Chemical properties

The pH of the top-soil is very variable. It ranges from 4.5 to 7.5; that is from strongly acid to neutral. The organic matter in the top-soil is generally low being 0.9 to 1.4 per cent, except at one test site where it is 2.4 per cent. The nitrogen is similarly low being 0.04 to 0.12 per cent. The extractable phosphorous is 11 Fg/g or lower which is very low, except for one site where the phosphorus is 39 Fg/g. The exchangeable potassium levels range from 0.38 to 2.05 cmol/kg. Thus the nutrient ranges from medium to very high.

Soil potential for agricultural use

The part of the site which is under fallow is where the effective soil depth is 36-40cm. The soil texture above the gravelly layers in this part is quite good; the land is being fallow because land pressure is not high in Mchinji. Thus the morphological properties, which are the most difficult to modify, are quite favourable at this gravel pit site. The nitrogen and phosphorus levels are low but they can be raised through soil management practices. Thus overall, the site has good soils for agricultural uses.

Table B-15 Properties of soils at the Bongela village gravel pit site (GP4A)

Profile no.	Depth to cemented gravelly layer	Texture over gravelly layer	Top-soil Texture	Soil structure over gravelly layer	TOP-SOIL				
					pH (H_2O)	OM (%)	N (%)	P (Fgg^{-1})	K (cmol/kg)
1	60	SL-SC	SL/SCL	good	6.0	1.3	0.07	7	0.68
2	>190	LS-SC	LS	good	7.5	2.4	0.12	39	2.05
3	65	SCL	SCL	good	5.1	0.9	0.04	3	0.33
4	40	SL-SCL	SL	good	5.0	1.2	0.06	11	0.45
5	36	SL-SCL	SL/SCL	good	4.5	1.4	0.07	8	0.38

Table B-16 Soil profile descriptions and corresponding analytical data for Bongela (GP4A)

Profile No.	GP4A/1 (02/08/96)	GP4A/2 (02/08/96)	GP4A/3 (02/08/96)	GP4A/4 (02/08/96)	GP4A/5 (02/08/96)
Location	Bongela Village, Mchinji District	Bongela Village, Mchinji District	Bongela Village, Mchinji District	Bongela Village, Mchinji District	Bongela Village, Mchinji District
Slope gradient	flat, 2%, Slope position: lower middle	almost flat, 2%, Slope position: lower	almost flat, 2%, Slope position: lower	almost flat, 2%, Slope position: lower middle	almost flat, 2%, Slope position: lower middle
Vegetation and land-use	maize garden	maize garden	maize garden	fallow, regenerating bush	fallow, regenerating bush
Drainage	well-drained	well-drained	well-drained	well-drained	well-drained
Surface moisture condition	dry	dry	dry	dry	dry
Depth to groundwater table	unknown, but >180cm	unknown, but >190cm	unknown, but >65cm	unknown, but >40cm	unknown, but >36cm
Evidence of erosion	none	none	none	none	none
Human influence	cultivation	cultivation	cultivation	none currently	none currently

/continued

Profile No.	GP4A/1 (02/08/96)	GP4A/2 (02/08/96)	GP4A/3 (02/08/96)	GP4A/4 (02/08/96)	GP4A/5 (02/08/96)
PROFILE DESCRIPTION	0-15cm Reddish brown (5YR 4/4) dry, and dark reddish brown (5YR ¾) moist; sandy clay loam; strong medium sub-angular blocky structure; hard, friable, slightly sticky; many tubular pores; many fine roots, diffuse smooth boundary.	0-22cm Dark brown/brown (7.5YR 4/4) dry and dark reddish brown (5YR 3/3) moist; loamy sand/medium sandy loam; strong medium crumb structure; soft, very friable, non-sticky; porous; abundant fine roots; abrupt smooth boundary.	0-20cm Dark yellowish brown (10YR 4/4) dry, and dark brown (7.5YR 3/2) moist; medium sandy loam/sandy clay loam; strong fine crumb structure; soft, very friable, slightly sticky; very porous; abundant fine roots; diffuse boundary.	0-20cm Dark brown/brown (7.5YR 4/4) dry, and dark reddish brown (5YR ¾) moist: sandy loam; moderate, fine sub-angular blocky structure; soft, very friable, non-sticky; very porous; abundant fine roots; clear smooth boundary.	0-15cm Dark brown/brown (7.5YR 4/4) dry, and dark reddish brown (5YR ¾) moist; sandy loam/sandy clay loam; strong fine crumb; soft friable, sticky; many tubular pores; very few small hard nodules; abundant fine roots; abrupt smooth boundary.
	15-32cm Yellowish red (5YR 4/6) dry and moist; heavy sandy clay; strong medium sub-angular blocky structure; hard slightly firm, sticky, plastic; many tubular pores, porous; few hard reddish nodules; common fine roots; diffuse, wavy boundary.	22-45cm Yellowish red (5YR 4/6) dry and moist; sandy clay loam/sandy clay; moderate; medium sub-angular blocky structure; soft, very friable, sticky, plastic; very porous; frequent, small hard reddish concretions; common fine roots; clear wavy boundary.	20-41cm Dark brown/brown (7.5YR 4/4) dry and dark reddish brown (5YR ¾) moist; sandy clay loam; moderate medium angular blocky structure; slightly hard, friable, slightly sticky; porous; common fine roots; clear smooth boundary.	20-40cm Yellowish red (5YR 4/8) dry and moist, sandy loam/sandy clay loam; moderate fine sub-angular blocky structure, slightly hard, friable; no nodules; abundant fine roots; abrupt smooth boundary.	15-36cm Yellowish red (5YR 4/8) dry and moist; moderate, medium sub-angular blocky; slightly hard, firm, sticky; common tubular pores; few hard small nodules; abundant fine roots; abrupt smooth boundary.
	32-60cm Red (2.5YR 4/6) dry, and dark-red (2.5YR 3/6) moist; sandy clay; weak, medium sub-angular blocky structure; slightly hard, friable, sticky, plastic; frequent hard reddish nodules; few fine roots; clear wavy boundary.	45-123cm Yellowish red (5YR 4/8) dry and moist; sandy clay, weak, fine sub-angular blocky structure; slightly sticky; porous; very frequent small, hard reddish nodules (not cemented); diffuse boundary.	41-65cm Brown (7.5YR 5/4) dry and brown/dark brown (7.5YR 4/4) moist: sandy clay loam; structureless (massive); hard, friable, sticky; porous; frequent, hard, small nodules, few fine roots; abrupt wavy boundary.	>40cm Strongly cemented gravelly horizon.	>36 Very strongly cemented gravelly horizon.
	60-150cm Partially cemented horizon; weathering yellowish rock; red nodules.	123-190cm Yellowish red (5YR 4/8) dry and moist, sandy clay; weak, fine sub-angular blocky structure. Many small hard reddish nodules (not cemented) and quartz stones.	>65cm Strongly cemented gravelly horizon.		

DEPTH (cm)	0-15	15-32	32-60	0-22	22-45	45-123	0-20	20-41	0-20	20-40	0-15	15-36
Clay (%)	20	30	36	12	24	40	26	26	16	20	20	26
Silt (%)	4	8	2	8	4	4	2	4	4	2	4	4
Texture class	SL/SCL	SCL	SC	LS	SCL	SC	SCL	SCL	SL	SL/SCL	SL/SCL	SCL
pH (H_2O)	6.0	5.4	5.3	7.5	5.5	4.9	5.1	4.7	5.0	4.5	4.5	4.5
OM (%)	1.3	1.1	0.7	2.4	1.0	0.5	0.9	1.6	1.2	0.8	1.4	0.8
N (%)	0.07	0.05	0.03	0.12	0.05	0.02	0.04	0.08	0.06	0.04	0.07	0.04
Ex K (cmol Kg^{-1})	0.68	0.56	0.43	2.05	0.47	0.68	0.33	0.34	0.45	0.28	0.38	0.28
Extr. P (Fgg^{-1})	7	4	3	39	6	4	3	10	11	3	8	3

B9 Soils of the Ncholonjo gravel pit site in Mchinji District

The physical environment

The Ncholonjo gravel pit (GP5) site is on an almost flat interfluve with slope gradients of about one per cent. This site is on fallow land where the main vegetation is regenerating bush.

Soils

Soils were studied at three test sites. The morphological and chemical data are summarised in Table B-17 on which the following discussion is based. Soil profile descriptions were prepared for each test site (Table B-18). Chemical data were also determined for each test site.

Morphological properties

The soils at this gravel pit site are deep; the effective depth ranges from 116 to 195 cm. The thickness of the top-soil ranges from 21 to 47 cm. The top-soil texture is sandy clay loam and the soils have good structure. The sub-soil texture is either sandy clay loam or sandy clay. The soils have good structure.

Chemical properties

The top-soil pH ranges from 4.6 to 5.3; thus the top-soil is acid to strongly acid. The organic matter content is 1.2 to 2.4 per cent which means it is either low or medium. The nitrogen level ranges from 0.06 to 0.12 in the top-soil; these are low levels. The extractable phosphorous levels range from 5 to 14 Fg/g; thus phosphorus is either very low or marginal. The exchangeable potassium level ranges from 0.32 to 0.46 in the top-soil, these levels show that potassium is adequate in the top-soil.

Soil potential for agricultural use

All the morphological properties are favourable. The nitrogen and phosphorus are deficient; but this problem can be corrected by soil management practices. Therefore, on the whole this gravel pit is sited on soils with good agricultural potential.

Table B-17 Properties of soils at the Ncholonjo gravel pit site

Profile no.	Depth to cemented gravelly layer	Texture over gravelly layer	Top-soil Texture	Soil structure over gravelly layer	TOP-SOIL				
					pH (H_2O)	OM (%)	N (%)	P (Fgg^{-1})	K (cmol/kg)
1	>195	SCL	SCL	good	4.6	2.2	0.11	14	0.46
2	116	SCL	SCL	good	5.3	2.4	0.12	12	0.32
3	120	SCL-SC	SCL	good	5.0	1.2	0.06	5	0.44

Table B-18 Soil profile descriptions and corresponding analytical data for Ncholonjo

	GP5/1 (26/09/96)	GP5/2 (26/09/96)	GP5/3 (26/09/96)
Location	Ncholonjo Village, Mchinji District	Ncholonjo Village, Mchinji District	Ncholonjo Village, Mchinji District
Slope gradient	flat, <0.5%, Slope position: Lower middle	almost flat, 1%, Slope position: Lower middle	almost flat, 1%, Slope position: Lower middle
Vegetation and land-use	fallow, but maize garden nearby	regenerating bush	regenerating bush
Drainage	well-drained	well-drained	well-drained
Surface moisture condition	dry	dry	dry
Depth to groundwater table	unknown, but >195cm	unknown, but >220cm	unknown, but >190cm
Human influence	none, but a garden nearby	none	none
PROFILE DESCRIPTION	0-21cm Dark yellowish brown (10YR 4/4) dry, and dark brown (10YR 3/4) moist; fine sandy loam/sandy clay loam; strong fine crumb structure, and strong medium sub-angular blocky structure; soft, very friable, non-sticky, very porous; very abundant fine roots; clear smooth boundary.	0-11cm Dark brown/brown (10YR 4/3) dry, and dark yellowish brown (10YR ¾) moist; sandy clay loam; moderate, coarse sub-angular blocky structure; hard, firm slightly sticky; porous; abundant fine roots, abrupt smooth boundary.	0-26cm Brown (7.5YR 5/4) dry, and dark brown/brown (7.5YR 4/4) moist; sandy clay loam; moderate medium sub-angular blocky structure; slightly hard, friable, slightly sticky; porous; abundant fine roots; diffuse boundary.
	21-44cm Dark brown/brown (7.5YR 4/4) dry, and dark reddish brown (5YR ¾) moist; strong medium sub-angular blocky structure; soft, very friable, slightly sticky; very porous, abundant fine roots; clear smooth boundary.	11-47cm Dark brown (10YR 3/3) dry, and dark brown (7.5YR 3/2) moist; sandy clay loam/sandy clay; moderate coarse angular blocky structure; very hard, firm, slightly sticky; common tubular pores; frequent fine roots; clear wavy boundary.	26-61cm Brown (7.5YR 5/4) dry, and yellowish red (5YR 4/6) moist; heavy sandy clay loam/sandy clay; moderate medium angular blocky structure; slightly hard, friable, slightly sticky; porous; frequent fine roots; diffuse boundary.
	44-83cm Brown (7.5YR 5/4) dry, and dark reddish brown (5YR ¾) moist; sandy clay loam; slightly hard, friable, slightly sticky; very porous, common fine roots; clear smooth boundary.	47-95cm Yellowish red (5YR 4/6) dry and moist; heavy sandy clay loam/sandy clay; weak, coarse angular blocky structure; hard, friable, slightly sticky; porous; few fine roots; abrupt wavy boundary.	61-120cm Strong brown (7.5YR 5/8) dry, and yellowish red (5YR 5/8) moist; sandy clay loam/sandy clay; weak, coarse sub-angular blocky structure; slightly hard, friable, slightly sticky; porous; few fine roots; abrupt smooth boundary.

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	GP5/1 (26/09/96)					GP5/2 (26/09/96)			GP5/3 (26/09/96)		
	83-141cm Strong brown (7.5YR 5/8) dry, and yellowish-red (5YR 4/6) moist; sandy clay loam; structureless (massive): slightly hard, very friable; slightly sticky; very porous; few fine roots; diffuse boundary.					95-116cm Weathering biotic rock materials; not cemented; abrupt smooth boundary.			120-190cm Gravelly layer; very frequent fine and coarse quartz gravels; weathering rock material.		
	141-195cm Strong brown (7.5YR 5/8) dry, and yellowish red (5YR 4/6) moist; sandy clay/sandy clay loam; structureless (massive); slightly hard, very friable, very porous; some weathering feldspar rocks at 195cm.					116-220cm Very gravelly layer; quartz gravels very frequent.					
DEPTH (cm)	0-21	21-44	44-83	83-141	141-195	0-11	11-47	47-95	0-26	26-61	61-120
Clay (%)	22	26	32	32	34	24	30	26	32	36	36
Silt (%)	4	5	2	4	6	8	4	2	2	2	2
Texture class	SCL	SCL	SCL	SCL	SCL	SCL	SCL	SCL	SCL	SC	SC
pH(H_2O)	4.6	4.4	4.7	4.5	4.9	5.3	5.5	5.0	5.0	4.5	4.6
OM (%)	2.2	1.7	0.8	0.6	0.7	2.4	1.5	0.9	1.2	1.0	0.6
N (%)	0.11	0.09	0.04	0.03	0.04	0.12	0.07	0.05	0.06	0.05	0.03
Ex K (cmol(+)kg^{-1})	0.46	0.25	0.35	0.21	0.52	0.32	0.39	0.44	0.44	0.41	0.28
Extr. P (Fgg^{-1})	14	5	6	8	2	12	4	2	5	2	2

Appendix C: Results of investigations after reinstatement

C1 Soils at the Muhura gravel pit site before and after restoration

Description of site

A comprehensive description and discussion of soils at the Muhura gravel pit site before gravel extraction were given in Appendix B of the first phase of this work. Summary comparisons of soil conditions before extraction and after are presented in Tables C-1 and C-2 below. Soil profile descriptions for the soils at Muhura after restoration of the site are presented in Table C-3. These give an idea of state of disturbance in the soil morphology.

Morphological properties

Slope

The original land surface at the Muhura gravel pit site was flat or almost flat with slope gradients of less than 2 per cent. The land surface sloped predominantly eastward. However after gravel-mining and restoration the land surface has been altered significantly. The land surface is no longer flat but is gently sloping with slope gradients of 4 per cent. The slopes are short and the land is sloping towards the bottom of the restored gravel pit. Overall, the land surface has been made very uneven.

Colour

Due to the influence of the organic matter, soils are normally dark in the top-soil with Munsell colour hues of 10YR and or low chromas. Lower layers normally have stronger colours with Munsell colour hues of 7.5YR or redder and or higher chromas because the organic matter content is very low in these layers. Table C-1 shows that this was the trend in the variation of colour in the original situation. In contrast, the colour variation is reversed in the restored state; the top layers have reddish colours of stronger hues (5YR, 7.5YR) whereas the lower layers have dark hues (10 YR).

Texture

Normally the texture of top-soils is course (sand, loamy sand, sand loam) whereas that of the lower layers is finer (sandy clay loam, sandy clay, clay). The texture of the natural top-soils ranged from loamy sand to sandy clay loam and that of the lower layers ranged from sandy clay loam to sandy clay (Table C-1). However for the restored state the top-soil texture is sandy clay loam and that of lower layers is sandy clay loam. The variation of soil texture with depth has been reversed in the restored state.

Physical and Chemical properties

Clay content

The effect of pedological processes on clay content is such that the clay content normally increases with depth. Hence the clay content of the top soil is lower than that of the lower layers. This is true of the Muhura site before the soil was interfered with; the clay contents in to the top-soil and lower layers were 18 per cent and 36 per cent respectively (Table C-1). After restoration the clay content in the top soil is 39 per cent whereas that of the lower horizons is 33 per cent. It is clear that the clay content has been somewhat homogenised during restoration.

Table C-1 Comparison of indicator morphological soil properties of the original and restored soil profiles at Muhura

	COLOUR		TEXTURE		SURFACE SLOPE (%)	
	ORIGINAL	RESTORED	O	R	O	R
TOP LAYER	Dark brown (10YR)	Dark reddish brown (5YR) Dark brown (7.5YR)	LS-SCL	SC	<2	32-4
LOWER LAYERS	Reddish brown (5YR) Yellowish red (5YR) Dark yellowish brown (10YR) Brown (7.5YR)	Dark yellowish brown (10YR) Dark brown (10YR)	SCL-SC	SCL	---	---

Table C-2 Comparison of indicator chemical soil properties of the original and restored soil profiles at Muhura

	CLAY		ORGANIC MATTER (%)		NITROGEN (%)	
	O	R	O	R	O	R
TOP LAYER	18 10-30	39 38-40	1.8 1.0-3.5	1.3 1.2-1.3	0.09 0.02-0.18	0.07 0.06-0.08
LOWER LAYERS	36 20-45	33 32-34	0.4 0.3-0.5	1.8 1.6-1.9	0.02	0.12 0.11-0.13

Organic matter content

In its original state the soil at Muhura had higher (1.8%) organic matter in the top-soil than in the lower layers (0.4%) (Table C-2). In the restored state, the difference in the organic matter content between the top-soil (1.3%) and lower layers (1.8%) is not significant. This is indicative of a mixing up of the top-soil and sub-soil during restoration. These contents also indicate that organic materials are likely to have been pulled to the test site from elsewhere during the restoration process.

Nitrogen content

The natural variability of nitrogen with depth closely follows that of organic matter. Nitrogen levels are normally higher in top-soils than in sub-soils. This is the case in the original state of the Muhura site (Table C-2). However this trend is reversed in the restored site.

Table C-3 Soil profile descriptions for restored sites at Muhura

Profile no.	Restored Muhura/1a	Restored Muhura/2	Restored Muhura/3
Location	Muhura	Muhura	Muhura
Slope gradient at profile site	almost flat, 2%	gently sloping, 3%	flat, <2%
Slope position (with respect to bottom of borrow pit)	middle	middle	middle
Slope of sides of restored borrow pit	gently sloping, 4%	gently sloping, 4%	gently sloping, 32%
Land-use	borrow pit	borrow pit	burrow pit

/continued

Profile no.	Restored Muhura/1a	Restored Muhura/2	Restored Muhura/3
Drainage	well-drained	well-drained	well-drained
Surface moisture condition	dry	moist due to rain	dry down to 25cm, moist below 25cm
Depth to groundwater table	unknown, but >68cm	unknown, but >135cm	unknown, but >140cm
Presence of gravels on surface	few to common	none	none
Evidence of erosion	rills	rills	none
Human influence	modified land surface	modified land surface	modified land surface
PROFILE DESCRIPTION	0-15cm Composed of back-fill soil material. Dark reddish brown (5YR 3/3) dry and moist; sandy clay/loam; weak, sub-angular blocky structure; soft, friable, slightly sticky; porous; abrupt smooth boundary.	0-60cm Composed of back-fill soil material. Dark reddish brown (5YR ¾) moist; sandy clay; weak moderate sub-angular blocky structure; firm, sticky, plastic; very porous; abrupt smooth boundary.	0-25cm Composed of back-fill soil material. Dark brown (7.5YR 4/4) dry, and dark reddish brown (5YR ¾) moist; sandy clay loam/sandy clay; weak angular blocky structure; very hard (compacted); firm, sticky, plastic; porous; very few fine roots; clear wavy boundary.
	15-68cm Gravelly layer; brown nodules of irregular shape; spherical black nodules.	60-135cm Composed of back-fill soil material. Dark yellowish brown (10YR ¾) dry, and dark brown (7.5YR 3/2) moist; sandy clay loam; moderate, medium granular structure; hard, friable, sticky; very porous; many grass remains.	25-60cm Composed of back-fill soil material. Dark reddish brown (5YR ¾) moist (due to rain); structureless (massive); few fine roots; clear smooth boundary.
			60-88cm Composed of back-fill soil material. Dark brown/brown (10YR 4/3) dry, and dark brown (10YR 3/2) moist; sandy clay loam; structureless (massive); hard, friable; common fine roots; abrupt smooth boundary.
			88-140cm Gravelly layer; large, hard nodules.

C2 Soils of the Khululira gravel pit sites before and after restoration

Description of site

Detailed information on the soils of the Khululira gravel pit site before working the borrow was given in Appendix B. The soil profile descriptions in Appendix B give an idea of the natural *in situ* morphologies of the soils at the Khululira site. Selected diagnostic properties of the soils before and after restoration are presented in the Tables C-4 and C-5. The soil profile descriptions for the soils after restoration are presented in Table C-6 and also give an idea of the soil morphologies.

Morphological properties

Slope

In its original state, the Khululira gravel pit site was flat with slope gradients of less than one per cent (Table C-4). Gravel-mining and the subsequent restoration rendered the site very uneven. The slope gradients created after these operations range from 2 to 3.5 per cent and the borrow pit is still very much evident.

Soil colour

In the natural state, top-soils were darkish with a Munsell colour hue of 10YR, the sub-soil were reddish, brown or grey with hues of 5YR, 7.5YR or 2.5Y (Table C-4). In the restored state the hues show some signs of mixing, although darkish soils still predominate the top-soil.

Soil texture

Top-soils of the original soil were either loamy sand or sandy loam whereas sub-soils textures ranged from loamy sand to sandy clay (Table C-4). In the restored state the soil texture of both the top-soil and sub-soil ranges from sandy loam to sandy clay loam. This indicates that the soil has become homogenised after restoration.

Physical and Chemical properties

Clay content

On average, the clay content of the top-soil of the original profile was 10 per cent, whereas that of the sub-soil was 20 per cent (Table C-5). In the restored profile, however, the clay content of the top-soil and sub-soil are almost the same. This indicates that the soil profile is homogenised.

Organic matter content

In the original state, the content of organic matter was higher in the top-soil than in the sub-soil, as expected. In the restored state, it is the sub-soil that has a higher level of organic matter, indicating a reversal of the profile (Table C-5).

Nitrogen content

Before the gravel-mining and restoration operations, the nitrogen level was higher in the top-soil than in the sub-soil (Table C-5). However in the restored state, the nitrogen levels in the top-soil and sub-soil are the same.

Table C-4 Comparison of indicator morphological soil properties of the original and restored soil profiles at Khululira

	COLOUR		TEXTURE		SURFACE SLOPE (%)	
	ORIGINAL	RESTORED	O	R	O	R
TOP LAYER	Dark yellowish brown (10YR) Dark brown (10YR)	Dark reddish brown (5YR) Dark brown/Brown (7.5YR) Dark yellowish brown (10YR)	LS-SL	SL-SCL	#1	2-32
LOWER LAYERS	Reddish brown (5YR) Yellowish red (5YR) Brown (7.5YR) Olive brown (2.5Y) Grey (2.5Y)	Dark brown (10YR) Dark brown (7.5YR) Dark yellowish brown (10YR)	LS—SC	SL-SCL	---	---

Table C-5 Comparison of indicator chemical and soil properties of the original and restored soil profiles at Khululira

	CLAY		ORGANIC MATTER (%)		NITROGEN (%)	
	O	R	O	R	O	R
TOP LAYER	10 8-12	20 12-26	0.4 0.1-0.7	0.8 0.2-1.4	0.03 0.02-0.04	0.05 0.01-0.08
LOWER LAYERS	20 16-38	19 14-26	0.2 0.1-0.3	1.0 0.1-1.5	0.02 0.01-0.02	0.05 0.01-0.09

Table C-6 Soil profile descriptions for restored sites at Khululira

Profile No.	Restored Khululira/1	Restored Khululira/2	Restored Khululira/3	Restored Khululira/4	Restored Khululira/5
Location	Khululira	Khululira	Khululira	Khululira	Khululira
Slope gradient at profile site	almost flat, 1%	gently sloping, 3%	almost flat, <2%	flat, <2%	flat, <2%
Slope position with respect to bottom of restored borrow pit	lower	middle	lower	bottom	middle
Slope of sides of restored borrow pit	gently sloping, 3%	gently sloping, 3%	gently sloping, 4%	gently sloping, 3%	almost flat, <1%
Land use	borrow pit	borrow pit	borrow pit	borrow pit	borrow pit
Drainage	well-drained	well-drained	well-drained	well-drained	well-drained
Surface moisture condition	moist due to rain	dry	dry	dry	slightly moist due to rains
Depth to groundwater table	unknown, but >100cm	unknown, but >160cm	unknown, but >120cm	unknown, but >55cm	unknown, but >85cm
Presence of gravels on the surface	none	very few	common	many	few to common
Evidence of erosion	rills	rills	rills	rills on sides of borrow pit	none
Human influence	modified land surface	modified land surface	modified land surface	modified land surface	modified land surface
PROFILE DESCRIPTION	0-25cm Composed of back-fill soil material. Dark reddish brown (5YR ¾) moist; heavy sandy loam/sandy clay loam; weak fine sub-angular blocky structure; friable, slightly sticky; porous; few fine roots; abrupt smooth boundary.	0-17cm Composed of back-fill soil material. Dark yellowish brown (10YR 4/4) moist; sandy clay loam; moderate, medium sub-angular blocky structure; slightly hard, friable, sticky, plastic; porous; few fine roots; clear wavy boundary.	0-23cm Composed of back-fill soil material. Brown/dark brown (10YR 4/3) dry, and dark yellowish brown (10YR ¾) moist; gravelly sandy loam; disturbed structure; soft, very friable, slightly sticky; very porous: few to common, small, hard gravels; few fine roots; abrupt wavy boundary.	0-11cm Composed of back-fill soil material. Brown (10YR 5/3) dry, and dark yellowish brown (10YR ¾) moist; sand; structureless (massive); soft, very friable, non-sticky; abrupt smooth boundary.	0-40cm Composed of back-fill soil material. Dark brown/brown (7.5YR 4/4) moist; sandy clay loam/sandy clay; structureless (massive); porous; few fine roots; abrupt wavy boundary.

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Profile No.	Restored Khululira/1	Restored Khululira/2	Restored Khululira/3	Restored Khululira/4	Restored Khululira/5
	25-100cm Composed of back-fill soil material. Strong brown (7.5YR 5/6) moist: sandy loam/sandy clay loam; structureless (massive); firm/brittle, sticky, plastic; porous; very few roots.	17-35cm Composed of back-fill soil material. Dark yellowish brown (10YR 4/4) dry, and dark yellowish brown (10YR ¾) moist; sandy clay loam; structureless (massive); soft, porous, few fine, hard spherical nodules; very few fine roots; abrupt smooth boundary.	23-41cm Composed of back-fill soil material. Brown/dark brown (7.5YR 4/4) dry, and dark reddish brown (5YR ¾) moist; gravelly sandy loam; structureless (disturbed soil); soft, very friable, slightly sticky; very porous; common fine gravels; very few fine roots; abrupt smooth boundary.	11-55cm Undisturbed layer. Very frequent, hard irregular nodules; weakly to strongly cemented.	40-55cm Composed of back-fill soil material. Brown (10YR 3/3) dry, and dark yellowish brown (10YR ¾) moist; coarse sandy loam/sandy clay loam; structureless (massive); soft; porous; abrupt smooth boundary.
		35-160cm Undisturbed layer. Brown/dark drown (10YR 4/3) dry, and dark greyish brown (10YR 4/2) moist; sandy clay loam/sandy clay; structureless (massive); hard, firm, sticky; slightly cemented; frequent black nodules.	41-85cm Undisturbed layer. Yellowish red (5YR 5/6) dry and moist; gravelly sandy clay loam/gravelly sandy clay; weak, coarse angular blocky structure; hard, firm, sticky; porous; very few roots; abrupt smooth boundary.		55-85cm Undisturbed layer. Gravelly layer; very frequent brown hard nodules; weakly to strongly cemented with depth.
			85-120cm Weathered feldspar-rich rocks.		

C3 Soils of the Matutu gravel pit site before and after restoration

Description of site

A comprehensive description of soils at the Matutu gravel pit site before gravel extraction was presented in Appendix B. Soil profile summaries for the Matutu site after restoration of the site, using uncontrolled procedures are presented in this appendix. The morphologies of soils at Matutu after restoration are distributed soil morphologies. Summaries of the detailed profile descriptions, both natural and disturbed, are presented in Tables C-7 and C-8. The comparison between the natural and disturbed states is based on these tables.

Morphological properties

Slope

The original land surface at the Matutu gravel pit site was almost flat with a maximum slope gradient of one per cent (Table C-7). The land sloped predominantly southwards. However after restoration, local slopes with gradients of 3 to 4 per cent were created. A depression had been created at the bottom of the borrow pit and surface run-off was flowing into this local depression. Soil erosion was evident from the rills formed and the siltation at the bottom of the depression.

Soil colour

Due to the influence of the organic matter, soils are normally dark in the top-soil with Munsell colour hues of 10YR and low chromas and other values. Lower layers normally have stronger colours with Munsell colour hues of 7.5YR, 5YR or 2.5YR and high chromas and colour values because the organic matter content is normally very low in the lower layers. Table C-7 shows that this was the trend in the variation of the soil colour in the original state of the site. In contrast, there is no such trend in colour variation is the restored state. In this state, most lower soil layers have dark colours whereas top-soils have strong colours with hues 5YR.

Soil texture

Normally the soil texture of the top-soil is coarser or higher than that of lower layers. In the original state, the top-soil was loamy sand or sandy loam; the lower layers were mostly sandy clay loam (Table C-7). In the restored state, the texture of the top-soil is sandy clay loam and gravels have been introduced into he top-soil. The lower layers are also sandy clay loam or sandy loam.

Physical and chemical properties

Clay content

In the original state, the average clay content of the top-soil was 17 per cent and that of the lower layers was 29 per cent (Table C-8). In the restored state, the clay content of the top-soil is 31 per cent and that of the lower layers is 20 per cent.

Organic matter content

In the original state, the top-soil had higher organic matter content (1.6 per cent) than the sub-soils (0.9 per cent) as shown in Table C-8. In the restored state, the top-soil has a much lower organic matter content (0.6 per cent) than the lower layer (1.2 per cent).

Nitrogen content

In the original state, the content of the nitrogen was higher (0.07 per cent) in the top-soil than in the lower layers (0.04 per cent). However, in the restored state, the top-soil has a lower (0.03 per cent) nitrogen content than the lower layers (0.06 per cent).

Table C-7 Comparison of indicator morphological soil properties of the original and restored soil profiles at Matutu

	COLOUR		TEXTURE		SURFACE SLOPE (%)	
	ORIGINAL	RESTORED	O	R	O	R
TOP LAYER	Dark brown (10YR) Brown (10YR)	Yellowish-red (5YR) Dark-reddish-brown (5YR)	LS-SL	SCL SCL	1	3 to 4
LOWER LAYERS	Yellowish-red (5YR) Strong-brown (7.5YR)	Very dark-grey (10YR) Dark-brown (10YR) Dark-reddish-brown (5YR) Reddish-brown (5YR) Yellowish-red (5YR)	SCL, SL SC	SCL SL	---	---

Table C-8 Comparison of indicator chemical soil properties of the original and restored soil profiles at Matutu

	CLAY		ORGANIC MATTER (%)		NITROGEN (%)	
	O	R	O	R	O	R
TOP LAYER	17 10-28	31 25-33	1.6 1.2-2.0	0.6 0.3-1.1	0.07 0.04-0.10	0.03 0.02-0.06
LOWER LAYERS	29 10-38	20 11-23	0.9 0.5-1.7	1.2 0.9-1.7	0.04 0.03-0.08	0.06 0.03-0.10

C4 Soils of the Ncholonjie gravel pit site before and after restoration

Description of site

The comprehensive description of soils at the Ncholonjo gravel pit site before gravel-mining and restoration, was presented in Appendix B. Summaries of the detailed profile descriptions, both natural and disturbed, are presented in Tables C-9 and C-10 below. In comparing the natural and disturbed states of Ncholonjo, reference is made to these tables.

Morphological properties

Slope

The original land surface at the Ncholonjo gravel pit site was almost flat with slope gradients of 0.5 to one per cent (Table C-9). After restoration, the slope gradients were one to 1.5 per cent. There was not significant change in slope gradient.

Soil colour

In the original state, the colour of the top-soils was dark-brown or dark-yellowish; lower layers were strong brown or yellowish-red (Table C-9). After restoration, the top-soil colour is dark-yellowish-brown, and the lower layers are strong brown, yellowish-brown or brown. Thus, the variation of the colour from the top-soil to lower layers after restoration is similar to that before restoration.

Soil texture

In the original state, the texture of the top-soil was sandy clay loam, and that of the lower layers was sandy clay loam or sandy clay (Table C-9). After restoration the top-soils are sandy loam or sandy clay loam, and lower layers are sandy clay loam or sandy clay. The variation of texture with depth is similar in both the natural and disturbed states.

Physical and chemical properties

Clay content

In the original state, the average clay content of the top-soil was 26 per cent, and that of the lower layers was 33 per cent (Table C-10). After restoration the average clay content of the top-soil is 32 per cent and that of the lower layers is 38 per cent. Thus the top-soil has a higher clay content in the restored state than in the original state.

Organic matter content

In the original state, the top-soil had a higher (1.9 per cent) organic matter content than the lower horizon (1.3 per cent as in Table C-10). In the restored state too, the top-soil has a higher (1.3 per cent) organic matter content than the lower layers (0.7 per cent). Thus the trend of organic matter content has been achieved in the restored state.

Nitrogen content

In the original state, the top-soil had a higher nitrogen content (0.1 per cent) than the lower layers (0.05 per cent), as in Table C-10. In the restored state too, the top-soil has a higher (0.06 per cent) nitrogen level than the lower layers (0.03 per cent).

Table C-9 Comparison of indicator morphological soil properties of the original and restored soil profiles at Ncholonjo

	COLOUR		TEXTURE		SURFACE SLOPE (%)	
	ORIGINAL	RESTORED	O	R	O	R
TOP LAYER	Dark brown (10YR) Dark brown (10YR)	Dark yellowish brown (10YR)	LS-SL	SL-SCL	#1	2-32
LOWER LAYERS	Reddish brown (5YR) Yellowish red (5YR) Brown (7.5YR) Olive brown (2.5Y) Grey (2.5Y)	Dark brown (10YR) Dark brown (7.5YR) Dark yellowish brown (10YR)	LS—SC	SL-SCL	---	---

Table C-10 Comparison of indicator chemical soil properties of the original and restored soil profiles at Ncholonjo

	CLAY		ORGANIC MATTER (%)		NITROGEN (%)	
	O	R	O	R	O	R
TOP LAYER	10 8-12	20 12-26	0.4 0.1-0.7	0.8 0.2-1.4	0.03 0.02-0.04	0.05 0.01-0.08
LOWER LAYERS	20 16-38	19 14-26	0.2 0.1-0.3	1.0 0.1-1.5	0.02 0.01-0.02	0.05 0.01-0.09