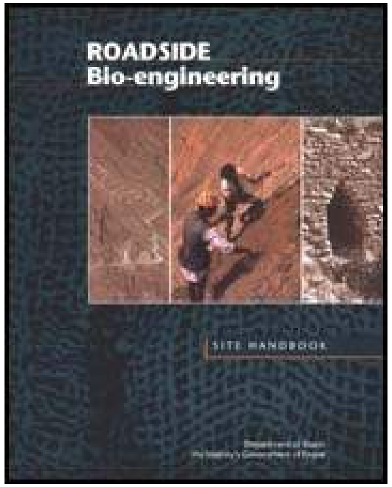


Roadside Bio-Engineering - Site Handbook (DFID, 1999, 160 p.)

Section Two - Civil engineering techniques

Figure

This section outlines the main civil engineering structures used for slope stabilisation and erosion control in conjunction with bio-engineering:

- **retaining walls (Section 2.1);**
- **revetments (Section 2.2);**
- **prop walls/dentition (Section 2.3);**
- **check dams (Section 2.4);**
- **drains (Section 2.5);**
- **stone pitching (Section 2.6);**
- **wire bolster cylinders (Section 2.7);**
- **other civil engineering techniques: notes on their use (Section 2.8).**

This section describes the main features of civil engineering structures and the ways in which they may *be* integrated with bio-engineering techniques. It does not give full design details of structures such as retaining walls and check dams but provides references to sources of further information.

Techniques that have been tried extensively in the Nepal road sector but rejected by the Department of Roads (e.g. waterproof slope covers and non-living wattle fences) are not included in this section. The reasons for their rejection are given in the *Reference Manual.*

2.1 Retaining walls

Functions

Retaining walls help to support mountainside slopes, or support the road or slope segments from the valley side. They are designed to stop an active earth pressure. Toe walls are normally considered to be a type of retaining wall found at the base of a slope or segment of slope.

Sites

Any slope where there is a problem of deep-seated (> 500 mm) instability, or where the steepness of the slope makes benching impractical.

Practical features

- **Use dry masonry in every case where it is applicable (see *special features of dry masonry walls* below). Only use other types of wall when you are certain you need greater strength and can justify the additional cost.**

- **Careful design and supervision of foundations are of paramount importance.**

- **While excavating foundations, remove debris to a safe location. Do not allow it to be thrown down the slope.**

- **In most locations, solving the drainage problem is a major difficulty. Therefore consideration should always be given to using the best-drained of structures.**

- **In bound masonry and reinforced concrete walls, weep holes of a minimum width of 75 mm, sloping downwards, should be given every one metre along and up the wall. There should be a line of weep holes along the wall at the lowest level at which it can be drained.**

- **Backfilling is critical: many walls are not backfilled and so retain nothing but air! Always ensure that retaining walls are properly backfilled and compacted in layers. Place a drainage blanket of aggregate with a porous membrane of filter fabric (geotextile if possible; but otherwise hessian) over weep holes or drainage areas.**

- **Once construction is complete, ensure that the slopes around the structure are tidied up and treated using appropriate bio-engineering measures. All surplus debris must be removed, or it will encourage the development of erosion.**

A dry masonry retaining wall with a scupper culvert

Figure 2.1: Comparison of retaining wall types*

WALL TYPE	MAXIMUM SAFE HEIGHT	WIDTH: HEIGHT RATIO	ADVANTAGES/LIMITATIONS
Dry masonry	4 metres	1:1 to 0.6:1	Well drained; flexible; relatively low cost; low strength threshold
Composite masonry	8 metres	0.75:1 to 0.5:1	Better drained than mortared masonry, but with reduced strength
Mortared masonry	10 metres	0.75:1 to 0.5:1	Relatively easy to construct on steep terrain; cannot tolerate settlement; poor drainage
Gabion	10 metres	Width = ½h	Flexible without rupturing; tolerates poor

		+ 0.5	foundations; well drained; relatively low cost for strength
Reinforced earth	8 metres	Depends on design	Reinforcing expensive or difficult to obtain; difficult to achieve tension
Reinforced concrete	10 metres	Depends on design	Relatively costly; requires advanced technical skills to build; poor drainage

*** Despite these general criteria, design must always be site specific rather than based on a 'typical' design.**

Figure 2.1 compares the main types of retaining wall.

Integration with bio-engineering

Bio-engineering techniques should be used in conjunction with retaining walls, according to site characteristics, as follows:

- **Protection of backfill.**
- **Protection from scour and undercutting of the foundations and sides.**
- **Flexible extension to the wall by planting large bamboos, shrubs or trees above the wall, increasing the catch function (refer to Sections 3.9 and 3.7 for details of these techniques).**

Further information

There is an entire chapter on road retaining walls in TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain* (chapter 11, *Road retaining walls,* pages 116 to 126). The design of retaining walls is also covered in

most geotechnical engineering text books.

2.2 Revetment walls

Function

Revetment walls are constructed to protect the base of a slope from undermining or other damage, such as grazing by animals. They give only protection, not support, and are not used on large, unstable slopes, where substantial retaining structures may be required. Breast walls are normally considered to be types of revetment.

Sites

Along the base of inherently stable cut slopes where seepage erosion can destabilise the base of large slopes; along the foot of abandoned spoil tips which have reached their angle of repose; along the foot of large fill sites.

Practical features

- **Excavate a foundation at the foot of the slope until you find a sound layer to build on.**

- **Construct walls of freely drained materials wherever possible, such as dry stone masonry or gabions.**

- **If using cement-bound masonry, include weep holes to drain water from behind the wall and reduce hydrostatic pressure. Weep holes should have a**

minimum width of 75 mm, slope downwards, and be constructed every one metre along and up the wall. There should be a line of weep holes along the wall at the lowest point at which it can be drained.

- **The back face should be vertical; the front face should slope back at the rate of 330 mm horizontally per metre of height (a gradient of 3:1);**

- **The ends of the wall should turn in to meet the slope, and should be raised about 250 mm: water falling on them will then run down over the wall and not scour the ends.**

- **If there is a risk of people or animals damaging the top of a dry stone wall, provide a capping beam of cement-bound masonry.**

- **Once the wall is complete, finish backfilling behind it and compact the fill thoroughly at a steep angle (at least 30°) to rejoin the original slope as high up as possible; plant into the fill as soon as you can.**

Figure 2.2: A guide to the dimensions of dry masonry retaining walls on different slopes

SLOPE	WALL HEIGHT	BASE WIDTH	TOP WIDTH
30 - 35° (58 - 70%)	1.5 - 2.0 m	1.25 - 1.5m	0.75 m
35 - 40° (70 - 84%)	2.0 - 2.5 m	1.5 - 2.0m	0.75 - 1.0 m
40 - 45º (84 - 100%) V	2.5 - 3.0 m	2.0 - 2.3 m	1.0 m

SPECIAL FEATURES OF DRY MASONRY RETAINING WALLS

- Careful design of dry masonry retaining walls can make them highly effective.
- Lay the foundations back into the slope at 1v:3h.
- Dress all stone (if it is rounded) into rectangular blocks.
- Lay stones so that they are tied into the slope, so that only the small ends, not long sides, are at the face of the wall.
- Overlap all joints.
- Use stones as large as possible. If mainly small stones are available, use large ones at least every one metre to improve the tying.
- Keep the angle of the foundations (1v:3h) with each layer of stone. The outer face of the wall will automatically come to 1h:3v if this is done.
- Use flatter stones for the top layer. Cover the top of the retaining wall with soil or build a bound masonry band along the top to stop it unravelling.
- Dry walls co-exist with, and are strengthened by plant roots. Encourage or plant vegetation.
- Use the dimensions in Figure 2.2 for dry stone retaining walls, depending on slope angle.

SPECIAL FEATURES OF GABION CONSTRUCTION

Gabions have many possible functions, including their use in toe walls, revetments and retaining walls. They have special properties of strength, flexibility and free drainage.

Practical features

- The normal width to height ratio is: width = ½ height + 0.5

- Ensure drainage is provided from the lowest point of the foundations

- Use heavily galvanised high-grade steel wire complying with the latest Nepal Standard.

- Mesh should be, either a heavily galvanised mild steel or a triple-twist hexagonal mesh (*i.e*. 1.5 complete turns), nominally of 100 mm width and 120 mm length.

- Panel frames should be made using 8 SWG wire, and mesh should be of 10 SWG wire.

- Special attention must be paid to binding the boxes together along the seams (selvedging).

- Wire all gabion boxes together using 12 SWG wire, allowing an additional 5% of wire for binding and tying.

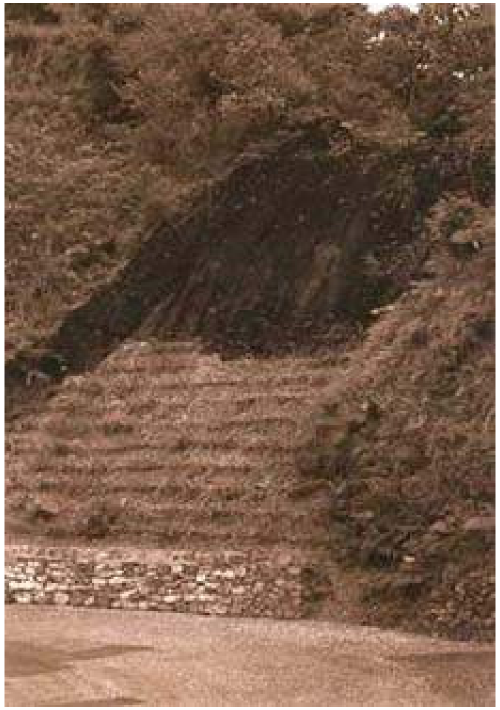
- During construction, add four or five cross-trusses (of 10 SWG wire) per square metre in each horizontal direction.

- Ensure that the minimum dimension of all stones is larger than the wire mesh size.

- Stones should be tabular and angular.

- All stones should be carefully and densely packed, not just the facings.
- Wire the lids down with additional wire of 12 SWG.
- Backfill behind the gabion structure with a filter blanket to improve drainage.

Integration with bio-engineering



A revetment toe wall is protected by grasses planted on the slope above

Bio-engineering techniques should be used in connection with revetment and toe walls as follows:

- **Protection of backfill.**

- **Protection from scour and undercutting of the foundations and sides.**
- **Flexible extension above the wall by the use of large bamboo or shrub and tree planting, increasing the catch function: refer to Sections 3.9 and 3.7 for details of these techniques.**

Further information

Revetments are covered in TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain* (page 136), with typical design diagrams given on page 137.

2.3 Prop walls/Dentition

Function

The term 'prop wall' also covers support walls and dentition. On very steep cut slopes, prop walls are used to support blocks of harder rock where they are underlain by softer rock bands. Where differential weathering occurs due to variations in adjacent strata, large segments of slope can become destabilised by a soft rock band eroding away underneath it. This presents two options: either remove all the material above or support it with a prop wall.

Prop walls do not usually offer total support to the full weight of all slope material above. Rather, they stop the erosion of softer bands below harder bands supported on them.

Sites

Only on steep cut slopes. Anywhere that a large slope-trimming job can be avoided by installing a relatively small wall. This technique is particularly useful in bands of alternating hard and soft rocks, such as are common in the Churia ranges.

Practical features

- **Excavate a foundation on a band of rock that is as hard as possible: this must be underneath the band that is being replaced by the prop wall and must show evidence of much greater resistance to erosion.**

- **Using dressed stones and a cement: sand mixture of 1:4 or 1:3, build a cement masonry wall following the line of the slope.**

- **For sections less than 2 metres high only, use dry stone masonry built with well-dressed stones.**

- **In cement-bound masonry, weep holes should be at least 75 mm in diameter, sloping downwards and should be installed every 500 mm (horizontally as well as vertically); they must also be included in the lowest level of masonry.**

- **Normally, the bound masonry wall should be no more than 500 mm thick; if support deeper than this is required, it can be provided by careful dry stone packing behind the masonry wall. There must be no cavities allowing collapse of even very small areas behind the wall.**

- **When the lower surface of the material to be supported is reached, it is**

important to pack in the stones and mortar very tightly; the whole wall is useless if the last millimetre is not solidly completed.

Integration with bio-engineering

Prop walls are usually used to support bands of harder strata and so there is usually a limited scope for close integration with bio-engineering techniques. However, where conditions give rise to a need for additional protection, bio-engineering techniques should be used as follows:

- **Protection from scour and undercutting of the foundations and sides.**

Further information

Prop walls are covered in TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain* under retaining structures (chapter 11, pages 116 to 126 and revetments (pages 136 and 137).

Constructing a cement masonry dentition wall to prevent undercutting of the upper part of a steep cut slope in differentially weathered gneiss

2.4 Check dams

Function

Check dams are simple physical constructions to prevent the downcutting of runoff water in gullies. They ease the gradient of the gully bed by providing periodic steps of fully strengthened material. Check dams are designed to accept an active pressure if it applied in the future, while permitting a safe discharge of water (and perhaps debris) via a spillway.

Sites

Any loose or active gully. In any rill that threatens to enlarge. In general, anywhere on a slope where there is a danger of scour from running water.

Practical features

- **Choose locations for the check dams so that the maximum effect can be achieved using the minimum possible volume of construction. Refer to the box on the spacing of check dams.**

- **Excavate a foundation in the gully bed until you find a sound layer to build on. The base of the dam should be at least 660 mm thick if it is one metre high; for every additional metre of height, add a further 330 mm to the width.**

- **Construct the check dam using the best-drained and most cost-effective materials. If possible, use dry stone masonry or gabions to improve drainage. If this will not work, use concrete-bound mortar.**

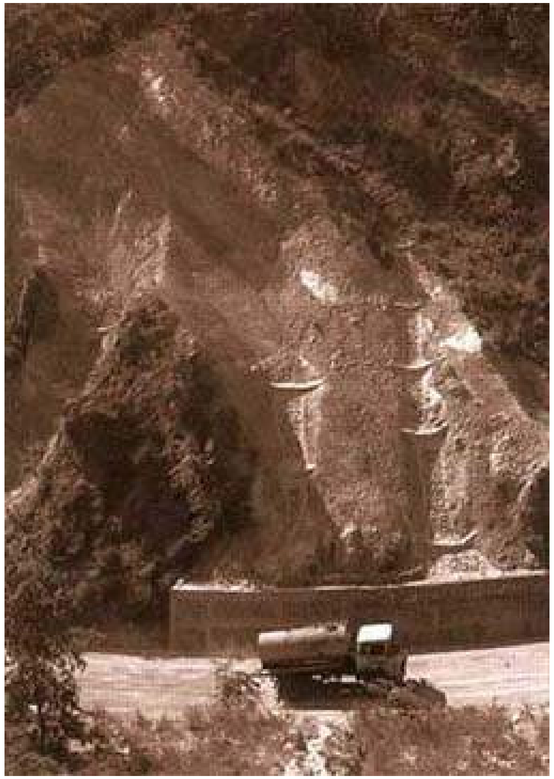
- **If using concrete-bound masonry, include weep holes to drain water from behind the check dam and reduce hydrostatic pressure.**

- **The ends of the dam should be keyed right into the gully sides and should be raised at least 250 mm to form a central spillway or notch: this ensures that water coming over the dam will then run down the middle and not scour the ends.**

- **An apron must be provided below the dam to ensure that energy is dissipated and that flow continues in the centre of the gully below the check dam.**

- **If there is a risk of people or animals damaging the top of the dam, or if it is in a gully likely to take a large flow of water, point the top layer with cement mortar.**

- **Once the construction of the check dam is completed, backfill behind the wings and sides, and compact the fill thoroughly.**



Small check dams at frequent intervals are effective, even in very steep gullies

SPACING OF CHECK DAMS

Check dams should normally be placed where:

- they protect weak parts of a gully from scour;
- they maximise effective gully protection for the smallest possible quantities, such as at natural nick points and the foot of debris heaps;
- adequate foundations are available.

In most cases, gullies are so irregular that the spacing of check dams will be determined by ground conditions. However, if the gully is sufficiently uniform, the spacing of check dams can be determined using the relationship devised in 1973 by Heede and Mufich.

This states that

$$X = \frac{H_E}{K \tan S \cos S}$$

where

X = *c*heck dam spacing in metres,
H_E = effective dam height metres as measured from the gully bottom to the spillway crest,
S = slope of the gully floor
and *K* is a constant,

K = 0.3 when tanS ≤ 0.2 and
K = 0.5 when tanS > 0.2.

The effective height (H_E) has to be estimated by the engineer on site. It is a function of the foundation conditions and the construction material used. The height should normally be maximised to reduce the number of check dams required.

Integration with bio-engineering

Bio-engineering techniques should be used in connection with check dams as follows:

- **Protection of backfill and gully floor above check dam.**
- **Protection from scour and undercutting of the foundations and sides.**
- **Construct live check dams between civil check dams, to reduce water velocity in the gully and improve stability (refer to Section 3.12); or line the gully bed with vegetated stone pitching (refer to Section 3.14 for details of this technique).**

Further information

Check dams are discussed in TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain* (page 108), with typical design diagrams given on pages 110 and 111.

Stone-pitched surface drains on a wet landslide scar

2.5 Surface and sub-surface drains

Function

Surface drains are installed in the surface of a slope to remove surface water quickly and efficiently. Surface-water drains often use a combination of bio-engineering and civil engineering structures.

Cascades are surface drains designed to bring water down steep sections of slope.

Sub-surface drains are installed in the slope to remove ground water quickly and efficiently. In practice they can be installed to a maximum of 1.0 to 1.5 metres (although the design depends on site conditions). Sub-surface drains are usually restricted to civil engineering structures, and do not normally use bio-engineering measures. However, bio-engineering techniques can be used to strengthen the slope around the drain.

Sites

Any site less than 35°. Certain drain types can be used on slopes up to 45° *(e.g.* drains constructed using gabion wire or concrete-bound masonry). Cascades are normally used on slopes steeper than 45°.

The same site, two years later, following establishment of the protective grass cover between the drains

Figure 2.3: Surface drains and cascades, and sub-surface drains: design and integration with bio-engineering (all drainage systems are assumed to be dendritic)

DRAIN TYPE				
STRUCTURE SURFACE DRAINS	**BIO-ENGINEERING**	**MAIN SITES**	**ADVANTAGES**	**LIMITATIONS**
Unlined natural drainage system (rills and gullies already developed on bare	Grasses in the rills and gullies, and grasses and other plants on the sides.	Existing landslide scars and debris masses.	By far the cheapest form of surface drain. Rapid drainage is assured.	There is a risk of renewed erosion in exceptionally heavy rain in weak materials.

surfaces).				
Unlined earth ditch system.	Grasses and other plants on sides and between feeder arms.	Slumping debris masses on slopes up to 45°, where the continued loss of material is not a problem (*e.g.* in debris masses well below a road, draining straight into large rivers).	By far the cheapest form of surface drain.	There is a serious erosion hazard, especially on steep main drains, so this type should be used only where further erosion is not a problem. Leakage into the ground may also occur.
Unbound dry stone system of ditches.	Grasses between stones (as vegetated stone pitching), and grasses and other plants on sides and between feeder arms.	Almost any site, however unstable, where the ground is firm enough to hold stone pitching and the flow of water is not too excessive for this construction technique.	A low-cost drain type. Strong and very flexible. These two features make it good on unstable slopes.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
Bound cement masonry ditch system.	Grasses and other plants on sides and between feeder arms.	Only on stable slopes with suitable material for good foundations.	A strong structure for heavy discharges.	Relatively high cost. Very inflexible, so there is a high risk of cracking and failure due to

				subsidence and undermining.
Wire bolster cylinders (herringbone pattern).	Grasses and other plants on sides and between feeder arms.	Almost any site, however unstable, without excessive amounts of stone, but where the ground is firm enough to hold the structure. The drainage discharge should not be excessive.	A medium-cost shallow type of drain. Very strong and flexible, which makes it good for unstable slopes.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
Open gabion ditch system.	Grasses and other plants on sides and between feeder arms.	Almost any site, however unstable, where the ground is firm enough to hold a relatively big structure, and where a large volume of discharge is possible.	A large and high-cost type of drain. Very strong and flexible, which makes it good for unstable slopes.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
CASCADES				
Dry stone cascade.	Grasses and other plants along the sides.	Any slope section steeper than 50° where foundations are adequate and discharge is relatively	A low-cost form of cascade with a degree of flexibility.	A membrane of thick, black polythene may be required to stop leakage back into

		low.		the ground.
Mortared masonry cascade.	Grasses and other plants along the sides.	Very stable slope sections steeper than 45°, where foundations are very good.	A strong structure for heavy discharges.	Relatively high-cost and inflexible cascade type, so there is a high risk of cracking and failure due to subsidence and undermining.
Gabion cascade.	Grasses and other plants along the sides.	Any slope section steeper than 45°, where foundations are adequate and discharge is likely to be high.	Very strong and flexible, which makes it good for unstable slopes.	A relatively large and high-cost cascade type. A membrane of thick, black polythene is required to stop leakage back into the ground.
Concrete cascade.	Grasses and other plants along the sides.	Very stable slope sections steeper than 45°, where foundations are very good.	A very strong structure for the heaviest discharges.	Very high-cost and inflexible cascade type. The risk of cracking and failure due to subsidence and undermining is partly offset by the innate strength of the construction.

Figure 2.3: Surface drains and cascades, and sub-surface drains: design and integration with bio-engineering (all drainage systems are assumed to be dendritic) ***continued***

DRAIN TYPE				
STRUCTURE	**BIO-ENGINEERING**	**MAIN SITES**	**ADVANTAGES**	**LIMITATIONS**
SUB-SURFACE DRAINS				
French drain system (perforated pipe of durable, high grade black polythene, 150 mm diameter with approximately 40 holes of 5 mm per metre) in a drainage medium of aggregates). Drain can be made more resistant to disruption by building it in a casing of gabion.	Grasses and other plants along the sides and between feeder arms.	Almost any site, however unstable, where the ground is firm enough to hold the structure and the flow of water is not too excessive for this construction technique.	A relatively low-cost and common sub-surface type of drain. Very flexible, which makes it good for unstable slopes.	A membrane of permeable geotextile should be used. If the flow is too great, piping may occur underground. The outfall must be monitored to check that the drain is functioning, but the hidden nature of the drain means that this cannot always be fully

				ascertained.
Site-specific design of drain to pick up seepage water. An open ditch or a drain with a flexible gabion lining is preferred.	Plant grasses and other species along the sides.	Any slope with obvious seepage lines.	Specific drains can be designed for any site, leading to the optimum collection of water.	Great care is needed to ensure all seepage water is trapped by the drain. Movement in the slope may affect this.
Deep surface drain types (deeper versions of the surface drains described above, designed to catch shallow ground water seepage).	As for each surface drain type described above.	As for each surface drain type described above.	Open drains allow easy cleaning and repair, as well as monitoring of effectiveness.	The usual practical maximum depth is about 1.5 metres. Special care must be used to allow water to seep into the drains.

Practical features

- **Always design drainage systems to run along natural drainage lines. Choose locations for the drains so that the maximum effect can be achieved using the minimum possible volume of construction.**

- **Always ensure that drain outfalls are protected against erosion.**

- **Only use a rigid geometrical pattern of drains on newly formed fill slopes where there are no clear natural drainage lines.**

- **Excavate a foundation until a sound layer to build on is located. Drains must be well founded like all other civil structures.**

- **Run main drains straight down the slope. Feed side drains in on a herringbone pattern.**

- **Never use contour drains: these block very easily and are also highly susceptible to subsidence. A blocked or cracked drain can create terrible damage as a result of concentrated water flow.**

- **Design and construct the drains in such a way that water can enter them easily on the higher side but not seep out on the lower side. Use weep holes and thick (≥ 20 gauge), black polythene membranes carefully to achieve this.**

- **A flexible design is usually an advantage. Concrete masonry can be easily cracked by the slightest movement in the slope, and then leakage problems result.**

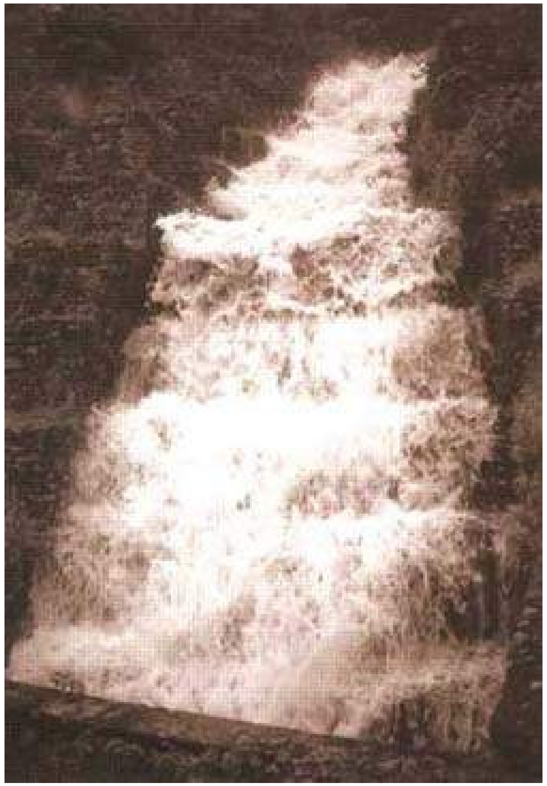
- **If there is a risk of people or animals damaging the drain, make sure that the construction is strong enough (*e.g.* use gabion rather than dry stone construction).**

- **Once the drain is completed, backfill around it and compact the fill thoroughly.**

- **Apply appropriate bio-engineering measures to enhance the effectiveness of the drain.**

- **Where the site requires deeper drainage and the machinery is available, drains can be drilled into the slope.**

- **Figure 2.3 gives comparison details of the main drain and cascade types.**



A gabion cascade in heavy rain. This type of structure can transport large volumes of water down steep slopes without damage

Further information

Surface drainage on slopes is covered on pages 136 to 139 of TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain.*

Sub-surface drainage on slopes is covered on pages 139 to 140 of TRL Overseas Road Note 16, *Principles of low cost road engineering in mountainous terrain.*

2.6 Stone pitching

Functions

A slope is armoured with stone pitching. This gives a strong covering. It is freely drained and will withstand considerable water velocities.

Note that in Section 3.14, among the bio-engineering techniques, full details are given of *vegetated stone pitching:* that is a stronger form of stone pitching, with emphasis given to its strengthening by vegetation.

Sites

Any slope up to 35°. This technique is particularly useful on slopes with a heavy seepage problem, in flood-prone areas or where vegetation is difficult to establish, such as in urban areas. It is also useful on gully floors between check dams and for scour protection by rivers.

Materials

- **Boulders;**
- **Tools for digging and for dressing stones.**

The largest available stones should be used which permits pitching to be done effectively on the site. The stones used should have one large flat side, and should be of equal size and angularity.

Spacing

Stone pitching effectively gives a complete surface cover.

Construction steps

1. Prepare a sound slope before constructing the stone pitching; it must be free of loose debris and topsoil, and trimmed to an even surface.

2. Bed the stones down well into the slope surface. Excavate as necessary to ensure an even upper surface to the stone pitching.

3. Build the stone pitching carefully, with the stones fitted together firmly, as if it is a dry masonry wall. Stones should be perpendicular to the slope, with the main point or narrow side down.

4. In drains and gullies, a rough surface can be left to retard water flow.

5. For further strengthening it is best to plant grasses or the hardwood cuttings of shrubs through the stone pitching (see below and Section 3.14).

6. Other options for strengthening are either to use a gabion mattress (of 0.3 to 0.5 metre thickness) instead of dry stone pitching; or to use cement mortar (but this can impede drainage).

WHY YOU SHOULD AVOID USING CUT-OFF DITCHES OR CATCH DRAINS ABOVE CUT SLOPES

Cut-off ditches, otherwise known as cut-off drains or catch drains are:

- almost certain to become Mocked;
- very likely to suffer from settlement of the foundations and crack as a result;
- often difficult to maintain because they are above the road and out of sight.

A cut-off ditch becoming blocked or cracked is a common cause of a landslide or the severe erosion of a cut slope in Nepal. Damage to a cut slope can be considered the usual outcome of the installation of a cut-off ditch.

This warning applies to all surface ditches that are out of sight of the road, and therefore they are best avoided unless there is no alternative.

Water should be brought down the slope along its natural course, protected with vegetation and civil structures as required, and if necessary carried into the nearest roadside ditch by a cascade. Localised damage can then be seen and repaired as soon as it occurs.

Integration with bio-engineering

For the best effects, bio-engineering techniques should be used in connection with

stone pitching as follows.

- **Strengthening of stone pitching: plant grass slips in the gaps between stones: see Section 3.14.**

- **Increased strengthening of stone pitching: insert live cuttings of shrubs into the gaps between stones: see Section 3.14.**

Maintenance

If stones are displaced, the pitching should be repaired as soon as possible. Otherwise the maintenance depends on the type of bio-engineering used (refer to the relevant part of Section 5 for details).

Main advantages

Stone pitching forms a strong and long-lasting method of reinforcing a slope surface and stopping gully development.

Main limitations

Stone pitching is relatively expensive in comparison with bio-engineering measures such as brush layers.

2.7 Wire Bolster Cylinders

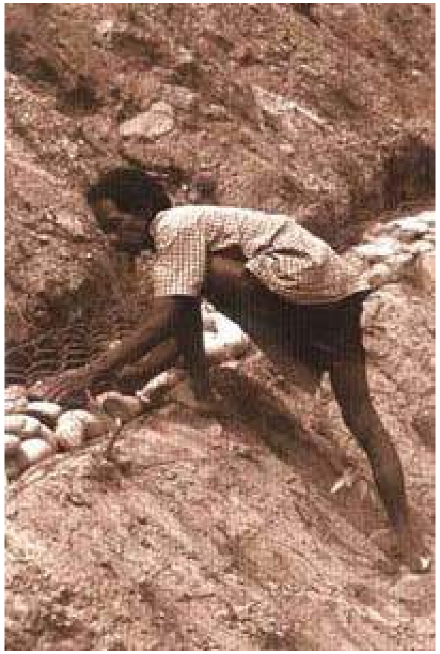
Function

Wire bolster cylinders (in cross-section, a gabion tube of 300 mm diameter filled

with stone) are laid in shallow trenches across the slope. They prevent surface scour and gullying (by reinforcing and fulfilling an intermittent armouring function), and provide shallow support. Bolsters can be laid in two ways: (1) along the contour; or (2) in a herringbone pattern (←←←←←) to double as a surface drainage system.

Sites

On most long, exposed slopes between 35° and 50° where there is a danger of scour or gullying on the surface. Contour bolsters are used on well drained materials; slanted (herringbone pattern) bolsters are used on poorly drained material where there is a risk of slumping.



Constructing a wire bolster (see *construction step 5,* overleaf)

Completed wire bolster cylinders on a steep colluvial slope

Materials

- **Woven gabion panels;**
- **16 mm rebar or high yield steel rod cut into 2 m lengths;**
- **Boulders:**

  for contour bolsters, angular,
  smallest dimension > 100 mm;
  for herringbone bolsters, rounded,
  smallest dimension > 100 mm;

- **Tools for digging trenches and for working with gabion wire;**
- **Sledge hammers.**
- **For herringbone bolsters, thick (≥ 20 gauge), black polythene sheet to line**

the trenches.

Gabion bolster panels are normally 5 m × 1 m. Where larger bolsters are required 5 m × 2 m panels can be woven. They are made on a conventional gabion weaving frame but with a smaller mesh than usual: this is normally 70 × 100 mm, triple twist. Heavy coated 10 SWG wire is used for the border and 12 SWG for the mesh.

Spacing

Contour bolsters are normally spaced as follows,

slope < 30°: 2000 mm centres;
slope 30 - 45°: 1500 mm centres.
Herringbone bolsters are placed at 1500 mm centres.

Construction steps (contour bolsters)

1 Trim the area to be treated to an even slope with no small protrusions or depressions which will interfere with the bolsters.

2 Starting about 2 metres from the bottom of the slope, mark out a contour line across the slope with the aid of a spirit level.

3 Dig a trench along the line: the trench should be about 300 mm wide and 300 mm deep (Figure 2.4; a).

4 Lay a gabion bolster panel lengthways along the trench: make sure the edge of the panel on the lower side is flush with the edge of the trench.

5 Fill the bolster with stones larger than the mesh size (Figure 2.4; b, c).

6 Fold the upper edge of panel over the stones and join it to the lower panel edge. Leave a 100 mm flap from the upper edge extending over the lower edge (Figure 2.4; d).

7 Join abutting bolsters: form the bolsters into a continuous line across the slope and close the extreme ends with wire.

8 Backfill the material around the bolsters, compact it and clean away surplus debris.

9 Drive steel bars into the ground at right angles to the slope every 2 metres along the bolsters. Position them immediately below and touching the bolsters, and drive them in far enough so that they cannot be pulled out by hand (Figure 2.4; e).

10 Cover remaining site: repeat steps (2) to (9) up the slope at the spacing required until the area is covered.

11 Starting from the top of the slope, clean away surplus debris and make sure that backfill is complete and firm.

12 Implement bio-engineering works throughout the site.

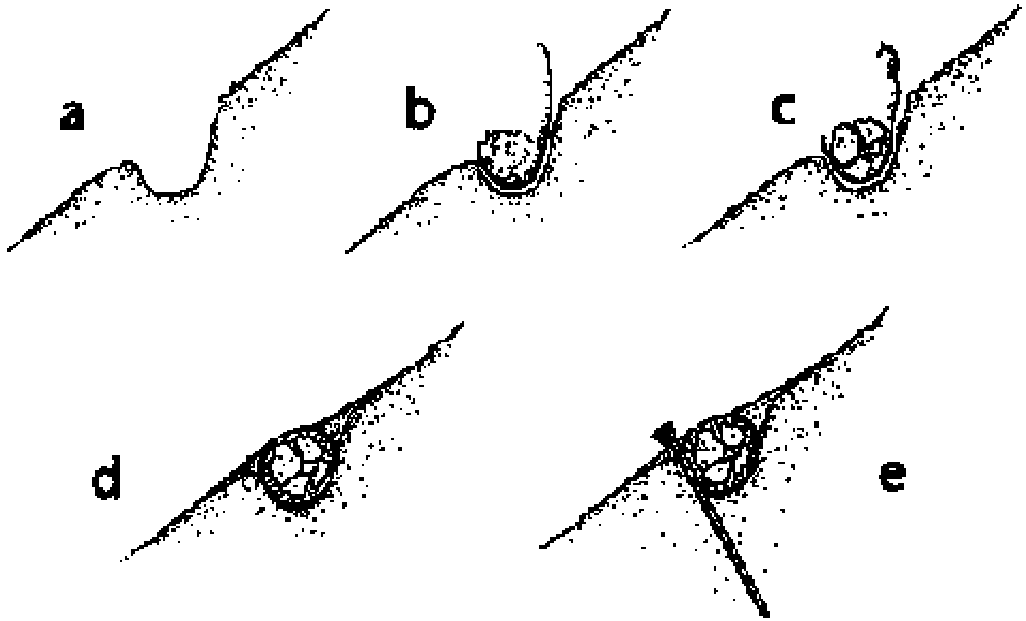


Figure 2.4: Wire bolster construction

Construction steps (herringbone bolsters)

1 The site to be treated should first be trimmed to an even slope: there should be no protrusions or depressions that will interfere with the bolsters; loose rocks should be removed if possible;

2 Starting about 2 metres from the bottom of the slope, mark out the lines for the bolsters; they should be at 45° to the line of the slope and each slanting piece should normally be 5 metres long (although the design must be flexible to take individual site conditions into account).

3 Dig trenches along the lines, about 300 mm wide and 300 mm deep.

4 Lay a sheet of black polythene along the bottom and lower side, but not

the higher side, of the trench.

5 Lay gabion bolster panels lengthways along the trenches. The edge of the panel on the lower side should be flush with the lower edge of the trench.

6 Fill the bolster with stones larger than the mesh size. Stones must not be packed carefully on top of each other as this reduces water flow: instead, they must be poured in from above and packed firmly but at random within the mesh.

7 Fold the upper edge of the panel over the stones and join it to the lower panel edge; at the end of the pattern, where the slanting lines meet, the bolster ends should be closed over with wire but not joined to adjacent patterns: this is so that each stack of V patterns can fail without affecting the pattern next to it.

8 Repeat steps 3 to 7 at 1.5 metre intervals, installing a series of bolsters up the slope.

9 Once the slanting lines are complete, dig a trench straight down the slope and install a 'vertical' bolster in it to collect water from the bottoms of each V, and run it to the base of the slope. Tie the herringbones or ribs to the spine.

10 Backfill the material around the bolsters, compact it and clean away surplus debris as necessary.

11 Drive mild steel bars into the ground at right angles to the slope every 2

metres along the bolsters: they should be positioned immediately below and touching the bolsters, and should be driven in far enough that they cannot be pulled out by hand.

12 Implement bio-engineering works throughout the site.

Integration with bio-engineering

The spaces between the bolsters should be treated with appropriate bio-engineering as soon as the subsequent rains have broken, as follows:

- **Between wire bolster cylinders: plant shrub and small tree seedlings at 1000 mm centres throughout the slope treated, according to site characteristics and as determined by the instructions in Section 1.2.**

- **If a more complete surface protection is required, the surface can be planted or seeded with grass between the wire bolster cylinders, using the techniques described in Sections 3.1 to 3.5, according to the site requirements described in Section 1.2.**

Maintenance

Maintain the bio-engineering works according to the needs of the particular treatment used.

If rills develop between the bolsters and threaten to undercut them, small-scale stone dentition should be used to support undermined places and stop scour erosion. In extreme cases, fully stone-lined gullies can be made between bolsters

in order to shed large amounts of accumulated runoff without damaging the slope.

Main advantages

Bolsters form the strongest and longest-lasting method of armouring a slope surface and preventing gully development.

Main limitations

Bolsters are relatively expensive in comparison with bio-engineering measures such as brush layers.

2.8 Other civil engineering techniques

Wire netting

Function

Wire netting (usually gabion wire mesh) is spread over the surface of a rocky slope. This can be carried out to reduce the shedding of rock debris and slow the degradation of the surface.

Sites

Slopes composed of hard rock with a degree of fragmentation leading to the occasional shedding of debris particles larger than about 100 mm.

Comments

The main difficulty with this technique is fixing the wire mesh to the face of the slope. This is normally done by hammering steel pegs into rock cracks or by cementing them into depressions. If this is done satisfactorily, then it can be a very robust measure.

If the slope has not been trimmed well in advance, the accumulation of loose boulders behind weakening wire netting could release a bigger and more dangerous load in one go, rather than a gradual shedding of individual boulders. But with a good maintenance regime this technique could be used to advantage.

Gunite (shotcrete)

Function

Gunite is a cement-stabilised aggregate sprayed on to a wire mesh slope covering. It can be used for surface armouring and to bind together the surface of weathered and fractured rock slopes.

Sites

This technique has potential on steep (> 50°) cut slopes less than about 30 metres in height.

Comments

This technique has been used successfully in Hong Kong and Malaysia. The main limitation is the difficulty of ensuring slope drainage through the covering, even when numerous weep holes are provided: it is generally considered to be

inappropriate on slopes with high groundwater seepage rates, such as are common in Nepal. The expense is also a limiting factor.

Chunam

Function

Chunam is a lime-based plaster applied as a slurry across the surface of a slope. It waterproofs and supports the immediate surface, armouring against scour of the surface and weathering of the material below. It can be reinforced using wire mesh already attached to the surface.

Sites

This technique has potential on steep (> 50°) cut slopes less than about 30 metres in height.

Comments

This technique has been successful in limited areas only. It is essential to install drainage or weep holes, sloping towards the outside of the material. Even with these, many surfaces have failed when treated with chunam because too much water has percolated behind the surfacing from higher up the slope and it has flaked away from the less weathered material behind. The best successes might be achieved in naturally dry sites, where hard chunam facings can stop surface erosion during heavy rains.

Cement slurry

Function

A watery cement slurry is poured into the ground. It percolates along pores and gaps in the material. When it sets, it binds the material together and increases the cohesive strength. The main engineering function is to reinforce.

Sites

This technique has potential in highly permeable debris materials, such as colluvium with a low proportion of fines.

Comments

There are no records of the widespread use of this technique in Nepal, but it has been used occasionally on colluvial slopes above roads. It is probably only worth using on the very porous materials described above, where there is adequate void space to absorb a critical quantity of slurry. Its best application is to reinforce material immediately upslope from a retaining structure which is considered too weak, such as a gabion wall which has bulged: in this situation, it may avoid the necessity of replacing one threatened structure with a stronger one. It could also be used in a purpose-designed situation, where there is inadequate space to construct a wall of the desired thickness, and where cement stabilisation of the retained debris can increase the factor of safety satisfactorily. In emergencies, it might be used shortly before the start of the monsoon rains, when there is not enough time to build a normal structure.

Reinforced earth

Function

A proprietary or purpose-designed material is laid at intervals into debris, which is built up in layers to form a slope of earth strengthened with the reinforcing material. The result is intermediate in strength between a straightforward fill slope and a retaining structure. The main engineering function is to reinforce.

Sites

This technique is best used on fill slopes, where the design angle is relatively low and the major disturbance involved in construction can be accomplished more easily.

Comments

There are various proprietary systems of reinforced earth, but there are no records of them being tried for slope stabilisation in Nepal. A form of earth reinforcement could be undertaken using a material such as gabion mesh laid into the slope at intervals as it is backfilled. However, reinforced earth systems present complex slope stability calculations, and the standard retaining structures are preferable in most cases.

Further information

Reinforced earth structures are covered in TRL Overseas Road Note 16; *Principles of low cost road engineering in mountainous terrain* (page 122), with typical design diagrams given on page 120.

Soil nailing

Function

Tensile strengthening is added to the slope in the form of steel bars inserted into the soil (or surface layers). Insertion is possible to a maximum depth of about 5 metres.

Sites

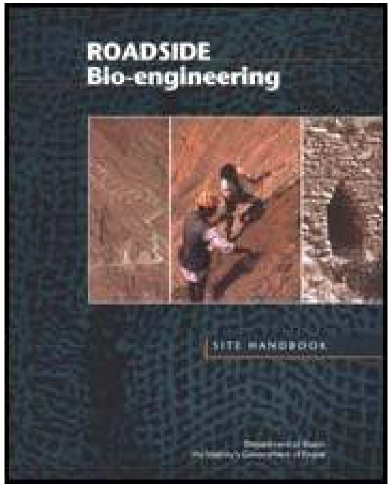
Any slope that is liable to creeping planar mass failures and where access for machinery is feasible. It is not effective against erosion or many shear failures.

Comments

There are two main methods. One uses a procedure of drilling and grouting, and the other hammers the nails in, normally using a mechanical percussion device. Both have advantages in certain situations, but both require machinery to gain access to the slope. The high cost of the technique makes its usefulness in Nepal dubious compared with the established systems of slope stabilisation.

Further information

Information is available from the companies offering proprietary systems of soil nailing, and their agents. No proven examples of this technique are known in Nepal.


ROADSIDE
Bio-engineering
SITE HANDBOOK

Roadside Bio-Engineering - Site Handbook (DFID, 1999, 160 p.)

Section Three - Bio-engineering techniques

Figure

This section gives details of the design and construction of the main bio-engineering systems used for stabilising slopes and controlling erosion. These are:

- grass planting, seeding and turfing (Section 3.1 to 3.6);
- shrub and tree planting and seeding (Sections 3.7 and 3.8);
- large bamboo planting (Section 3.9);

- **brush layering (Section 3.10);**
- **palisades (Section 3.11);**
- **live check dams (Section 3.12);**
- **fascine constructions (Section 3.1 3);**
- **vegetated stone pitching (Section 3.14);**
- **jute netting: detailed information on its use and construction: standard mesh (Section 3.15) and wide mesh (Section 3.16);**
- **mulching: detailed information on the use of mulch as an aid to bio-engineering (Section 3.1 7);**
- **vegetated gabions (Section 3.18);**
- **live wattle fences (Section 3.19);**
- **hydro-seeding (Section 3.20).**

Details of all of the civil engineering measures used in combination with these bio-engineering systems are given in Section 2.

3.1 Planted grass lines: contour/horizontal

Planting grass lines. Use a planting bar to make holes just big enough for the roots

Function

Grass slips (rooted cuttings), rooted stem cuttings or clumps grown from seed are planted in lines across the slope. They protect the slope with their roots and, by providing a surface cover, reduce the speed of runoff and catch debris, thereby armouring the slope. The main engineering functions are to catch, armour and reinforce.

Sites

Almost any slope less than 65°. This technique is mostly used on dry sites, where moisture needs to be conserved. It is most widely used on well-drained materials where increased infiltration is unlikely to cause problems. On cultivated slopes

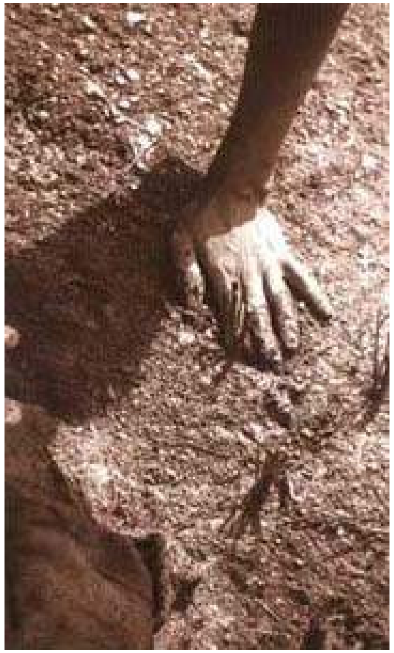
less than 35°, horizontal lines planted at intervals across the field can be used to avoid loss of soil and to help conserve moisture, as a standard soil conservation measure. Planted grass lines at intervals are essential if cultivation has to be carried out on slopes greater than 35°.

Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface

Materials

- **Grass plants raised in a nursery or cuttings obtained elsewhere;**
- **Short planting bars;**
- **Line string;**
- **Spirit level;**
- **Tape measure (30 metres);**

- **A means of transporting plants to site;**
- **Hessian and water to keep the roots moist;**
- ***(Optional)* Manure or compost.**



Fill the soil in around them, firming it gently with your fingers

SPECIES SUITABLE FOR PLANTED GRASS LINES: CONTOUR/HORIZONTAL

Local name	Botanical name	Altitude range	Sites summary
Amliso	*Thysanolaena maxima*	Terai -2000m	Varied
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai -1500 m	Hot and dry
Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist

Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	Terai - 2000 m	Hot and dry; varied
Khus	*Vetiveria lawsoni*	Terai - 1500 m	Varied
Narkat	*Arundo clonax*	Terai - 1500 m	Hot and dry; varied
Padang bans	*Himalayacalamus hookerianus*	1500 - 2500 m	Moist
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied
Tite nigalo bans	*Drepanostachyum intermedium*	1000 - 2500 m	Varied

Spacing

Line spacing depends largely on the steepness of the slope.

Within rows: plants at 100 mm centres (except padang and tite nigalo bans, which should be spaced at 500 mm centres)

Row spacings:

slope < 30°: 1000 mm;
slope 30-45°: 500 mm;
slope > 45°: 300 mm.

Where this technique is used on agricultural land, a compromise must be reached between ease of cultivation and reduction of soil and water movement. A vertical interval of 2 metres or more is generally adequate.

Construction steps

1 Prepare the site well in advance of planting. Remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start. If the site is on backfill material, it should be thoroughly compacted, preferably when wet.

2 Always start grass planting at the top of the slope and work downwards.

3 Mark out the lines with string, using a tape measure and spirit level. Make sure the lines run exactly as required by the specification, along the contour.

4 Split the grass plants out to give the maximum planting material. Trim off long roots and cut the shoots off at about 100 mm above ground level. Wrap the plants in damp hessian to keep them moist until they are planted. Remember that you will need two slip cuttings per drill (planting hole) if the grass is a fibrous rooting type (*e.g.* babiyo, kans, khar, phurke, *etc.*) but only one if it is rhizomatous (*e.g.* amliso, padang bans, *etc.*), and only one rooted stem cutting or seedling.

5 With a planting bar, make a hole just big enough for the roots. Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface. Fill the soil in around them, firming it gently with your fingers. Take care to avoid leaving an air pocket by the roots.

6 If compost or manure are available, scatter a few handfuls around the grasses. This is especially important on very stony sites, where compost or manure can help to improve early growth. You may have to incorporate it

into the surface material to prevent it being washed off.

7 If it looks rather dry and there is no prospect of rain for a day or two, consider watering the plants by hand.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Grass cutting (check on Poush 1).

Main functions

Contour grass lines catch material moving downslope. They also armour slopes on highly impermeable materials by retarding runoff and reinforcing slope materials.

Main limitations

Contour grass lines can increase the infiltration rate to the point of liquefaction on poorly drained materials, particularly on steeply sloping, fine-textured debris.

3.2 Planted grass lines: downslope/vertical

Function

Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines running down the slope. They protect the slope with their roots, provide a

surface cover and help to drain surface water. They do not catch debris. The main engineering functions are to armour, reinforce and drain. Using this technique, a slope is allowed to develop a semi-natural drainage system, gullying in a controlled way.

Sites

Almost any slope less than 65°. It is mostly used on damp sites, where moisture needs to be shed. It is also most widely used on poorly drained materials where an increase in infiltration can lead to liquefaction of the soil.

Materials

- **Grass plants raised in a nursery or cuttings obtained elsewhere;**
- **Line string;**
- **Triangular set square or frame with a plumb line;**
- **Spirit level;**
- **Tape measure (30 metres);**
- **A means of transporting plants to site;**
- **Hessian and water to keep the roots moist;**
- ***(Optional)* Manure or compost.**

Vertical grass lines allow a slope to develop a semi-natural drainage system, reducing infiltration and the likelihood of liquefaction of the soil

Spacing

If the site is a newly cut slope, then a simple geometrical pattern can be used. The normal spacing is as follows:

> **Within rows: plants at 100 mm centres (except padang and tite nigalo bans, which should be spaced at 500 mm centres)**
>
> **Row spacings: 500 mm.**

SPECKS SUITABLE FOR PLANTED GRASS LINES: DOWNSLOPE/VERTICAL

Local name	Botanical name	Altitude range	Sites summary
Amliso	Thysanolaena maxima	Terai - 2000 m	Varied
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai - 1500 m	Hot and dry

Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist
Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	Terai - 2000 m	Hot and dry; varied
Khus	*Vetiveria lawsoni*	Terai - 1500 m	Varied
Narkat	*Arundo clonax*	Terai - 1500 m	Hot and dry; varied
Padang bans	*Himalayacalamus hookerianus*	1500 -2500m	Moist
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied
Tite nigalo bans	*Drepanostachyum intermedium*	1000 -2500m	Varied

However, if a gully system has already partly developed, then the spacing is defined naturally. Lines of grass should not be more than 500 mm apart if possible and, if ridges are bigger, a series of small lines in a chevron pattern (<<<<<) is required to protect gaps. Careful supervision is required on site to ensure that all planted lines follow the direction of natural fall.

Construction steps

1 Prepare the site well in advance of planting. Remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start.

2 Always start grass planting at the top of the slope and work downwards.

3 Mark out the lines with string, using a tape measure. Use the spirit level, string and set square, or the frame to check the maximum line of fall. Make

sure the lines run exactly as required by the specification, down the slope or drainage line.

4 Split the grass plants out to give the maximum planting material. Trim off long roots and cut the shoots off at about 100 mm above ground level. Wrap the plants in damp hessian to keep them moist until they are planted. Remember that you will need two slip cuttings per drill (planting hole) if the grass is a fibrous rooting type (*e.g.* babiyo, kans, khar, phurke, *etc.*) but only one if it is rhizomatous (*e.g.* amliso, padang bans, *etc.*), and only one rooted stem cutting or seedling.

5 With a planting bar, make a hole just big enough for the roots. Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface. Fill the soil in around them, firming it gently with your fingers. Take care to avoid leaving an air pocket by the roots. Mound the soil along the grass line, to encourage water to run mid way between the lines rather than close to the plant stems.

6 If compost or manure is available, scatter a few handfuls around the grasses. This is important on very stony sites, where it can help to improve early growth. You may have to incorporate it into the surface material to prevent it being washed off.

7 If it looks rather dry and there is no prospect of rain for a day or two, consider watering the plants by hand.

Maintenance

This normally involves:

- **Protection (check on Kartik 1);**
- **Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);**
- **Grass cutting (check on Poush 1).**

If gullies develop, they must be controlled. If they become large enough to endanger the site, they must be checked with dry stone pitching and small check dams. If caught early enough, a few stones may be all that is required to create an armoured rill in which the runoff can safely pass. If allowed to grow too big, much more work will be required.

Main functions

Downslope grass lines provide the maximum amount of surface drainage by channeling runoff and minimising infiltration. They still armour against erosion and reinforce the slope.

Main limitations

On impermeable materials, runoff can become damaging. In drier sites, grass plants can suffer from drought due to the increased drainage. On some weak materials, rills can develop down the side of the plant line, damaging the grass slips and reducing their growth.

3.3 Planted grass lines: diagonal

Function

Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines running diagon-ally across the slope. They armour the slope with their roots and by providing a surface cover. They have limited functions of catching debris and draining surface water. The main engineering functions are to armour and reinforce, with secondary functions to catch and drain. This technique offers the best compromise of the grass line planting systems in many situations.

Sites

Almost any slope less than 65°. It is mostly used on poorly drained materials where an increase in infiltration can lead to liquefaction of the soil. It is also useful on damp sites, where moisture needs to be shed. It should be used whenever there is doubt as to which grass line planting system should be used, as a result of uncertainties over site environmental characteristics or material properties.

Materials

- **Grass plants raised in a nursery or cuttings obtained elsewhere;**
- **Line string;**
- **Tape measure (30 metres);**
- **Triangular set square or frame with a plumb line (optional);**
- **Spirit level (optional);**
- **A means of transporting plants to site;**
- **Hessian and water to keep the roots moist;**
- ***(Optional)* Manure or compost.**

Spacing

If the site is a newly cut slope, then a simple geometrical pattern can be used. The normal spacing is as follows:

Within rows: plants at 100 mm centres (except padang and tite nigalo bans, which should be spaced at 500 mm centres)

Row spacings: 500 mm.

However, if a gully system has already partly developed, then the spacing is defined naturally. Lines of grass should not be more than 500 mm apart if possible and, if ridges are bigger, a series of small lines in a chevron (<<<<<) or herringbone (←←←←←) formation is required to protect gaps.

Construction steps

1 Prepare the site well in advance of planting. Remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start.

2 Always start grass planting at the top of the slope and work downwards.

3 Mark out the lines with string using a tape measure. Make sure they run exactly as required by the specification, diagonally across the slope or towards drainage lines. It may help to use a spirit level and set square or frame to check the maximum line of fall.

4 Split the grass plants out to give the maximum planting material. Trim off long roots and cut the shoots off at about 100 mm above ground level. Wrap the plants in damp hessian to keep them moist until they are planted. Remember that you will need two slip cuttings per drill (planting hole) if the grass is a fibrous rooting type *(e.g.* babiyo, kans, khar, phurke, *etc.)* but only one if it is rhizomatous *(e.g.* amliso, padang bans, *etc.),* and only one rooted stem cutting or seedling.

5 With a planting bar, make a hole just big enough for the roots. Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface. Fill the soil in around them, firming it gently with your fingers. Take care to avoid leaving an air pocket by the roots.

6 If compost or manure is available, scatter a few handfuls around the grasses. If the site is very stony, this is important for improving early growth. You may have to incorporate it into the surface material to prevent it being washed off.

7 If it looks rather dry and there is no prospect of rain for a day or two, consider watering the plants by hand.

SPECIES SUITABLE FOR PLANTED GRASS LINES: DIAGONAL

Local name	Botanical name	Altitude range	Sites summary
Amliso	*Thysanolaena maxima*	Terai - 2000 m	Varied
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai - 1500 m	Hot and dry

Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist
Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	Terai - 2000 m	Hot and dry; varied
Khus	*Vetiveria lawsoni*	Terai - 1500 m	Varied
Narkat	*Arundo clonax*	Terai - 1500 m	Hot and dry; varied
Padang bans	*Himalayacalamus hookerianus*	1500 - 2500 m	Moist
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied
Tite nigalo bans	*Drepanostachyum intermedium*	1000 - 2500 m	Varied

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Grass cutting (check on Poush 1).

Main functions

Diagonal grass lines armour and reinforce slopes effectively, and can also drain and catch material moving down the slope. This system appears to combine the best features of both horizontal and vertical planting in the majority of sites.

Main limitations

Where the specific advantages of contour or downslope planting patterns are

critical, diagonal planting should not be used. On certain very weak materials, small rills can develop down the slope.

3.4 Planted grasses: random planting

Function

Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted at random on a slope, to an approximate specified density. They armour and reinforce the slope with their roots and by providing a surface cover. They also have a limited function of catching debris. This technique is most commonly used in conjunction with standard mesh jute netting, where complete surface protection is needed on very steep, harsh slopes. In most other cases, however, the advantages of one of the grass line planting systems (*i.e.* contour, downslope or diagonal) offer better protection to the slope.

Sites

Almost any slope less than 60° that allows grass planting. Normally used only on sites where jute netting (standard mesh) has already been applied. This implies slopes steeper than 45° and less than 15 metres in length, where moisture is not a serious problem.

Materials

- Grass plants raised in a nursery or cuttings obtained elsewhere;
- Short planting bars;
- A means of transporting plants to site;

- **Hessian and water to keep the roots moist;**
- ***(Optional)* Manure or compost.**

Spacing

Plants should be at an average of 100 mm centres (*i.e.* 100 plants per square metre). No gap should exceed 200 mm.

Construction steps

1 Apply the jute netting (standard mesh) well in advance of the monsoon, as described in Section 3.15. Start the grass planting as soon as the rains allow. If the site has not been treated with jute netting, prepare it well in advance of planting: remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start.

2 Always start grass planting at the top of the slope and work downwards. Workers should stand on the pegs holding the netting, not on the netting itself.

3 Split the grass plants out to give the maximum planting material. Trim off long roots and cut the shoots off at about 100 mm above ground level. Wrap the plants in damp hessian to keep them moist until they are planted. Remember that you will need two slip cuttings per drill (planting hole) if the grass is a fibrous rooting type (*e.g.* babiyo, kans, khar, phurke, *etc.*) but only one if it is rhizomatous (*e.g.* amliso, padang bans, *etc.*), and only one rooted stem cutting or seedling.

4 With a planting bar, make a hole just big enough for the roots. Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface. Fill the soil in around them, firming it gently with your fingers.

5 Plant grasses at random over the surface, but aim for an average spacing of 100 mm centres (i.e. 100 plants per square metre). No gap should be greater than 200 mm.

6 If compost or manure is available, scatter a few handfuls around the grasses.

7 If it looks rather dry and there is no prospect of rain for a day or two, consider watering the plants by hand.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Grass cutting (check on Poush 1).

Main functions

Random grass planting armours and reinforces slopes effectively. This is particularly the case when it is used in conjunction with standard mesh jute netting.

Main functions and limitations

Where the specific advantages of contour, downs-lope or diagonal planting patterns are critical, random planting should not be used.

SPECIES SUITABLE FOR PLANTED GRASSES: RANDOM PLANTING

Local name	Botanical name	Altitude range	Sites summary
Amliso	*Thysanolaena maxima*	Terai - 2000 m	Varied
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai - 1500 m	Hot and dry
Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist
Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	Terai - 2000 m	Hot and dry; varied
Khus	*Vetiveria lawsoni*	Terai - 1500 m	Varied
Narkat	*Arundo clonax*	Terai - 1500 m	Hot and dry; varied
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied

3.5 Grass seeding

Function

Grass is sown directly on to the site. It allows easy vegetation coverage of large areas. This technique is often used in conjunction with mulching and jute netting to aid establishment. The main engineering functions are to armour and, later, to

reinforce.

Sites

Almost any bare site with slopes up to 45°. Grass seeding is mostly used on well-drained materials, where increased infiltration does not give rise to problems.

Materials

- **A supply of a carefully chosen grass seed;**
- **Tools to scarify the surface to be sown;**
- **Mulch (cut plant material) or hessian sheeting to cover the seed once sown (see Section 3.17).**
- **On slopes of 30° to 45°, wide mesh jute netting will be required to hold the mulch in place on the slope (see Section 3.16).**

SPECIES SUITABLE FOR GRASS SEEDING

Local name	Botanical name	Altitude range	Sites summary
Babiyo	*Eulaliopsis binata*	Terai - 1500 m	Hot and dry
Dhonde	*Neyraudia reynaudiana*	Terai - 1500 m	Hot and dry
Kans	*Saccharum spontaneum*	Terai - 2000 m	Hot and dry; moist
Katara khar	*Themeda* species	Terai - 2000 m	Varied
Khar	*Cymbopogon microtheca*	500 - 2000 m	Hot and dry; varied
Phurke	*Arunduella nepalensis*	700 - 2000 m	Varied; stony
Sito	*Neyraudia arundinacea*	Terai - 1500 m	Varied

In grass seeding, spread the seeds or grass seed heads liberally over the slope. Ideally, the whole surface should be very lightly covered in seed material

Construction steps

1 Well in advance of the date of sowing, prepare the site. Remove all irregularities likely to allow slumps or gullies and clean loose debris away.

2 Immediately before sowing, scarify the surface of the slope. This means scratching the surface or carrying out basic cultivation to give a loose surface into which the germinating grass seeds can send their roots.

3 Start sowing from the top of the slope and work downwards. Spread the seeds or grass seed heads liberally over the slope. Ideally, the whole surface should be very lightly covered in seed material. An application rate of 25 grammes per square metre is normal.

4 Cover the seeds completely with a layer of mulch, made from cut herbs such as ban mara *(Eupatorium adenophorum),* or with hessian sheeting. A vegetation mulch is preferable. Wide mesh jute netting (150 mm × 500 mm

mesh size) should be used to hold mulch on to the surface if the slope is greater than 30°.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Grass cutting (check on Poush 1).

Main functions

Grass seeding armours surfaces effectively: it can be used to create an even cover over all surfaces. It reinforces slopes after a few years of growth.

Main limitations

This technique gives none of the structural advantages of grass slip planting. Plants take longer to develop from seeds than from slips. Very heavy rain in the days immediately after sowing can lead to seeds being washed off the slope, or to damage to the very small seedlings.

3.6 Turfing

Function

Turf, consisting of a shallow rooting grass and the soil it is growing in, is placed

on the slope. A technique commonly used on gentle embankment slopes. Its only engineering function is to armour.

Sites

This technique can be used on any gently sloping site (less than 30°). It is normally used on well-drained materials, where there is a minimal risk of slumping

Materials

- **Flat shovel with a sharp edge to cut the turf;**
- **Old khukuri to cut the turf to shape;**
- **Water to keep the turf moist;**
- **Wooden rammer (mungro);**
- **If the slope to be turfed is greater than about 25°, wooden pegs about 300 mm long and 30 mm in diameter will be required.**

SPECIES SUITABLE FOR TURFING

Local name	Botanical name	Altitude range	Sites summary
Dubo	*Cynodon dactylon*	Terai - 1800 m	Varied

Construction steps (making turf)

Turf should be cut the same day as it is to be placed; if this is not possible, it should be kept very moist in a shady place. To cut the turf:

1 Mark out with lines the size and shape to be cut (300 mm square is easy to manage but 300 × 600 mm is better);

2 Cut the sides of the shapes with a khukuri, to at least 50-mm depth;

3 Using a broad, flat shovel with a sharp edge, cut horizontally under the shapes and lift them out.

If the ground where the turf is to be taken from is hard and dry, it may be helpful to water it thoroughly the day before cutting.

Turfing provides instant surface protection, as used on this road shoulder (the embankment has been treated with grass lines and brush layering)

Construction steps (placing the turf)

1 Well in advance of the turfing operation, thoroughly smooth the surface to be covered. It is most important to obliterate all irregularities;

2 If the slope to be turfed is a gravel-fill embankment, then a 50-mm layer of topsoil should be laid and compacted by hand;

3 Immediately before placing the turf, scarify the ground surface slightly and water it well if it is not already moist;

4 Place the turf, taking care to fit the pieces together with no gaps

between. Use the khukuri to cut the pieces to shape;

5 If the slope is steeper than about 25°, wooden pegs should be hammered through the turf to stop it sliding;

6 Once the slope has been satisfactorily covered, compact the turf with the wooden rammer.

7 Finally, water the fresh turf thoroughly.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Grass cutting (check on Poush 1).

Main functions

Turfing armours slopes: it gives a complete instant surface cover.

Main limitations

Turfing is relatively costly, and creates equal bare areas at the source of the turf, where erosion can start. For this reason its use needs to be restricted in hill areas. In addition, there is a discontinuity between the turf and the underlying material which, in extreme conditions, can give rise to gradual creep or a shallow planar failure. Because turfing has to be carried out using the small grass dubo, there are

no higher plants to discourage animal tramping, so damage can be caused by this means.

3.7 Shrub and tree planting

Function

Shrubs or trees are planted at regular intervals on the slope. As they grow, they create a dense network of roots in the soil. The main engineering functions are to reinforce and, later, to anchor. In the long term, large trees can also be used for slope support.

Sites

This method can be used without adverse effects on almost any slope up to 30°. With care, it can be used on slopes between 30° and 45°. It can be used on any material and in any site.

Materials

- **Plants raised in a nursery, usually as polypot seedlings;**
- **Tools to dig holes and a means of transporting the plants to site;**
- ***(Optional)* Compost.**

Spacing

The spacing of plants is important. The main considerations are cost and the speed with which a full cover is required. In most bio-engineering sites a spacing of 1 ×

1 metre is necessary, requiring 10,000 plants per hectare. Plants should be planted in off-set rows unless a different pattern is needed for specific bio-engineering requirements.

Construction steps

1 Prepare the site well in advance of planting. Remove all debris and remove or fill surface irregularities. If the site is on backfill material, thoroughly compact it, preferably when it is wet. Cut all weeds.

2 If possible, dig pits for the shrubs or trees well in advance of the planting programme, but refill them the same day. Pits should be 300 mm deep and 300 mm in diameter if this is possible without causing excessive damage to the slope.

3 When the ground is wet enough to support reasonable growth, plant out the seedlings. The bigger the hole made, the better it is for the plant; but there must be a compromise between helping the plant and avoiding excessive disturbance to the slope.

4 Carefully remove the polypot by slicing it down the side with a razor blade or tear it carefully along the fold. Take care not to cut the roots.

5 Plant the seedling in the pit, filling the soil carefully around the cylinder of roots and soil from the polypot. Ensure there are no cavities. Firm the soil all around the seedling with gentle foot pressure.

6 If available, mix a few handfuls of well-rotted compost with the soil

around the roots when you are backfilling the hole.

7 Remove any weeds around the plant. Add mulch around the seedling, but with a slight gap so that it does not touch the stem.

SPECIES SUITABLE FOR SHRUB AND TREE PLANTING

Local name	Botanical name	Altitude range	Sites summary
Shrubs			
Areri	*Acacia pennata*	500 - 1500 m	Hot and dry; harsh
Dhanyero	*Woodfordia fruticosa*	Terai - 1500 m	Hot and dry; harsh
Dhusun	*Colebrookea oppositifolia*	Terai - 1000 m	Hot and dry; harsh
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Keraukose	*Indigofera atroturpurea*	Terai - 2000 m	Hot and dry; harsh
Tilka	*Wendlandia puberula*	Terai - 1500 m	Hot and dry; harsh
Trees			
Bakaino	*Melia azedarach*	Terai - 1800 m	Hot and dry; harsh
Chilaune	*Schima wallichii*	900 - 2000 m	Varied; dry - moist
Gobre salla	*Pinus wallichiana*	1800 - 3000 m	Dry; varied
Kalo siris	*Albizia lebbeck*	Terai - 1200 m	Hot and dry; harsh
Kbanyu (khosro)	*Ficus semicordata*	Terai - 2000 m	Hot and dry; varied
Khayer	*Acacia catechu*	Terai - 1000 m	Hot and dry; harsh
Lankuri	*Fraxinus floribunda*	1200 - 2700 m	Varied; moist best
Painyu	*Prunus cerasoides*	500 - 2400 m	Varied/dry; stony
Rani (khote) salla	*Pinus roxburghii*	500 - 1950 m	Hot and dry; varied

Rani (khote) salla	*Pinus roxburghii*	500 - 1950 m	Hot and dry, varied
Rato siris	*Albizia julibrissin*	800 - 3000 m	Varied and moist
Seto siris	*Albizia procera*	Terai - 1350 m	Moist
Sisau	*Dalbergia sissoo*	Terai - 1400 m	Varied
Utis	*Alnus nepalensis*	900 - 2700 m	Varied and moist

This eight-year old utis plantation, raised from polypot seedlings, is established enough to reinforce and anchor the roadside slope

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Planting shrubs and trees reinforces and anchors the slope by establishing a community of larger plants.

Main limitations

Seedlings take about five years to contribute significantly to slope strengthening. Care and protection are required in the first three years.

3.8 Shrub and tree seeding

Function

Shrub (or tree) seeds are applied directly to the site. This technique allows very steep, rocky and unstable slopes to be revegetated where cuttings and seedlings cannot be planted. There are two methods: (1) direct sowing and (2) broadcasting. In the first, seeds are placed individually, whereas the second involves throwing the seed all over the site. The main engineering functions are to reinforce and, later, to anchor.

Sites

Any steep, rocky or unstable sites. This technique is particularly useful on fractured rock slopes where normal planting cannot be done. Direct sowing can be practised on very steep slopes *(i.e.* up to about 60°) and it is rarely necessary to use this technique on slopes more gentle than 45°. Broadcasting seeds can be carried out on any slopes up to 45°, but is usually less successful on slopes steeper than 30°.

Materials

- A supply of the seeds to be sown;
- Small planting bars (if direct seeding).

Construction steps: direct seeding

The sowing of shrub seeds directly into the material of the site. Choose larger seeds such as areri or bhujetro.

1 In advance of the sowing programme, clear all very loose debris from the site.

2 Start seeding from the top of the slope and move downwards. Make a small hole, a little bigger than the seed, using a planting bar.

3 Push the seed right into the hole and cover it with soil; or, if it is in a rocky crevice, check that it is right out of direct sunlight. Make sure that the seed coat is not damaged in this process.

Construction steps: broadcasting

The sowing of tree and shrub seeds by throwing them over the site. It is normal to choose small seeds such as khanyu or utis, although larger seeds can be used as well.

1 In advance of the sowing programme, clear all very loose debris from the site.

2 Any smooth surfaces should be scarified to give a rough, looser surface for the seed to be held on and put roots into.

3 Throw the seeds on to the surface of the slope, ensuring that they do not blow away or slide down into concentrated masses in crevices and rills.

Spacing

Seeds are normally sown or broadcast to give a coverage of one plant every 250 mm, centre to centre. The actual seeding rate should be increased to three seeds for every plant required to give a reasonable survival rate.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

SPECIES SUITABLE FOR SHRUB AND TREE SEEDING

Main species used for direct seeding

Local name	Botanical name	Altitude range	Sites summary
Shrubs			
Areri	*Acacia pennata*	500 - 1500 m	Hot and dry; harsh
Bhujetro	*Butea minor*	500 - 1500 m	Hot and dry; harsh

Bhujetro	*Butea minor*	500 - 1500 m	Hot and dry; harsh
Keraukose	*Indigofera atroturpurea*		Hot and dry; harsh

Main species used for broadcasting

Local name	Botanical name	Altitude range	Sites summary
Shrubs			
Areri	*Acacia pennata*	500 - 1500 m	Hot and dry; harsh
Bhujetro	*Butea minor*	500 - 1500 m	Hot and dry; harsh
Keraukose	*Indigofera atroturpurea*	Terai - 2000 m	Hot and dry; harsh
Trees			
Bakaino	*Melia azedarach*	Terai - 1800 m	Hot and dry; harsh
Gobre salla	*Pinus wallichiana*	1800 - 3000 m	Dry; varied
Khanyu (khosro)	*Ficus semicordata*	Terai - 2000 m	Hot and dry; varied
Khayer	*Acacia catechu*	Terai - 1000 m	Hot and dry; harsh
Rani (khote) salla	*Pinus roxburghii*	500 - 1950 m	Hot and dry; varied
Sisau	*Dalbergia sissoo*	Terai - 1400 m	Varied
Utis	*Alnus nepalensis*	900 - 2700 m	Varied and moist

Main functions

Seeding shrubs and trees reinforces and anchors any slope, however rocky, by establishing a community of larger plants.

Main limitations

Seedlings take about five years to contribute significantly to slope strengthening. Protection is required in the first few years.

3.9 Large bamboo planting

Function

Large bamboos can reduce movement of material and stabilise slopes. Large bamboos are usually planted by one of two methods: (1) the traditional planting method or (2) to plant rooted culm cuttings from a nursery. Large clumps of the larger stature bamboos are one of the most substantial vegetation structures available to reinforce and support a slope. However, they do not have deeply penetrating roots and so do not have an anchoring function; also, they can surcharge upper slope areas.

Sites

Mostly used at the base of slopes and in gullies, where the slope segment has an angle of less than 30°. Any fill site can be planted. Bamboos do not thrive on very dry or excessively stony sites.

SPECIES SUITABLE FOR LARGE BAMBOO PLANTING

Local name	Botanical name	Altitude range	Sites summary
Traditional planting method only			
Mal bans	*Bambusa nutans*	Terai - 1500 m	Dry/varied
Nibha/ghopi/ lyas bans	*Ampelocalamus patellaris*	1200 - 2000 m	Varied

Tharu bans	*Bambusa nutans*	Terai - 1500 m	Varied

Either traditional planting method or rooted single-node culm cutting method

Choya/ tama bans	*Dendroclamus hamiltonii*	300 - 2000 m	Moist
Dhanu bans	*Bambusa balcooa*	Terai - 1600 m	Varied
Kalo bans	*Dendrocalamus hookeri*	1200 - 2500 m	Varied

Materials

- **For the traditional method; one-year-old rhizomes and 2-2.5 metres of culm, removed from the clump carefully with minimal damage to the roots;**
- **For the rooted culm cutting method, rooted single-node culm cuttings from a nursery;**
- **Hessian and water to wrap around the root ball to keep it moist;**
- **A means of transporting the cutting to the planting site;**
- **Tools to dig a hole for planting;**
- **Material for mulching after planting;**
- **For the traditional method, the upper sections of the culm should be kept to support the cutting once it has been planted.**

Spacing

Planting large bamboos is so much bigger a job than with other plants that it is almost impossible to plant too many. However, they should never be planted closer than 2 metres apart across a slope and perhaps 5 metres up and down the slope.

Construction steps: traditional method

The traditional planting method for bamboos is well known throughout the hills and Terai. It involves taking a very large rhizome and culm cutting. Source clumps should be identified well in advance and an agreement reached with the owners. This method can be used for any bamboo species.

1 Remove all loose debris from the site and prepare the surface well in advance of the planting day;

2 Select a suitable culm near the edge of the parent clump and dig out the rhizome carefully. Cut off the culm about 2 metres above ground level. Cut the rhizome where it branches from the main plant, taking great care not to damage the buds and small roots;

3 Wrap the root ball in damp hessian and transport the big cutting to site for planting on the same day;

4 Dig a large hole (at least five times the size of the cutting's rhizome) and plant the rhizome either upright or at right angles to the slope. Carefully backfill the hole and firm the soil as much as possible;

5 Mulch well the disturbed and surrounding soil.

6 Form a depression around the roots to act as a water collection area. If possible, water it thoroughly;

7 *(Optional)* If available, use two pieces from the higher part of the culm to make a tripod structure with the planted piece. Lash them together with jute string (not wire) as high as possible. This holds the plant much more firmly when disturbed by grazing animals.

A stand of large bamboos can catch debris and support the base of a slope

Construction steps: rooted culm cutting method

This is suitable for many large bamboos that have heavy branching. It can be used for choya/tama bans, dhanu bans and kalo bans. It requires a rooted culm cutting brought from a nursery (see Section 4.6 for details on this).

1 Keep the root ball wrapped in wet hessian until you are ready to plant it, so that it does not dry out.

2 Remove all the loose debris from the site and carry out any other site

preparation well in advance of the planting day.

3 Dig a sufficiently large hole and plant the cutting in it.

4 Carefully backfill the hole, making sure that you do not damage buds at the base of the cutting. Firm the soil.

5 Place a layer of mulch over the disturbed soil and the surrounding area.

6 Form a depression around the roots to act as a water collection area;

7 Water thoroughly.

Maintenance

This normally involves:

Protection (check on Kartik 1);
Watering in the first year (check weekly in Chaitra, Baisakh and Jestha);
Mulching in the first two years (check on Mangsir 1).

Main functions

Large bamboos support the base of a slope by establishing a very strong line of plants. With their multiple stems, they catch debris moving down the slope.

Main limitations

Bamboos take about five years to contribute significantly to slope strengthening.

Protection is required in the early years. This technique cannot be used in most in hot, dry sites, since bamboos generally require cool, moist sites. Bamboos planted in steep upper slope situations are prone to slumping some years (seven or more) after planting.

3.10 Brush layering

Function

Woody cuttings (or hardwood cuttings) are laid in lines across the slope, usually following the contour. These form a strong barrier, preventing the development of rills, and trap material moving down the slope. In the long term, a small terrace will develop. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, brush layers can be angled to provide a drainage function.

SPECIES SUITABLE FOR BRUSH LAYERING

Local name	Botanical name	Altitude range	Sites summary
Assuro	*Adhatoda vasica*	Terai - 1000 m	Varied
Bainsh	*Salix tetrasperma*	Terai - 2700 m	Moist
Dabdabe	*Garuga pinnata*	Terai - 1300 m	Varied and dry
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Namdi phul	*Colquhounia coccinea*	1000 - 2000 m	Varied
Phaledo	*Erythrina species*	900 - 3000 m	Varied
Saruwa/ bihaya	*Ipomoea fistulosa*	Terai - 1500 m	Varied; hot or wet

Simali	*Vitex negundo*	Terai - 1750 m	Hot and dry, varied

Brush layering. Lay the first layer of cuttings along the terrace, with a 50 mm interval between the cuttings (see also step 4);

Brush layering. A second layer of cuttings is placed on top (step 6);

Brush layering. Layers are positioned at 1 to 2-metre intervals up the slope (step 8);

Brush layering. In the long term, small terraces develop

Sites

This technique can be used on a wide range of sites up to about 45°. It is particularly effective on debris sites, fill slopes and high embankments. Avoid using the technique on materials that are poorly drained and are subject to high rates of small-scale slumping (see Section 3.13, Fascines, which may be more appropriate for poorly drained sites).

Materials

- **Cuttings made from woody material that is 6 to 18 months old. They should be 20 to 40 mm in diameter and 450 to 600 mm long. When taking the cuttings, cut the top at right angles to the stem and the bottom at 45° to make it clear as to which way it should be inserted. If possible, take the cuttings the same day that they are to be planted.**
- **Hessian and water to keep the cuttings moist until planting.**

- **Shovels and pick axes to make the trenches for planting.**
- **Line string.**
- **Tape measure (30 metres).**
- **For brush layering on gravel fill embankments, a supply of forest topsoil at the rate of 1 cu. m per 20 metres of layering.**

Spacing

Spacing between brush layers depends on the steepness of the slope. The following spaces should be used.

Slope less than 30°	2 m interval;
Slope 30 to 45°	1 m interval.

Within the brush layers, cuttings should be at 50 mm centres, in the double layer described above. A wider gap than this is acceptable on gentle slopes, but on steep slopes this spacing is required to give adequate protection.

Construction steps

1 Using string, mark the lines to be planted, starting 500 mm from the base of the slope.

2 Always install brush layers from the bottom of the slope, and work upwards.

3 Form a small terrace, with a 20 percent fall back into the slope. The terrace should be 400 mm wide. If you are brush layering a gravel-filled road embankment you should lay a 50 mm thick layer of soil along this terrace to improve rooting conditions.

4 Lay the first layer of cuttings along the terrace, with a 50 mm interval between the cuttings. Leave at least one bud and up to one-third of the cuttings sticking beyond the terrace edge and the rest inside. The branch growing tips should point towards the outside of the terrace.

5 Lay a 20 mm-thick layer of soil in between the cuttings to provide a loose cushion.

6 Lay a second layer of cuttings on top of this, staggered with the first layer. On a gravel-filled embankment slope lay an 80 mm layer of soil over the cuttings before you do any backfilling.

7 Partly backfill the terrace with the excavated materials. This should not be more than 50 mm thick.

8 Mark a line 1 metre above the first brush layer and set the string for the next layer.

9 Follow steps 3 to 7. As the next terrace is cut, always fill the lower bench with the material excavated from above and compact it reasonably well by gentle foot pressure.

Good site supervision is essential to ensure that lines run along the contours and

do not concentrate runoff; also to make sure that cuttings are not allowed to dry in the sun. Well-buried cuttings have a higher survival rate.

Maintenance

Since the spacing of plants recommended here is very dense, there is unlikely to be a need for replacing failures, but some thinning of the trees or shrubs may be required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Brush layering armours and reinforces the slope; it catches debris; and, if angled, it helps to drain the slope. Brush layers provide a very strong and low-cost barrier, especially on debris slopes, however loose.

Main limitations

The main limitation is that construction gives rise to a considerable level of disturbance to the slope.

3.11 Palisades

Function

Woody (or hardwood) cuttings are planted in lines across the slope, usually following the contour. These form a strong barrier and trap material moving down the slope. In the long term, a small terrace will develop. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, palisades can be angled to give a drainage function.

Sites

This technique can be used on a wide range of sites up to about 60°. It is particularly effective on steep landslide debris slopes. Materials that are poorly drained and are subject to high rates of small-scale slumping should be avoided (see Section 3.13, Fascines, which may be more appropriate for poorly drained sites of up to 45°).

Materials

- **Cuttings made from woody material that is 6 to 18 months old. They should be 20 to 40 mm in diameter and 300 to 500 mm long. Cut the tops at right angles to the stems and cut the bottom at 45°; it is then clear as to which way each cutting should be inserted. If possible, take the cuttings the same day that they are to be planted.**
- **Hessian and water to keep the cuttings moist until planting.**
- **Pointed planting bars or crowbars to make the holes for planting.**

A completed palisade

A simali palisade excavated after one growing season to show the development of roots

Spacing

Spacing between palisades depends on the steepness of the slope. The following spaces should be used.

Slope less than 30°	2 m interval;
Slope 30 to 60°	1 m intervals.

Within the palisade lines, cuttings should be at centres of between 30 and 50 mm. A wider gap than this is acceptable on gentle slopes, but on steep slopes this spacing is required to give adequate protection.

SPECIES SUITABLE FOR PALISADES

Local name	**Botanical name**	**Altitude range**	**Sites summary**
Assuro	*Adhatoda vasica*	Terai - 1000 m	Varied
Bainsh	*Salix tetrasperma*	Terai - 2700 m	Moist
Dabdabe	*Garuga pinnata*	Terai - 1300 m	Varied and dry;
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Namdi phul	*Colquhounia coccinea*	1000 - 2000 m	Varied
Phaledo	*Erythrina* species	900 - 3000 m	Varied
Saruwa bihaya	*Ipomoea fistulosa*	Terai - 1500 m	Varied; hot or wet
Simali	Vitex negundo	Terai - 1750 m	Hot and dry, varied

Construction steps

1 Trim and clean the site well in advance of the planting operation. Remove irregularities and loose debris.

2 With string, mark out the lines to be planted.

3 Always start at the top of the slope and work downwards.

4 Using a pointed bar, make a hole in the slope that is bigger than the cutting and deep enough to take at least two-thirds of its length.

5 Carefully place the cutting in the hole, so that at least two-thirds is buried. Firm the soil around it, taking care not to damage the bark. Ideally, only one node of the cutting or about the top 100 mm should protrude from the soil. On steep, unstable sites, however, a greater protrusion helps to raise the delicate new shoots above the zone of moving debris, and to catch more debris.

Good site supervision is essential to ensure that lines run along the contours and do not concentrate runoff; also to make sure that cuttings are not allowed to dry in the sun. Cuttings buried completely have a higher success rate than those planted with the tops partially exposed. Under extreme conditions, cuttings can be hammered into the slope. However, this is likely to cause physical damage and reduce the chances of success.

Maintenance

Since the spacing of plants recommended here is very dense, there is unlikely to be a need for replacing failures, but some thinning of the trees or shrubs may be

required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Palisades armour and reinforce the slope, catch debris and, if angled, provide drainage. They form a strong and low-cost barrier built with the minimum disturbance to the slope.

Main limitations

Palisades are not as strong as brush layering.

3.12 Live check dams

Function

Large woody (or hardwood) cuttings are planted across a gully, usually following the contour. These form a strong barrier and trap material moving downwards. In the longer term, a small step will develop in the floor of the gully. The main engineering functions are to catch debris, and to armour and reinforce the gully floor.

Sites

This technique can be used on a wide range of gully sites, on slopes of up to 45º. However, materials subject to high rates of small scale slumping should be avoided.

Materials

- **Large cuttings (2 metres long and 20 to 50 mm in diameter) made from woody material that is 6 to 30 months old. Cut the tops at right angles to the stem and the bottom at 45°; it is then clear as to which way it should be inserted. If possible, take the cuttings on the same day that they are to be planted.**

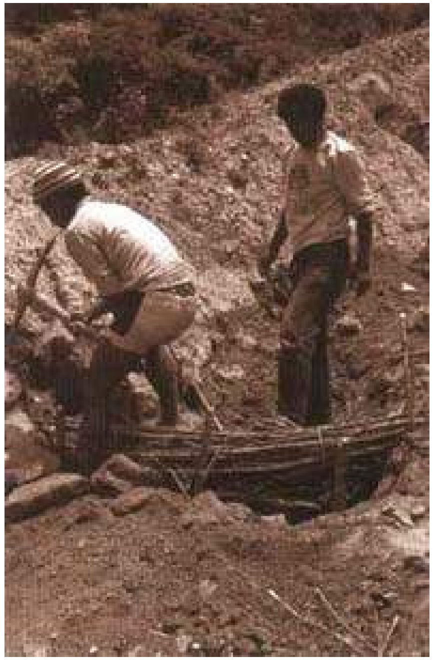
- **Truncheon cuttings 2 metres long and 30 to 80 mm in diameter, preferably of simali, dabdabe or phaledo.**

- **Hessian and water to keep the cuttings moist until planting.**

- **Pointed planting bars or crowbars to make the holes for planting.**

Spacing

Spacing between check dams depends on the steepness of the gully slope and the profile of the gully floor. Live check dams should normally be at intervals of between 3 and 5 metres. Within the check dams, cuttings should be about 30 to 50 mm apart. A wider gap than this is acceptable on gentle slopes, but on steep slopes this spacing is required to give adequate protection. If a double, offset line is planted, it will give a much stronger check dam.



Backfill around the check dam and compact the soil with foot pressure

Live check dams form a strong barrier on a wide range of gully sites, on slopes up to 45°

Construction steps

1 Choose a location for the live check dam so that the maximum effect can be achieved in terms of gully stabilisation.

2 Make a hole deep and big enough to insert vertical hardwood cuttings of the largest size available (truncheon cuttings up to *2* metres in length of species such as dabdabe and phaledo are best). Use a crowbar if necessary to extend the hole.

3 Insert the vertical cuttings by carefully pushing them into the hole and firming the soil around them. Try not to damage the bark. They should protrude about 300 mm above the ground surface.

4 Place fascines or long hardwood cuttings on the uphill side of the vertical stakes.

5 Key these horizontal members into the wall of the gully.

6 Backfill around the check dam and compact the soil with foot pressure.

Maintenance

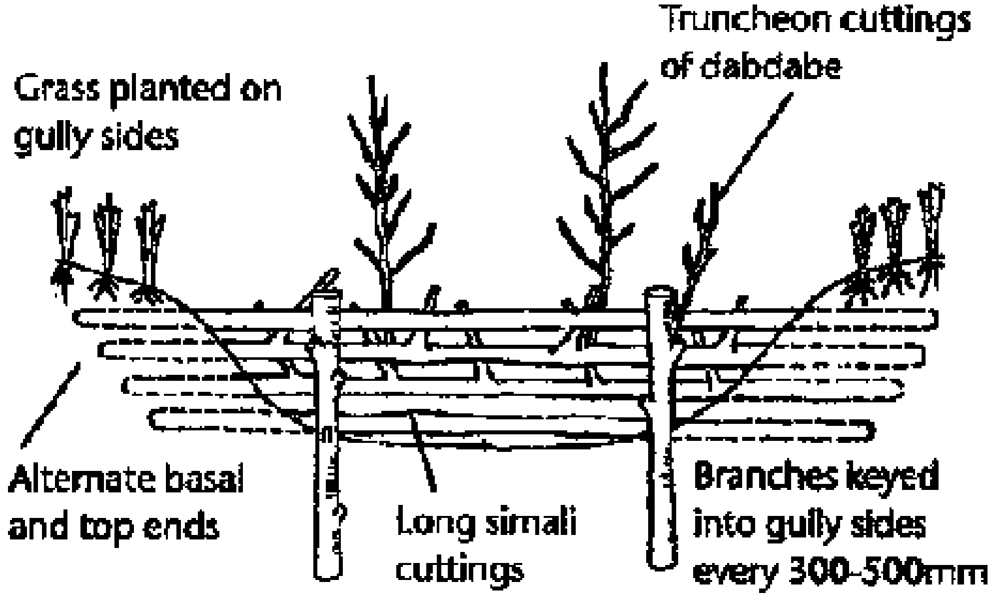
Since the spacing of plants recommended here is very dense, there is unlikely to be a need for replacing failures, but some thinning of the trees or shrubs may be required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

SPECIES SUITABLE FOR LIVE CHECK DAMS

Local name	Botanical name	Altitude range	Sites summary
Horizontal cuttings			
Assuro	*Adhatoda vasica*	Terai - 1000 m	Varied
Bainsh	Salix tetrasperma	Terai - 2700 m	Moist
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Namdi phul	*Colquhounia coccinea*	1000 - 2000 m	Varied
Saruwa bihaya	*Ipomoea fistulosa*	Terai - 1500 m	Varied; hot or wet
Simali	*Vitex negundo*	Terai - 1750 m	Hot and dry; varied
Main vertical support member cuttings			
Dabdabe	*Garuga pinnata*	Terai - 1300 m	Varied and dry
Phaledo	*Erythrina species*	900 - 3000 m	Varied

The cuttings to provide vertical support should be of the biggest and strongest materials, In the form of truncheon cuttings (2 metres long and 30 to 80 mm in diameter). Dabdabe and phaledo are excellent for this. Other possible species are chuletro (*Brassaiopsis hainla*), kavro *(Ficus lacor)* and gliricidia *(Gliricidia sepium).*



Components of a live check dam

Main functions

Live check dams catch debris and to a lesser extent, also armour and reinforce gully floors. They are an effective low-cost structure in smaller gullies, or can be used in between masonry check dams. Their flexibility and the relative lack of site disturbance during construction make them very suitable for use on weak materials, where civil engineering can easily be scoured around.

Main limitations

Large and very active gullies require stronger measures than can be provided by vegetation alone.

3.13 Fascines

Function

The word 'fascine' means a bundle of sticks. In this technique, bundles of live branches are laid in shallow trenches. After burial in the trenches, they put out roots and shoots, forming a strong line of vegetation. It is sometimes called live contour wattling. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, fascines can be angled to provide drainage. Where time is at a premium, brush layers may be more appropriate as these are quicker to establish than fascines (see Section 3.10, Brush layering).

SPECIES SUITABLE FOR FASCINES

Local name	Botanical name	Altitude range	Sites summary
Assuro	*Adhatoda vasica*	Terai - 1000 m	Varied
Bainsh	*Salix tetrasperma*	Terai - 2700 m	Moist
Dabdabe	*Garuga pinnata*	Terai - 1300 m	Varied and dry
Kanda phul	*Lantana camara*	Terai - 1750 m	Hot and dry
Namdi phul	*Colquhounia coccinea*	1000 - 2000 m	Varied
Phaledo	*Erythrina species*	900 - 3000 m	Varied
Saruwa/ bihaya	*Ipomoea fistulosa*	Terai - 1500 m	Varied; hot or wet
Simali	*Vitex negundo*	Terai - 1750 m	Hot and dry; varied

Fascines are effective on consolidated debris. They put out roots and shoots which develop into a strong line of vegetation, catching falling debris as well as armouring and reinforcing the slope

Fascines are effective on consolidated debris. They put out roots and shoots which develop into a strong line of vegetation, catching falling debris as well as armouring and reinforcing the slope

Sites

Fascines are best used on consolidated debris or soft cut slopes. If the material is too hard, growth will be unacceptably slow. The maximum slope is about 45°. On well-drained materials, contour fascines are used; on poorly drained materials, a herringbone pattern (←←←←←) of fascines is used to improve drainage.

Materials

- **Woody cuttings of suitable species, at least one metre long and 20 to 40 mm diameter;**
- **Hessian and water to keep the cuttings moist until planting;**
- **Tools to dig trenches;**
- ***(Optional)* Jute or coir string or wire to bind the fascine as it is laid.**

Spacing

Spacing between fascines depends on the steepness of the slope.

Less than 30°	4 m interval;
30 to 45°	2 m interval.

Within the fascines, there should be at least four but no more than eight cuttings.

Construction steps

1 Prepare the site well in advance of planting. Clear all loose material and protrusions and firmly infill depressions.

2 Mark on the slope the lines where fascines are to be installed. Supervise workers carefully to ensure that the lines follow the contour or desired angle precisely.

3 Always construct fascines from the bottom of the slope, and work upwards.

4 Dig about five metres of trench at a time, carrying out Step 5 at the same

time. This ensures that the soil in the trench is exposed only for a short period, thereby minimising the loss of residual soil moisture. The trench should be about 100 mm deep and 200 mm wide.

5 Lay the cuttings together, filling the trench and with their ends overlapping so that they form a single cable right across the slope. Four cuttings per bundle is normal, but use eight per bundle if there is a lot of material available or if the site is very critical.

6 The fascines can be bound as they are installed by first laying strings across the trench and then tying it when the cuttings are in place. This helps to keep the cuttings together during backfilling but is not essential.

7 Backfill the trench as soon as possible, lightly covering the cuttings, and tamp the soil down firmly around it.

8 If the slope angle is more than 25°, you should peg the fascine. This can be done by placing a large cutting at right angles into the slope immediately below the fascine. Use one peg per 500-mm run of fascines.

Maintenance

Since the spacing of plants resulting from fascines is very dense, there is unlikely to be a need for replacing failures, but some thinning of the shrubs may be required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);

Thinning (check on Kartik 1, starting three years after site works).

Main functions

Fascines armour and reinforce the slope, catch debris and, if angled, provide drainage. They form a very strong and low-cost barrier, useful on a variety of sites.

Main limitations

Fascines do not form a physical barrier immediately as do brush layers, but require a period of growth to become effective. Construction causes disturbance to the slope.

3.14 Vegetated stone pitching

Function

Slopes are strengthened by a combination of dry stone walling or cobbling, and vegetation planted in the gaps between the stones. There are two distinct uses: (1) reinforced toe walls; and (2) protected gully beds. This technique provides a very strong form of armouring. Because it specifically uses vegetation to strengthen a simple civil engineering technique, it represents a stronger form of normal stone pitching (see Section 2.6).

Sites

Steep, low slope toe walls of up to 2 metres in height, and gully floors with a

maximum slope of 45°.

Vegetated stone-pitched toe walls

These provide strong armouring at the base of a slope and prevent undermining. Where major support is needed, gabion or masonry toe walls may be required. Dry stone toe walls can only be used in limited applications. Walls using this technique should not be more than 2 metres high and should be laid back at an angle of about 60°.

Cobbling with vegetation planted between the stones provides strong armouring

Cobbling with vegetation planted between the stones provides strong armouring

Vegetated stone-pitched gully floors

Gully beds are cobbled to prevent downcutting, and then plants are established between the cobbles to stop them being pulled out by running water.

Materials

- **Stones for construction.**
- **Hardwood cuttings or seeds of suitable shrubs (but not of large trees) for walls.**
- **Grass slips for gully floors.**

Spacing

Plants should be established at 250 mm centres initially, on a random pattern.

Construction steps

Walls

1 Construct the wall normally, but make sure that there is plenty of soil in the backfill mixture;
2 once the wall is ready, wait until the monsoon rains are imminent. Then place the cuttings or seeds carefully between the stones, taking care not to damage the bark or seed coat.

Gullies

1 Clean the gully floor completely of all debris and excavate as necessary until a firm base is exposed;

2 lay the stones carefully together, always keeping the flattest sides on the surface. Reduce gaps to a minimum and pack all voids with soil. The stone pitching should have a U-shaped cross-section to prevent scour at the sides;

3 once the monsoon rains have started, plant grass slips between the stones. Ideally, smaller grasses should be planted in the main channel, with larger grasses along the sides.

Maintenance

Since the spacing of plants in vegetated stone pitching is very dense, there is unlikely to be a need for replacing failures, but some thinning of shrubs may be required after a few years. The main maintenance checks should be as follows.

Protection (check on Kartik 1);
Weeding in the first few years (check on Shrawan 1, Bhadra 1 and Aswin

1);

Thinning (check on Kartik 1, starting three years after site works).

Main functions

Vegetated stone pitching provides a very strong form of armouring. This is particularly useful for gully floors carrying large flood discharges.

Main limitations

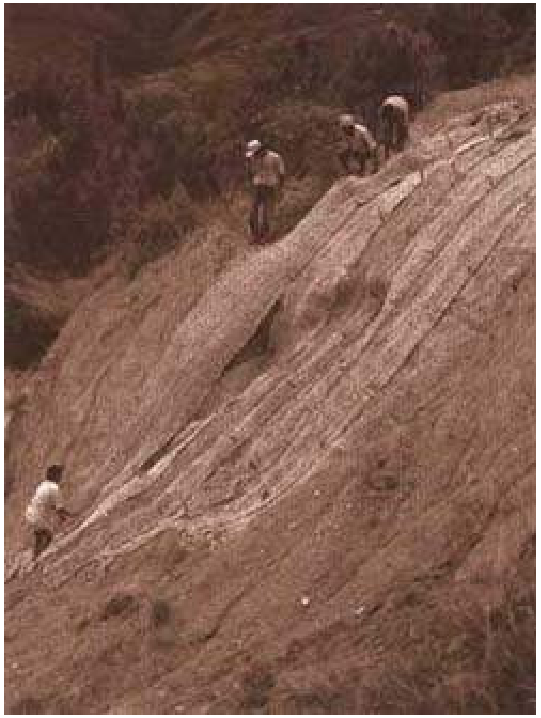
The main limitation is that over a large area it becomes costly; although relative to many toe walls or other forms of gully control, this may not in fact be limiting.

3.15 Jute netting (standard mesh)

Function

A locally made geotextile of woven jute netting is placed on the slope. Standard mesh jute netting (mesh size about 40 × 40 mm) has four main functions:

- **Protection of the surface, armouring against erosion and catching small debris;**
- **Allowing seeds to hold and germinate;**
- **Improvement of the microclimate on the slope surface by holding moisture and increasing infiltration;**
- **As it decays, it acts as a mulch for the vegetation established.**



Jute netting is a temporary measure, designed to enhance the establishment of vegetation

Ensure that the jute netting is loose enough to be held against the surface over the whole slope.

Live pegs will grow to add more strength to the slope

Any use of jute netting is a temporary measure designed to enhance vegetation

establishment. It does not protect a surface in itself for more than one or two seasons of monsoon rains.

Sites

Standard netting is used on steep, hard slopes where the existing conditions are too harsh for vegetation to establish itself without assistance. Slope angles of 45 to 60° are normal. It is best on well-drained materials that are too hard for vegetation to grow in unaided, or on slopes exposed to hot sun and where extreme drought would otherwise be a problem. It should not be used on soft or poorly drained materials. It should never be used on materials with a high rate of shallow slumping. Drainage is so important in sites treated with jute netting that slopes less than 45° should not normally be covered. This excludes all debris materials.

Materials

- **Woven jute netting.**

- **Hardwood cuttings from shrubs or trees, 20 to 50 mm in diameter and 300 to 400 mm long, or other pegs, such as split bamboos.**

- **Tools for cutting wood and jute; an iron bar for making holes, and a wooden mallet.**

Standard jute netting rolls are normally 10.0 to 11.5 metres long by 1.0 to 1.2 metres wide. The yarn is of 5 to 8 mm diameter. Across the net there should be an average of 27 warp ends (length-ways threads) per metre; along the length of the

net, there should be 20 to 24 weft strands (cross threads) per metre. The average mesh size should be 40 mm square holes. The weight should be 1.0 to 1.2 kg per square metre. These specifications are higher than those used in the Indian road sector (where 0.5 and 0.75 kg/sq. m are recommended). Experience has shown that the heavier grade material hangs better on the slope, catches more material, retains more moisture and remains effective for longer.

The life of jute netting can be extended by soaking in a bath of bitumen diluted with kerosene. However, this has the effect of reducing the water retention capacity of the material, which is a desirable attribute on many sites.

Spacing

Completely cover the affected area with netting, anchoring pegs spaced at 500 to 1000 mm centres.

Construction steps (standard netting)

1 Trim the site to an even slope, ensuring that there are no small protrusions or depressions that will interfere with the netting.

2 Starting at one end of site, peg the end of one roll of netting 300 mm above the slope to be covered.

3 Slowly unroll the netting down the slope.

4 Allowing some slack in the netting, begin to peg it from the bottom of the slope. Hammer hardwood cuttings or pegs through it at intervals of 500 to

1000 mm, leaving the cuttings protruding about 80 mm.

5 Repeat the process, making sure that the vertical edges of the net meet, until the whole slope is covered in netting.

6 Place a series of pegs down each side of the net so that there is no gap between the strips.

7 Adjust the netting in order to reduce the tension and let it hug the surface closely. If it remains tight it will not lie right against the slope surface.

8 Add further pegs as necessary to ensure complete contact with the surface.

9 Trim the netting strips to the length required.

10 As soon as the monsoon rains permit, plant grass slips randomly through the netting over the entire area (see Section 3.4).

Integration with bio-engineering

Standard mesh jute netting should only be used in conjunction with bio-engineering techniques as follows:

- **Through the netting: plant grass slips in a random pattern, at an average spacing of about 100 mm centres, according to site characteristics and as determined by the instructions in Section 3.4.**

- **If a deeper reinforcing is required, the surface can be seeded with shrubs or small trees (direct seeding is best, but broadcasting is also possible), using species appropriate to the site and following the techniques described in Section 3.8.**

It is important to ensure that the netted area becomes protected with vegetation during the first two planting seasons, because it has to take over the role of surface protection from the jute in that time.

Maintenance

The jute netting itself is not normally maintained, but simply allowed to rot away. Maintenance is carried out only for the bio-engineering measures.

Main advantages

A very effective aid to the establishment of a permanent grass cover on hard, dry materials on steep cut slopes.

Main limitations

Since jute netting forms a mulch, it raises the moisture content of the soil: if the material has poor internal drainage, this can lead to liquefaction following intense rainfall.

3.16 Jute netting (wide mesh)

Function

A locally made geotextile of woven jute netting is placed on the slope. Wide mesh jute netting (mesh size about 150 × 450 mm) is used to hold mulch on slopes that have been seeded.

Any use of jute netting is a temporary measure designed to enhance vegetation establishment. It does not protect a surface in itself.

Sites

Wide-mesh netting is normally used on any site where plant seeds have been covered in mulch, where the slope angle is between 30° and 45º. Sites less than 30° do not normally need netting to hold the mulch in place.

Materials

- **Woven jute netting.**
- **Hardwood cuttings from shrubs or trees, 20 to 50 mm in diameter and 300 to 400 mm long, or other pegs.**
- **Tools for cutting wood and jute; an iron bar for making holes, and a wooden mallet.**

Rolls of wide-mesh jute netting are usually 10.0 to 11.5 metres long by 1.0 to 1.5 metres wide. The yarn is of 3 to 5 mm diameter. Across the net there should be an average of seven warp ends (length-ways threads) per metre; along the length of the net, there should be an average of three weft strands (cross threads) per metre. The average mesh size should be 150 × 450 mm rectangular holes. The

weight should be 0.2 kg ±10% per square metre.

Spacing

Mulch (placed over seeds) is covered with netting. Anchoring pegs are normally placed at 500-mm centres.

Construction steps (wide mesh netting)

1 Place the netting only on to sites which have been seeded and covered in mulch: for details of these, refer to grass seeding (Section 3.5) and mulching (Section 3.17).

2 Open the net to its full length and place it carefully on the slope.

3 Allowing some slack in the netting, begin to peg it from the bottom of the slope. Hammer hardwood cuttings or pegs through it at intervals of 500 mm, leaving the cuttings protruding about 80 mm.

4 Repeat the process, making sure that the vertical edges of the net meet, until the whole slope is covered in netting.

5 Place a series of pegs down each side of the join between strips and bind the strips of net together, so that the jute is held together as a continuous net.

6 Adjust the netting to ensure that it holds the mulch firmly on to the slope surface throughout the site.

7 Add further pegs as necessary to ensure complete contact with the surface.

8 Trim the netting strips to the length required.

Integration with bio-engineering

Wide mesh jute netting should only be used in conjunction with bio-engineering techniques as follows:

- Before the netting is applied, the slope is seeded with grass (see Section 3.5) and covered in mulch (see Section 3.17).

- If a deeper reinforcing is required, the surface can be seeded with shrubs or small trees (direct seeding is best, but broadcasting is also possible if done before the mulch is applied), using species appropriate to the site and following the techniques described in Section 3.8.

Maintenance

The jute netting itself is not normally maintained, but simply allowed to rot away. Maintenance is therefore that of the vegetation, and the relevant part of Section 5 should be consulted for details.

Main advantages

A useful way of ensuring that mulch stays in position on a slope, while the seeds underneath germinate and establish a complete vegetation cover.

Main limitations

Like the mulch underneath, the jute netting is only a very temporary aid to vegetation establishment. Mulch cannot normally be held on slopes steeper than 45°.

Mulching helps to keep the soil cool and moist close to young seedlings

3.17 Mulching

Function

Mulch is used only as a temporary measure to aid the establishment or growth of vegetation. Alone it will not protect a slope or establish a vegetation cover. There are two main ways of applying mulch: either it is placed around individual plants or it is applied over a whole slope.

In the first, it is to help keep the soil cool and moist, to enhance the growth and early establishment of shrub and tree seedlings, and particularly of large bamboos.

Where mulch is to treat the entire site, chopped plant material or brushwood is laid across the slope to form a surface cover. This is an extremely temporary measure useful only to help other plants establish. It is normally used to aid the establishment of grass seed, and therefore is a temporary form of surface armouring.

Sites

Any site suitable for grass seeding. This is almost any bare site with slopes up to 45°; mostly on well-drained materials, where increased infiltration does not give rise to problems. Also anywhere that large bamboos, or shrub or tree seedlings, have been planted.

Materials

- **Cut stems and leaves of any plants. It is important not to use plant parts carrying seeds, as this will lead to a big weeding problem. Annual herbs such as ban mara *(Eupatorium adenophorum)* and tite pate *(Artemisia vulgaris)* are best if they are allowed to wilt before use. This is the only use of these plant species in bio-engineering.**

- **On slopes greater than 30°, wide mesh jute netting (150 mm × 500 mm mesh size) is needed to hold mulch on to the surface (see Section 3.16).**

Spacing

A complete cover of mulch to the depth described in the construction steps.

Construction steps

1 Collected material should be chopped to a maximum size of 150 mm. It can be stored until required if necessary.

2 When mulching grass seeded areas, the mulch is evenly spread over the surface to give a cover of 50-mm thickness.

3 When mulching individual seedlings, the mulch is spread around the plant being treated in a layer between 50 and 100 mm thick. A circle of radius 150 mm should be left by the plant itself. Outside this, the mulch should form a circle of about 750 mm radius.

Integration with bio-engineering

Bio-engineering techniques should be used in connection with mulching as follows.

- Large areas: before the mulch is applied, the slope is seeded with grass (see Section 3.5); if the slope is greater than 30°, then the mulch should in turn be covered by wide mesh jute netting (see Section 3.16).

- Where large bamboos have been planted, mulch is always applied around the new plant during the first two years.

- If the mulch is being used around other existing plants, then it is normally applied to aid the growth of planted shrubs or trees by keeping the soil cooler and more moist at the hot, dry time of the year.

Maintenance

This is a temporary technique, requiring no maintenance. Future maintenance is for the bio-engineering technique for which the mulch is an aid.

Main advantages

A cheap aid to the establishment of different kinds of vegetation, particularly important on hot and dry slopes, and where lack of soil moisture can limit growth.

Main limitations

Mulch is only very temporary in nature. Freshly cut ban mara and tite pate used in the monsoon may root and start to grow. It must be allowed to wilt in the sun before being applied to the site. Mulch carrying seeds can cause a massive problem from weeds.

3.18 Vegetated gabions

Function

Gabion walls are strengthened by trees growing on them. There are two distinct types: (1) normal stone gabions; and (2) earth-filled gabions. This technique provides a form of slope support.

Sites

Any slope where gabion walls are suitable for slope retention. Stone gabions

require damp sites for trees to establish on them.

Vegetated stone gabions

These tend to come about naturally where trees have seeded existing gabion walls, although they could be seeded artificially. There is no distortion of the gabion boxes. The benefit is that the trees will provide flexible binding to the structure once the wire has corroded.

Vegetated earth-filled gabions

These have been tried in some locations as a lower-cost alternative to stone gabions. A fill of *in situ* earth is placed behind a single layer of dry stone within the gabion basket (the stone layer prevents the washing out of the earth fill). Tree seedlings are planted on the gabion.

Materials

- **Stones, wire and tools for gabion construction. In earth-filled gabions, the material from the excavation is used as a fill.**

- **For stone gabions, seeds of suitable trees: utis *(Alnus nepalensis)* and dar *(Boehmeria rugulosa)* colonise existing walls most often. Alternatively, if holes can be made right through the gabion wall, long hardwood cuttings can be used of species such as dabdabe *(Garuga pinnata)* or phaledo *(Erythrina species).***

- **For earth-filled gabions, polypot seedlings of tree species appropriate to**

the site.

Spacing

Plants should be established at 500 mm centres initially, on a random pattern.

Construction steps

1 Construct the gabion normally, depending on the fill type.

2 For stone gabions, sow the seeds directly into the gaps between the stones. A rate of 25 seeds per cu. m of gabions allows for the high rate of failure, which should be expected.

3 If hardwood cuttings are to be used, a hole must be made right through the gabion into the original ground below. This is normally practical only for gabion mattresses or revetments of 1-metre thickness.

4 For earth-filled gabions, plant four polypot tree seedlings per cu. m of gabion at an equal spacing in the top panel of each box.

Maintenance

Since the spacing of plants in vegetated gabions is very dense, there is unlikely to be a need for replacing failures, but some thinning of trees may be required after a few years. The main maintenance checks should be as follows:

Protection (check on Kartik 1);

Weeding in the first few years (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

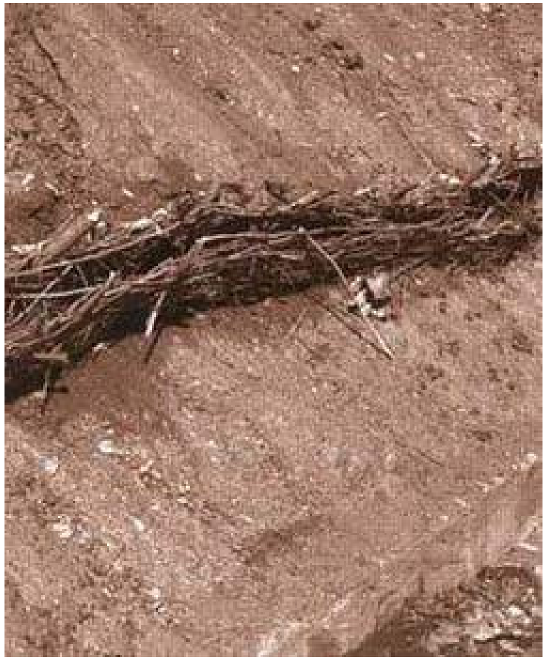
Main functions

Vegetated gabions may offer a lower cost option for supporting certain slope types.

Main limitations

For stone-filled gabions, trees are unlikely to contribute much to the strength of the structure until the wire has corroded seriously. The stability of a gabion wall with serious corrosion problems, with or without trees, is not well researched in Nepal, and remains uncertain at present. Numerous observations demonstrate that tree roots do not distort gabion structures, as is sometimes claimed.

The use of vegetated earth-filled gabions may well have great potential in Nepal. Experiments have been limited in scope and the results have consequently not been conclusive. At the time of writing this manual, the Geo-Environmental Unit of the Department of Roads had not recommended them for use on the strategic road network; but nor had it ruled them out as a future possibility.



Live wattle fences can be effective at catching falling debris on gentle slopes

3.19 Live wattle fences

Function

Fences made out of live cuttings are placed across the slope. Debris moving down the slope is trapped behind them. This is a relatively poor technique used to catch material on gentle slopes.

Sites

Slopes up to a maximum of 30°.

Materials

The following will be required:

- **Hardwood cuttings, as for fascines, at least 1 metre long and 20 to 40 mm in diameter.**
- **Hessian and water to keep the cuttings moist.**
- **Tools for digging grooves in the slope.**

Spacing

Wattle fences should be placed about every 4 to 5 metres down the slope.

Construction steps

1 Prepare the site well in advance of planting. All loose material and protrusions should be cleared away, and depressions firmly infilled.

2 Mark on the slope the lines where wattle fences are to be installed. Careful supervision will be required to ensure that the lines follow the contour precisely.

3 Place pegs at intervals of about 250 mm along the lines: this is done by placing large cuttings into the ground. Pegs should protrude about 300 mm.

4 Dig out a groove along the contour between the pegs: it should be at least 100 mm deep.

5 Place the cuttings with their lower ends in the groove, bending them

down along the line of the fence. Weave them in and out between the pegs. Firm the soil back into the groove.

6 The end result should have the cuttings almost horizontally above each other, but with the ends firmly planted in the soil.

Maintenance

Because the spacing of plants in wattle fences is very dense, there is unlikely to be a need for replacing failures, but some thinning of shrubs may be required after a few years. The main maintenance checks should be as follows:

Protection (check on Kartik 1);
Weeding in the first few years (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Main functions

Live wattle fences catch debris moving down the slope, and have limited functions of armouring and reinforcement.

Main limitations

Often the structure is too weak to support the volume of debris that is caught. They have not been found to be as effective as techniques such as brush layering and fascines; or, on more critical slopes, as reliable as wire bolster cylinders.

3.20 Hydro-seeding

Function

'Hydro-seeding' covers a range of possible options, which use high pressure pumps to spray a mixture of seed and mulch, and sometimes other materials, directly on to a slope. These techniques provide a random cover of vegetation and do not have the structural benefits of manual bio-engineering systems. The main functions are to armour and reinforce the slope.

Sites

Hydro-seeding is reputed to be capable of use on almost any site. However, pumps and their hoses tend to limit reach to a maximum of 100 metres or less from the nearest road point. This technique should not be used on poorly drained materials, where there is any risk of slumping or shallow mass movement.

Experience in Nepal

At the time of writing this handbook, there had never been any widespread use of hydro-seeding in Nepal. The Department of Roads, through several donor-assisted projects, had conducted experiments on a number of different technical systems. There appears to be scope for these techniques on well-funded road construction projects, but a number of limitations affect its routine use in maintenance activities. These limitations are chiefly as follows: (1) high cost, complex machinery is required to spray the mixtures; (2) a large number of inputs (such as seed, mulch, and fertiliser) are required; (3) a number of special skills are required for the team implementing the work; (4) the unit cost is extremely high

for small areas, but diminishes with increased scale.

Manual methods of bio-engineering are cheaper and easier to implement than mechanical techniques such as hydro-seeding

Manual methods of bio-engineering are cheaper and easier to implement than mechanical techniques such as hydro-seeding

For routine works, the experience of the Department of Roads, and of most

projects, is that the manual methods of bio-engineering described in this handbook are cheaper and more straightforward to implement. They also allow very precise treatment of slope surfaces.

Materials

- **High pressure solids pump, with mixing tanks, agitators, hoses and spray nozzles.**
- **A lorry with a mounted crane to carry the pump, tanks and other equipment.**
- **A water tanker.**
- **For steep slopes greater than 15 metres above or below the road, scaffolding is required.**
- **A mix (between 1 and 30 litres per sq. m) of seeds (usually grasses and shrubs), fertiliser, mulch, soil improver, binding agent and water. Some methods also add a mixture of forest topsoil and clay loam to improve surface rooting conditions, bringing the mix to about 100 litres per sq. m (*i.e.* 0.1 cu. m/sq. m).**

Construction steps

1 Prepare the site well in advance of planting. Remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start. If the site is on backfill material, it should be thoroughly

compacted, preferably when wet.

2 Collect together the various materials needed for the operation. It is normal to have a training session with the hydro-seeding team in a suitable off-site location.

3 Mix the ingredients together in the tank and spray them on to the site immediately. Delays cannot be allowed because of the need to keep all parts of the mixture agitated in suspension, and because the binding agent will start to act.

4 The thickness of the surface cover depends on the technique being used and the nature of the sprayed mixture. A minimum of 5 to 20 mm is normal. Techniques adding a soil base are usually 50 to 100 mm thick, often requiring two sprayings.

Maintenance

Since the spacing of plants resulting from hydro-seeding is very dense, there is unlikely to be a need for replacing failures, but some thinning of the shrubs may be required after a few years. The main maintenance checks should be as follows:

Protection (check on Kartik 1);
Weeding (check on Shrawan 1, Bhadra 1 and Aswin 1);
Thinning (check on Kartik 1, starting three years after site works).

Hydro-seeding can yield spectacular results for surface covering, but this example was estimated to cost about thirty times more than the manual method

Main functions

Hydro-seeding is used in many countries to armour and reinforce slopes. The vegetation also has a limited catching effect. In appearance, the overall results often appear spectacular.

Main limitations

Hydro-seeding has none of the structural advantages of the planted grass lines, or

techniques such as brush layering and fascines. It lacks the detailed treatment of site conditions offered by all the manually applied techniques. However, the greatest limitations lie in the relatively high cost, and its reliance on a wide range of complex inputs, of which the high-pressure pump is only one.

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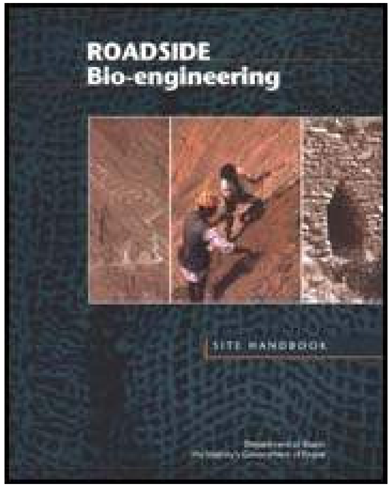
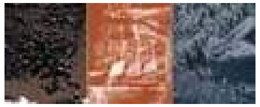


Roadside Bio-Engineering - Site Handbook (DFID, 1999, 160 p.)

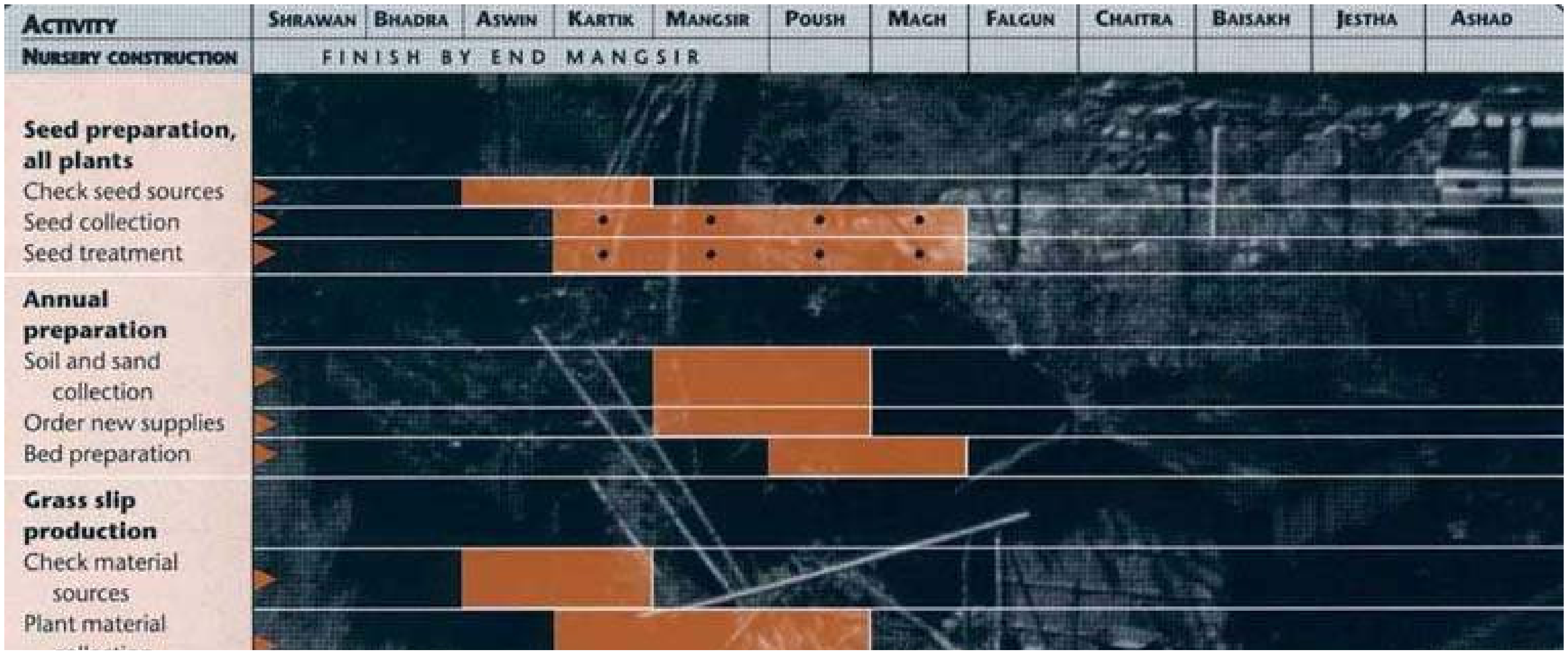
Sector Four - Production of bio-engineering plants



Figure

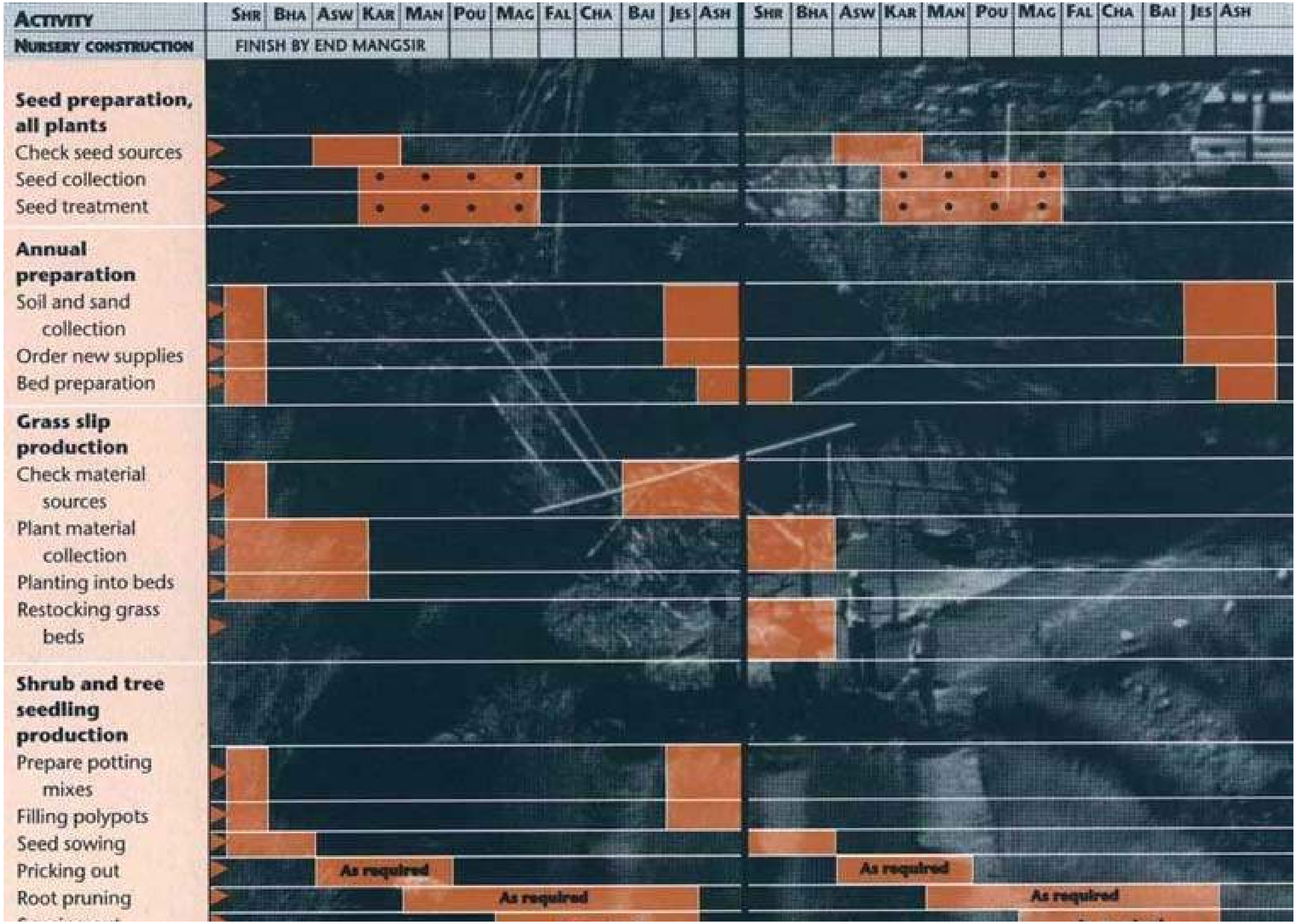
This section gives the following information:

- **where to establish a nursery (Section 4.1);**
- **the components, layout and materials of a nursery (Section 4.2);**
- **propagation of grasses (Section 4.3);**
- **propagation of shrubs and trees (Section 4.4);**
- **propagation of bamboos (Section 4.5);**
- **nursery management (Section 4.6);**
- **seed collection and storage (Section 4.7);**
- **assessing the quality of bio-engineering nurseries (Section 4.8)**




collection
Transplanting
Re-spacing
As required
Re-stocking grass beds
Transplanting grass slips
Shrub and tree seedling production
prepare potting mixes
Filling polypots
Seed sowing
Pricking out
As required
Root pruning
As required
Spacing out
As required
Sowing for large plants
Extraction of plants from the nursery
Uplifting and preparing
As required
Transporting to site
As required
Site planting works
Depends on rain
Depends on rain
Routine activities
Weeding
Maintain water supply
Watering
As required
Shading of young plants
As required
Record keeping
General maintenance
Regular checks and repairs made
Pest and disease control
Daily checks and action taken when necessary
Protection of the nursery
Compost production
Making compost

Figure 4.1: Nursery activity calendar: low-altitude nurseries For nurseries below about 1200 to 1500 metres above sea level



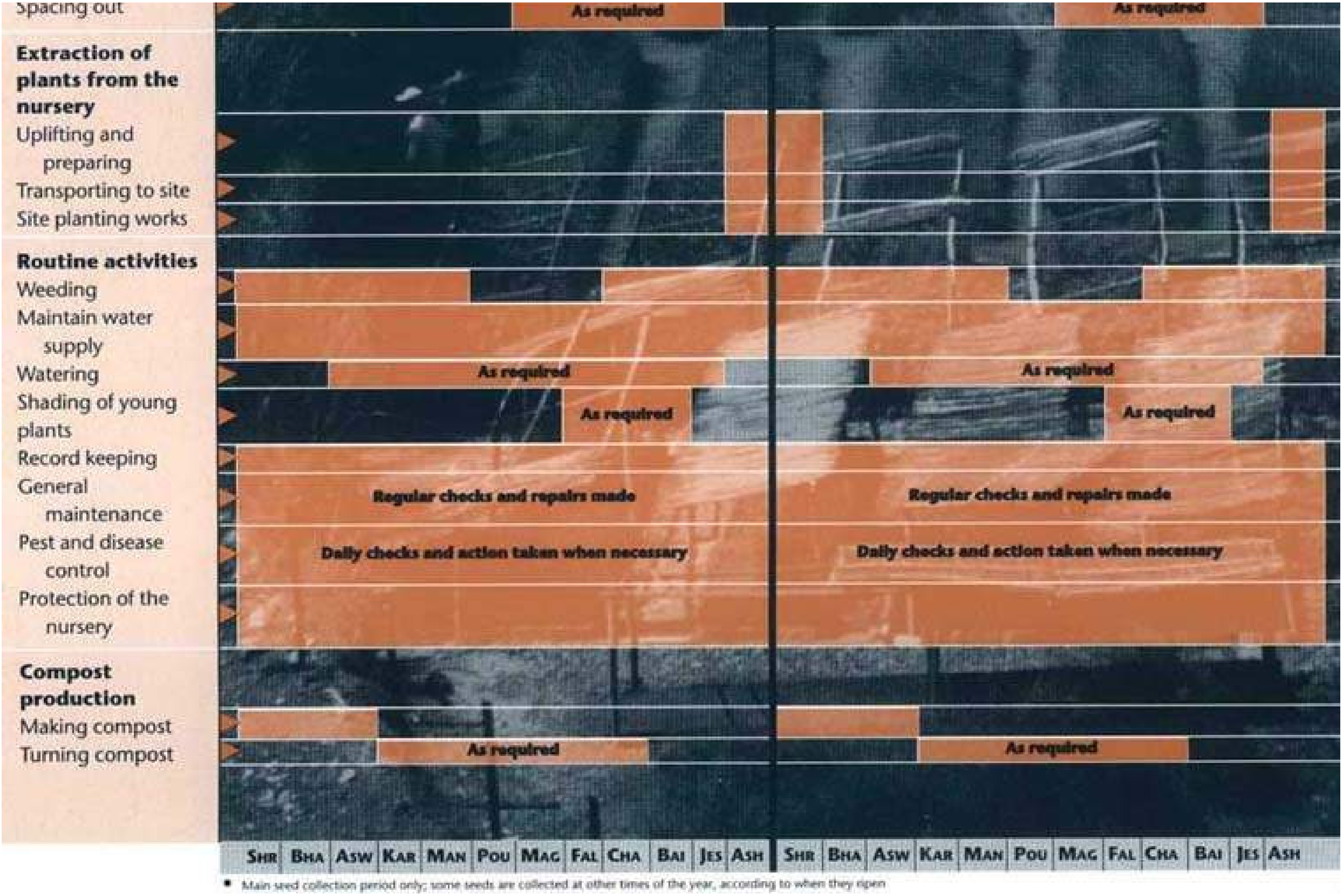


Figure 4.1: Nursery activity calendar (continued): high-altitude nurseries For nurseries above about 1200 to 1500 metres above sea level

4.1 Nursery establishment

What are nurseries for?

A nursery is a factory to supply plants, in this case, for a bio-engineering programme. A good nursery will supply:

- **enough plants of the right species,**
- **in good, healthy condition,**
- **in the form required for planting;**
- **at the right time; and,**
- **at a reasonable cost.**

Young plants are delicate organisms and their production is a skilled business. For this reason, nurseries require careful organisation and operation.

When are nurseries used?

Nurseries are a permanent feature. The production of plants is seasonal at lower altitudes (below about 1200 or 1500 metres, depending on the warmth of each individual nursery location) but continues throughout the year above this altitude. The calendars in Figures 4.1 show the variations.

Selecting a suitable site

Before choosing a site, carefully define the objectives of the nursery, including:

- **the approximate number of plants of each type (*i.e.* grass, shrubs/trees and bamboos) to be produced each year;**

- **the location of the planting sites that the nursery must supply;**

- **the availability of land belonging to the Department of Roads.**

The choice of site is the single largest factor affecting the quality of plants. The nursery must be carefully prepared to receive seeds and cuttings. Therefore, you must choose the site at least six months before the first seed is to be sown.

Nurseries need to be on land owned by the Department of Roads (or leased for at least 10 years) and as close as possible to the sites they will serve. At the same time, however, the location must be technically suitable. You will rarely be able to get everything just right, so the final selection should be based on evaluating the relative advantages and disadvantages of three or more possible sites after you have thoroughly inspected them

The following are the main technical factors that *must be satisfied* when establishing a nursery.

Water supply

A reliable, adequate water supply is essential for all nurseries. A guaranteed supply is required at the following rates:

- **150 litres (0.15 cu. m) of water per day for every 10 sq. m of grass beds;**
- **500 litres (0.5 cu. m) of water per day for every 10,000 polypot seedlings;**

if watering is done with a watering can, and rather more for watering with hose pipes. Whatever the source of the water, check that it is available throughout the year; especially check the flow in the driest months: March, April and May (Chaitra to Jestha).

Figure 4.2: Calculating the nursery size

NURSERY COMPONENT	CALCULATION BASIS	AREA ALLOWED
Office/Store/Chowkidar's hut	Estimate	Normally allow 15 sq. m
Vehicle access and turning area	Estimate	Normally allow 50 to 100 sq. m
Pathways to all parts of the nursery	Estimate	Normally allow 50 to 100 sq. m
Working area	Estimate	Normally allow 25 sq. m
Soil and sand stores	Estimate	Normally allow 20 sq. m
Compost bays	Standard size	Normally allow 10 sq. m
Water tank and accessories	Standard size	Normally allow 10 sq. m
Drainage systems	Estimate	Normally allow 25 to 50 sq. m
Grass beds: see Figure 4.4	100 cuttings per sq. M	Depends on requirement: see below
Seed beds		Normal requirement Normally allow 5 sq. m
Standout beds for polypot seedlings	128 polypots per sq. m	Number of seedlings required × 1.25 ÷ 128
Beds for hardwood cuttings	40 cuttings per sq. m	Above 1500 m: number required × 2 ÷ 40 Below 1500 m: number required ÷ 40
Bamboo beds	4 cuttings per sq. m	Above 1500 m: number required × 3

		÷ 4 Below 1500 m: number required × 2 ÷ 4
Space between beds	Estimate	Total area of beds × 0.75
Space for terracing on slopes	Estimate	Total area of nursery × 0.5

General location

The site should be near to the road and as close as possible to the centre of the area to which plants will be supplied.

Physical features

Aspect is very important. North-facing slopes are cooler and more humid and are better for nurseries at lower elevations, whereas nurseries above 1200 metres are better on warmer southern slopes.

Drainage is important to avoid waterlogging of the beds. In the Terai, a slope of 2 - 3 percent is best if possible. In the hills, terracing is usually necessary.

Avoid areas threatened by landslides, flooding or strong winds, and at higher elevations avoid sites which are particularly liable to frost (*e.g.* small valley bottoms).

Availability of materials and labour

You should select a location with the best quality soil available. If possible, it should be an old forest soil, loamy and with a good content of organic matter, and

on a well-drained site.

Additional soil will be required for the production of polypot seedlings. This should be a sandy loam forest topsoil; if the available soil is too heavy *(i.e.* contains too much clay), sand will also be required.

Easy access to stone for building the nursery wall and beds as well as other items, such as a water tank, a shed and a compost bin, is also an advantage. Otherwise stone or bricks have to be brought in.

A lot of labour is required for constructing the nursery and later on for tasks like transplanting grasses, carrying soil and filling pots. You should locate the nursery where it is possible to obtain labour without difficulty at most times of the year.

Calculating the appropriate size

The amount of space required for a nursery depends upon the number of plants to be produced, the time they will spend in the nursery and the density at which they will stand in the beds. The slope and the quality of the site will also influence the decision on how much space to allocate.

Before you start to calculate the area needed, list the various components of the nursery that you require and calculate the area required for each. Figure 4.2 summarises this.

Figure 4.2: Calculating the nursery size (continued): worked examples

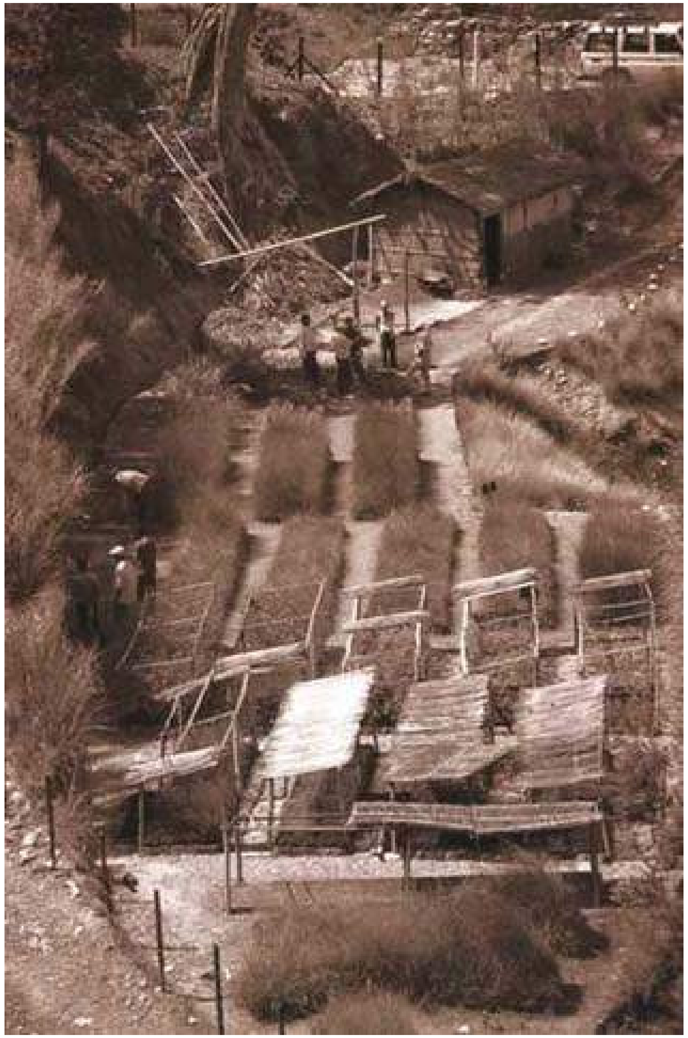
NURSERY COMPONENT	TERAI	NURSERY	NURSERY

	NURSERY**	AT 1400 METRES	AT 2000 METRES
Fixed elements (Office/Store/ Chowkidar's hut, vehicle access, pathways, working area, soil and sand stores, compost bays, water tank and drainage)	**265 sq. m**	**265 sq. m**	**265 sq. m**
Grass beds	290	633	633
Seed beds	5	5	5
Standout beds for polypot seedlings	98	98	195
Beds for hardwood cuttings	25	25	25
Bamboo beds	50	50	75
Sub-total: beds	**468 sq. m**	**811 sq. m**	**958 sq. m**
Space between beds	351	608	718
Sub-total: all above components	**1,084 sq. m**	**1,684 sq. m**	**1,941 sq. m**
Space for terracing on slopes	0	842	970
Total area required*	**1,084 sq. m or 2.1 ropani or 0.2 bigha**	**2,526 sq. m or 4.8 ropani**	**2,912 sq. m or 5.6 ropani**

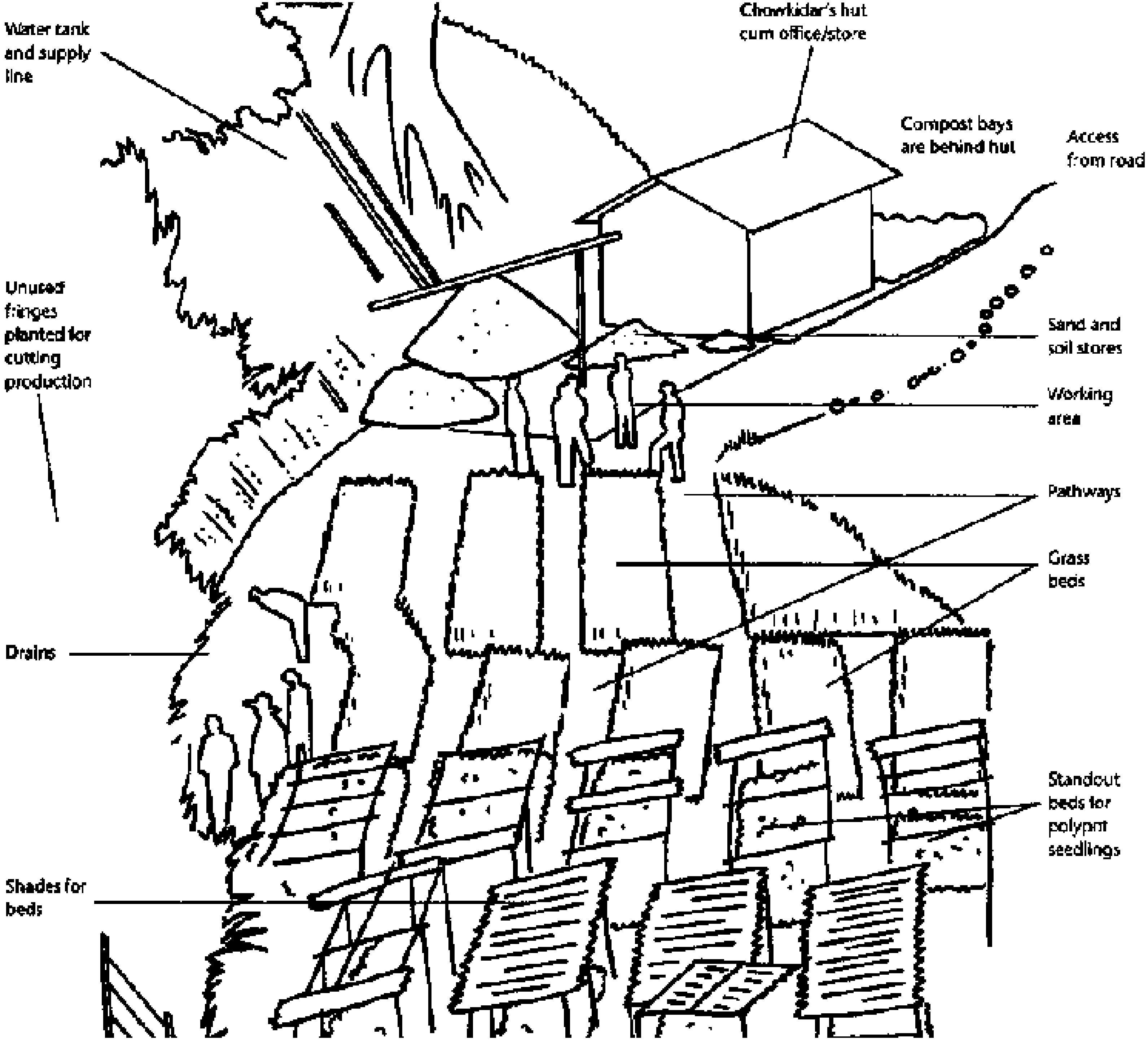
***1 ropani = 0.052 hectare.**

****Assume that each nursery is expected to produce, per year 100,000 grass slips, of which 10,000 are amliso; 10,000 polypot shrub and tree**

seedlings; 1,000 rooted hardwood cuttings; and 100 rooted bamboo culm cuttings.



Figure


Water tank and supply line
Chowkidar's hut cum office/store
Compost bays are behind hut
Access from road
Unused fringes planted for cutting production
Sand and soil stores
Working area
Pathways
Grass beds
Drains
Standout beds for polypot seedlings
Shades for beds

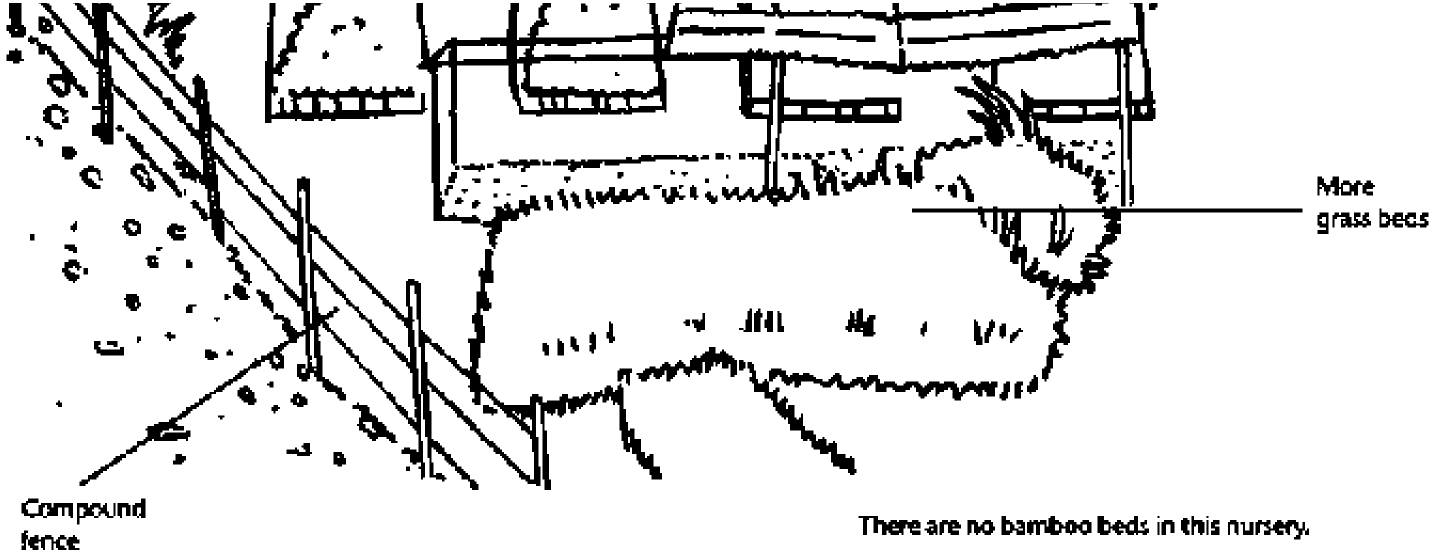


Figure 4.3: Typical low-altitude nursery that has been well laid out

The main components of *a* nursery are as follows:

General:	Compound wall or fence
	Office/Chowkidar's hut
	Vehicle access and turning area
	Pathways to all parts of the nursery
	Working area
Storage:	Nursery store
	Soil and sand stores
	Compost bays
Water:	Water tank and accessories
	Drainage systems
Beds:	Grass beds

Seed beds
Standout beds for polypot seedlings
Bamboo beds
Shades for beds

Other areas and corners for perennial grass and hardwood stock plants

How to estimate the requirement for grass beds

Grass slips are produced in nursery beds from cuttings made from either a portion of root and stem, or just stem. They are planted in nursery beds at a density of 100 per sq. m.

Bio-engineering nurseries have to produce more grass slips than any other plants. It is therefore important to estimate the quantity of grass slips required, and the nursery space they need, early on. This is done in two stages: determining the number of slips per planting drill, which depends on the type of grass; and then calculating the multiplication factor for the production of the grass.

Number of grass slips per planting drill

The planting drills described in the rate analysis norms, given in the *Reference Manual,* consist of different numbers of slips, depending on the type of grass, the nature of its rooting and the parts used for vegetative propagation. Rhizomatous grasses[1], such as amliso, require only one slip per planting drill. Fibrous rooting grasses, such as babiyo, kans, khar and phurke, require two slips per drill. Grasses

grown from single or double-node stem cuttings, such as dhonde, narkat and napier, require only one slip per planting drill.

> **1 Some grasses, especially bamboos, grow with a form of underground stem called a rhizome. Roots and shoots form from nodes on the rhizome.**

Calculation of grass slip multiplication in the nursery

The nursery multiplication of grasses by slips produces a three to seven times increase in the number of plants each time the grass clumps are split out, depending on the species, altitude and time of planting in the nursery. At altitudes below 1200 metres, slips of grasses except amliso can be multiplied by seven times; amliso can usually only be multiplied by three times. At higher altitudes, usually above about 1200 metres, a three-times multiplication is usually only possible in one warm season. However, the timing of planting in the nursery bed also regulates the productivity. Figure 4.4 summarises all this information.

How to estimate the requirement for hardwood cutting beds

Hardwood cuttings can be propagated at the rate of 40 cuttings per square metre of bed. However, in nurseries above 1500 metres, you need to allow two complete bed areas. The reason for this is that above 1500 metres the cuttings often have to remain in the nursery for 16 months or more.

Figure 4.4: Calculation of grass slips numbers

NURSERY	PROPAGATION	SPECIES	CUTTINGS PLANTED	NUMBER TO

ALTITUDE	METHODS		IN NURSERY	PLANT
Above 1800 m	Rooted slip cuttings	Amliso	Previous August	Final site number ÷ 3
		Any other grasses	Previous August	Final site number × 2 ÷ 3
	Stem cuttings	Dhonde, narkat	Previous August	Final site number × 0.25
1200 to 1800 m	Rooted slip cuttings	Amliso	February/March	Final site number ÷ 3
		Any other grasses	February/March	Final site number × 2 ÷ 3
	Stem cuttings	Dhonde, narkat	February/March	Final site number × 0.25
Terai to 1200 m	Rooted slip cuttings	Amliso	February	Final site number ÷ 3
		Any other grasses	February	Final site number × 2 ÷ 7
			April/May	Final site number × 2 ÷ 3
	Stem cuttings	Dhonde, narkat	March	Final site number × 0.25

Figure 4.5: Main construction features of nursery beds

BED TYPE	GRASS BEDS	SEED BEDS	STAND	BAMBOO CUTTING

BED TYPE	GRASS BEDS	SEED BEDS	STAND OUT BEDS	BAMBOO CUTTING BEDS
Purpose	Beds for grass seeds, grass slips, hardwood and stump cuttings of shrubs and trees	Very finely prepared beds for germinating small shrub and tree seeds	Frames in which to stand polypot seedlings	Beds for the propagation of bamboo culm cuttings
Bed size *	1000 mm wide × 250 mm high	1000 mm wide × 170 mm high	1000 mm wide × 150 mm high	1000 mm wide × 300 mm high
Details of construction	50 mm of washed gravel placed above the ground; then 50 mm of 1:1 mix of sieved soil and compost; and topped with 150 mm of 3:1 mix of sieved forest topsoil and washed sand	50 mm of washed gravel placed above the ground; then 50 mm of unsieved forest soil; 50 mm of 1:3 mix of sieved forest soil and washed sand; and topped with 20 mm of washed, sieved and sterilised sand.	50 mm drainage layer of gravel placed above compacted ground. A flat stone or brick surround	Ground below the bed is dug to a depth of 300 mm. Bed is made with 100 mm of unsieved soil (lower) and 200 mm of sieved soil (upper). A bund 100 mm high is formed around the edge
Shade type	No shade; hessian sheet can be laid on the surface if	Complete top shade of thick thatch and polythene sheet	Removable top shade of rolling	Top shade of thick thatch; side shades of hessian sheet

	required		bamboo slats, made from split culms	

*** Beds may be constructed to any length**

How to estimate the requirement for bamboo beds

Bamboo culm cuttings can be propagated at the rate of four cuttings per square metre of bed. However, in nurseries below 1500 metres, you need to allow two complete bed areas, and in nurseries above 1500 metres, three complete bed areas. The reason for this is that below 1500 metres the cuttings remain in the nursery for 16 months and, above 1500 metres, for 28 months.

Layout and construction of the nursery

Nurseries are essentially a form of factory and need to be laid out with the production process in mind. Some aspects are usually pre-set. For example, the point of road access is usually fixed. The office/store/chowkidar's hut is normally placed near this gate. In the hills, the water tank has to be at the highest point of the nursery in order to allow gravity feed by hose pipe; in the Terai it should be located in the centre, as water is needed equally throughout the nursery (see Figure 4.3).

Other considerations are as follows.

- **Place the soil and sand store beside the vehicle access and turning area.**

- **Locate the working area beside the soil and sand store.**

- **Locate the seed beds close to the chowkidar's hut, since these require more attention.**

- **If it is a remote area, make the chowkidar's hut big enough for his family as well.**

- **Ensure easy access to all parts of the nursery. Do not put the beds too close together. Remember that when shades are erected, they will reduce the space between the beds.**

- **Make sure that the whole nursery is well drained. In particular, check that there is no risk of any of the plant beds being flooded.**

- **Use any remaining corners and rough areas for long-term production of grass and hardwood cuttings.**

All construction must be done to a high standard, as per the norms and specifications. Nurseries are usually permanent fixtures, and therefore must be designed and built to last.

Figure 4.5 summarises the main features of nursery bed construction.

4.2 Components of a nursery

Nursery equipment

Main permanent equipment

The main equipment required is as follows.

Pate kuto	Chuche kuto
Hasiya	Shovel
Kodalo	Kodali
Chuppi	Khukuri
Dante	Axe
Hammer	Doko
Crowbar/khanti	Watering can with roses
Hose pipe	Scissors/secateurs
Tin trunks with	Flit gun sprayer
padlocks	Leather or paper punch
Soil and sand sieves	First aid kit

Tape measure

Plant carrying trays (metal or wood, ideally 400 × 2009 mm, with sides 100 to 200 mm high)

Seed trays (optional; make by cutting oil tins in half).

Tools and equipment must be kept in good working order. Replace defective items before they are needed, and keep blades sharp.

Expendable materials

The main expendable materials required are as follows:

Soil	Sand
Compost	Seeds
Grass slips	Bamboo cuttings
Hardwood cuttings	Fungicide and insecticide
Fertiliser	Polypots: 4" × 7", 200
Heavy gauge polybags for storage	gauge black polythene polythene sheeting
Shade material (bamboo, thatch, hessian)	String Wire mesh Soap
Wire	Waterproof marker pens
Nails	Registers: grass slip/ hardwood cutting, seedling
Seedbed labels	
Pens/pencils	

Expendable materials need to be re-supplied each year and you should order them well in advance, normally by the end of Mangsir, after discussion with the naike.

Most of these materials are simple and easily obtainable. Some technical details about the more complex items are given below.

Soil

For polypot seedlings especially, you will need to bring in large quantities of sandy loam or loam forest topsoil. If only heavy soils such as clays are available, they will have to be mixed with sand.

SOIL TEXTURE TEST
You can tell when the soil texture is right by trying to roll a little moist soil to pencil thickness between your fingers. If this is not possible, there is too much sand. If the roll can be bent in a semi-circle without breaking, there is too much clay.

Certain species of trees have special requirements for micro-biological soil constituents. To satisfy these, you need to try to collect soil from under existing stands of the trees concerned. The species in this category are given below; of all of them, it is most important that soil for pine seedlings comes from under pine trees (the other species usually grow reasonably well without the relevant microbes).

Pines (salla) require special mycorrhizal soil[1].

The legume genera *Acacia* (*e.g.* khayer), *Albizia* (siris) and *Dalbergia* (sisau) require soil containing *Rhizobium* bacteria[2].

The genus *Alnus* (utis) requires soil containing *Frankia*[3].

[1] Mycorrhizae are a living arrangement produced between special fungi and the roots of a plant, which increase the growth of the plant considerably. This is a form of symbiosis, where two organisms live together for mutual benefit. Soils from pine forests contain the necessary fungi to bring this about.

[2] *Rhizobia* are the nitrogen-fixing bacteria that form nodules on the roots of many leguminous species, including those listed here.

[3] *Frankia* are actinomycetes that form a symbiotic relationship with the roots of certain species, and which also fix nitrogen.

The quantity of soil required is often under-estimated. A nursery with a target of 10,000 usable plants would fill 12,500 pots. For 100 × 175 mm (4" × 7" inch) pots, this would require 6.1 cu. m of potting mixture. For a 2:1:1 soil: sand: compost mixture you would need about 3.1 cu. m of soil and 1.6 cu. m of sand, which would weigh about 4.5 and 2.7 tonnes. If sieving was done in the nursery you need 15 percent more soil and 5 percent more sand.

Compost

Details of the making and use of compost are given in Section 4.6. Compost is used to enrich the soil in the nursery beds.

Seeds

Seed collection and storage is covered in Section 4.7.

Grass slips

The collection and propagation of grasses from slips are covered in Section 4.3.

Hardwood cuttings

The propagation of shrubs and trees from hardwood cuttings is covered in Section 4.4.

Bamboo cuttings

The propagation of bamboos in nurseries from single node culm cuttings is described in Section 4.5.

Registers

The use of nursery registers is described in Section 4.6. The register forms are given in Annex C.

Nursery staff

Each nursery normally requires a staff of one naike, one watchman and two labourers. During the peak nursery season of February to June (Magh to Ashad), the number of labourers may need to be increased to five.

The staff of bio-engineering nurseries should be drawn from rural areas, to ensure that they have a good understanding of how to handle delicate plants. Only naikes and specialist seed collectors are considered to be skilled workers. The abilities

and roles of the various staff are given below.

Nursery naikes

Naikes (or nursery foremen) are each responsible for the operation of one nursery. They must understand all aspects of nursery work and be able to motivate labourers and keep them busy. Training is usually necessary, but this can either be done within the Division (perhaps by the Supervisor), by attachment to another Division with a well-established nursery, or with help from the Geo-Environmental Unit. Literacy (in Nepali) is required for record keeping. The Naike should work full time in his nursery and manage his team of labourers. Duties include:

1 Daily operation of the nursery and attendance to all matters concerned with keeping a clean and healthy environment for seedlings and plants to thrive in.

2 Carrying out with due care all nursery operations.

3 Reporting to the local and senior road line supervisors any problems of plant health or growth.

4 In general, the provision of quality planting material for use in roadside planting.

5 Keeping records of all nursery stock.

In summary, nursery naikes should have the following attributes:

- **good understanding of local plants;**
- **experience in nursery work;**
- **very active in the nursery at all times;**
- **knowledge of seed collection, treatment and storage;**
- **know how to motivate others.**

Nursery watchmen

Anyone employed as a watchman has to be thoroughly trustworthy. He will be working alone all the time and has to be sufficiently motivated to work long hours in uncomfortable conditions. He should be in the nursery 12 hours a day or night, seven days a week. The best watchmen are usually the most reliable of the labour force and may be non-literate and poorly educated. In summary, nursery watchmen should have the following attributes:

- **reliable and trustworthy;**
- **intelligent approach to work and show initiative;**
- **self motivated.**

Labourers

Whenever possible, employ local farmers as labourers as they have a good understanding of plants. They should be from as close to the nursery or work site as possible. There is no need for literacy, but a good level of intelligence helps a lot. In summary, nursery labourers should have the following attributes:

- **local farmers;**
- **good understanding of local plants;**

- **reliable.**

Seed collectors

Seed collection requires skilled personnel who have been specifically trained for the job. There are three distinct elements: timing of seed collection and selection of good seed trees; ability to climb trees safely and pick the seeds; and knowledge of seed treatment and storage. People selected for this job should, therefore, be experienced, with a sound knowledge of local trees.

Some literacy is useful for reading training information and seed-collection calendars. In summary, seed collectors should have the following attributes:

- **good understanding of local plants;**
- **knowledge of seed collection, treatment and storage;**
- **specially trained in tree climbing and seed collection.**

In practice, each Division or project is unlikely to have specially trained seed collectors. Instead, labourers who are particularly good at this can be retained on the payroll to ensure that they are always available.

Tree climbing equipment can be partly purchased and partly made in the nursery. The Department of Forests sometimes gives training courses on making equipment.

The following questions can be used when interviewing people who are possible employees as nursery naikes, watchmen and labourers.

- **Have they worked in the subject area before? For how long? Where?**
- **Have they ever done anything beyond the normal requirements of their job? What?**
- **How can you show a previous interest in or commitment to this job?**
- **What do they know about this job and why do they think they can do it?**
- **What tasks required in this job have they actually performed before?**
- **Have they ever worked in a team before? To do what?**
- **Have they ever organised others to work before?**
- **Have they ever had a bad accident or injured anyone? How?**
- **Do they live locally? Where exactly?**
- **How much land do they have? What do they grow on it? Do they have many private trees?**
- **Why did they leave their last job?**
- **How many days per month do they take off?**
- **Ask them to show you a khukuri or hasiya; if it is sharp and in good condition, the person should know how to look after their tools.**

4.3 Propagation of grasses

This section explains how to produce grass plants in simple soil beds in a nursery.

Introduction: the methods of grass production

Perennial grasses usually form the main part of a bio-engineering scheme. Propagating these grasses vegetatively (*i.e.* from cuttings) is not difficult technically and various vegetative methods of propagation are highly successful. However, the reason for using a particular propagation method in the nursery is

often related to the availability of material.

There are three methods for propagating grasses in bio-engineering, as described in Figure 4.6. Some grasses (*e.g.* dubo and kikiyu) can also be propagated from stolon cuttings[1], but these are not normally used in bio-engineering. Seed is a cheap means of propagating grasses, but requires much longer growing in the nursery before the plants can be used on site.

[1] A stolon is a stem that grows along the ground, producing at its nodes new plants with roots and upright stems.

Grasses from cuttings always grow much faster than those produced from seed. Also, they are tougher and do not go through such a delicate stage as seedlings.

Propagation of grasses from slip and rhizome cuttings

All of the bio-engineering grasses can be propagated by this method. It is by far the most widely used method of propagation in bio-engineering.

Grass clumps are split up and trimmed.

Grass clumps are split up to make slips.

Slips are then planted in nursery beds to multiply.

Take a clump of the grass, cut the shoots off about 100 to 150 mm above the ground and then split the whole clump carefully into sections. Each section should

include several old shoots, any new buds that are visible and as much root as possible. You need to balance getting the maximum number of transplants from one clump while making sure each is a viable plant.

When you are planting the slips, bury the root parts carefully into loose, moist soil, trying to keep them as straight as possible and about 20 mm below the surface. If they are more shallow they may dry out. The tops can be either at an angle or vertical. After planting, lay a sheet of hessian over the tops of the cuttings to give shade. Keep it there until the new shoots are about 50 mm long and then remove it in stages, starting by removing the hessian for a few hours a day.

Rhizome cuttings

Some grasses have a rhizome system (*e.g.* amliso and the small bamboos, padang and tite nigalo). The method involves making a slip, which includes part of the rhizome.

Take a clump of the grass and cut off the shoots above the first or second node above the ground. Separate the clump, taking care not to damage the rhizomes and fine roots. Keep at least 50 mm of the rhizome, or horizontal part, per cutting. Each cutting should have some buds at the nodes on the rhizome, but often these are difficult to see. The new growth will come from these buds. When you plant the slip, keep the level of the soil as it was originally, making sure the rhizome is well covered. The method of planting and covering is similar to that of other slip cuttings.

Propagation of grasses from culm or stem cuttings

This is suitable for grasses that have heavy branching, such as dhonde and narkat. Usually, a piece of stem with at least two or three nodes is used, but the most vigorous species, such as napier, can be propagated from single-node cuttings if material is scarce.

Select material that is between one and two years old. Cut the stem horizontally about 30 mm above the higher node and at 45° about 30 mm below the lower node. The different cuts help you to tell at a glance which way up the cutting should be planted.

Insert the cutting into loosened, moist soil, so that it is two-thirds buried. Cuttings can be inserted at an angle of about 45° but vertical insertion is also acceptable. Many plants survive equally well if cuttings are planted horizontally. Often the upper node gives shoots and the lower node gives roots, but a large, strong shoot may also emerge from the lower node.

After planting, lay a sheet of hessian over the tops of the cuttings to give shade. Keep it in place until the new shoots are about 50 mm long, and then remove it in stages, starting by removing the hessian for a few hours a day.

Stolon cuttings

If the grass produces a stolon, it is usually possible to make cuttings from the individual nodes. This is particularly easy with dubo and kikiyu.

Often, roots grow naturally from the nodes on the stolon. This is called 'layering'.

If this happens you only have to cut the stolon mid-way between the nodes and carefully transplant it with its roots and shoots intact. It is already a new plant. If roots have not yet appeared, you can cut off a node and plant it not more than 10 mm below the surface. Keep any leaves attached to it and plant the cutting with them above the ground. Avoid damaging any shoots or buds that exist. The node will shoot and root very quickly.

Figure 4.6: Propagation methods for bio-engineering grasses

PROPAGATION METHODS	DESCRIPTION	MAIN SPECIES
Slip cuttings	The main method of propagating grasses for bio-engineering. Rooted cuttings are made by splitting out grass clumps grown in the nursery. If the grass is rhizomatous (like amliso or tite nigalo), then the slip consists of a section of the rhizome and some shoots, and must include root buds	All bio-engineering grass species
Stem cuttings	Propagation by planting a section of the stem, usually with two nodes and a section of culm. This is carried out either in the nursery for transplanting as a rooted cutting, or directly on site	Dhonde, napier, narkat
Seeds	Grass plants are grown up from seeds. This is carried out either in the nursery for transplanting as a rooted plant, or directly on site	Babiyo, dhonde, kans, katara khar, khar, phurke,

		sito

Propagation of grasses from seeds

Most grass seeds will remain viable for several years, but you should use them within one year if possible.

Sow the whole remains of the seed heads on the surface of a recently cultivated bed. Dense sowing is usually the best method (*i.e.* 25 g of seed per 1 sq. m of bed), so that several thousand seeds germinate per square metre.

Very young grass seedlings can be scorched by the sun and killed if they do not have enough shade. Avoid this problem by covering them with a sheet of dampened hessian. Similarly, spreading a layer of dampened hessian jute over newly sown seeds can protect them from intense heat. Keep the jute damp as much as possible, because very intense sun can dry out the surface even underneath it. Remove the hessian in stages once the seedling stems are about 10 mm long. First remove it for a few hours during the early morning and late afternoon, then for longer, and finally completely. Thin the seedlings heavily from time to time.

Most of the soil conservation grasses require warmth before the seeds will germinate. This may be an in-built survival mechanism, as small seeds do not have very big reserves. In order to overcome this problem, do not sow too early. If you have to sow early, you can use cloches[1] to increase the temperature in the seed bed.

[1] **A temporary tunnel of clear polythene sheeting used in nurseries and horticulture farms during the winter. The tunnel produces a warm, sheltered microclimate around young plants.**

A cloche is made by placing bamboo hoops across the bed and covering the bed with polythene, which is kept well clear of the seeds.

Management of grasses in the nursery

Keep grass beds well watered and weeded. Replant any gaps where plants have failed as soon as possible. Grass seedlings will need to be thinned heavily every week or so, to allow clumps to develop. Eventually you should aim to have 100 plants per square metre.

When grasses grown from slips have grown up and completely filled the beds, there are two options. The usual one is to cut the shoots off about 150 mm above the soil, to encourage the development of new shoots. However, if the planting season is a long time off, you can lift the grasses out, split them up and replant them. One bed of large plants ready for splitting usually fills three to seven beds after transplantation.

Grass beds in a bio-engineering nursery

4.4 Propagation of shrubs and trees

This section explains how to grow shrubs and trees[2] in a nursery, starting from either seed or from hardwood cuttings.

> 2 A shrub is a woody plant with multiple stems growing up from the ground; a tree has usually one stem growing up from the ground. For bio-engineering purposes, shrubs and small-stature trees have the same functions.

Introduction: methods of shrub and tree production

There are many ways of propagating shrubs and trees. Although this is a very specialised activity the bio-engineering species have been chosen partly for ease of propagation. In the road sector, two main methods are used: polypot seedlings and hardwood cuttings. A third method (stump cuttings) is particularly useful for sisau and some other species, and is also described here (see Figure 4.7 for a summary of these methods).

Polypot seedlings

There are distinct steps in the production of seedlings in polythene pots ('polypots') (see Figure 4.8). These depend on the size of the seed, and whether they need to be sown into a seed bed, or can be sown directly into the polypots.

Figure 4.7: Propagation methods for shrubs and trees

PROPAGATION METHODS	DESCRIPTION	MAIN SPECIES
Polypot seedlings	Plants are raised from seed in a nursery. They are grown on in polythene containers ('polypots'), and also moved in them to site for final transplanting. If the seed is reasonably large (e.g. khayer or sisau), it is sown directly into the prepared polypot. If it is very small, however, like utis seed, it is sown in a seed bed and later is pricked out to the polypot	Areri, dhanyero, dhusun, keraukose, bakaino, chilaune, gobre salla, kalo siris, khanyu, khayer, lankuri, painyu, khote salla, rato siris, seto siris, sisau, utis
Hardwood cuttings	A section of woody stem (a 'cutting') is cut from a parent plant and inserted into the soil. From the buds on the cutting, shoots and roots develop to form a new plant. This is usually done on site but, in some cases, it is done in the nursery, and the entire rooted plant moved to site later on. Techniques such as brush layering (Section 3.10)	Assuro, bainsh, kanda phul, namdi phul, saruwa/bihaya, simali, dabdabe, phaledo

	and palisades (Section 3.11) use hardwood cuttings	
Stump cuttings	'Stumps' are cuttings consisting of sections of the plant that include both root and shoot. They are made from seedlings more than one year old raised in soil beds (e.g. standard nursery grass beds)	Sisau
Direct seeding	Plants are sown directly on site, either by broadcasting small seeds across the surface, or by inserting larger seeds directly into the soil. This technique is described in detail in Section 3.8. It does not involve a nursery stage	Broadcasting: khanyu, utis; direct seeding: areri, bhujetro
Root suckers	Some plants put out new shoots from the root level: banana trees are a common example. You can propagate new plants by digging around the existing plant and separating off the new shoot or 'sucker' growing from the roots. This technique does not involve a nursery stage	Kettuke
Budding, grafting and layering	These are specialist techniques used mostly in horticulture and the production of high-yielding fodder trees. Budding and grafting combine different plants for specific properties. For example, one plant may contribute better root stock to fruit or fodder trees. Layering encourages the development of roots from a node on a branch, which is then separated to form a new plant.	Not normally used in bio-engineering

Preparing seed beds.

See Section 4.1.

Polypots

Polypots should have the following attributes.

Material: 200 gauge (0.05 mm thick) black polythene.
Size: 4" × 7" laid flat.
Drainage holes: 8 to 12 holes, about 5-6 mm in diameter, in the lower third of the pot; corners may also be cut off.

Potting mixture in polypots

Use only topsoil with the texture of sandy loam or loamy sand (40 to 70 per cent sand). You can identify these soils by trying to roll a little moist soil to pencil thickness between your fingers. If this is not possible, there is too much sand. If the roll can be bent in a semi-circle without breaking, there is too much clay. Add washed sand as required to improve the soil texture. Add sieved, well-rotted compost to improve the fertility and moisture retention.

An ideal potting mixture has the following characteristics:

- **light weight;**
- **homogeneous;**
- **easily available;**
- **fertile, and retains nutrients well;**

- a pH between 4.5 and 6.0;
- well drained, but retains sufficient moisture;
- sufficiently cohesive to maintain the root ball after removal from a polypot.

Soil for growing pines must be collected from a pine forest. Alternatively, add mycorrhizal soil to the potting mixture. If possible, when propagating khayer, siris, sisau or utis, soil should be used from forests of these species; however, this is not as critical as it is for pines.

Filling polypots

When the mixture of soil/sand/compost is ready you can fill the polypots by hand. A scoop made from an old half-litre plastic bottle will help speed up the process. Make the mixture very slightly moist, but keep it loose so that you can easily pour it. Fill the pot in three or four stages, firming down the mixture after each stage. Do not fill the whole pot and then try to firm all the soil at once, because this leaves air pockets. Fill the pot completely. Allow the mixture to settle for about four weeks. Do not allow the pots to dry out during this period. Water them periodically to permit the development of micro-organisms. This is especially important if the soil has been stored dry for some time. The pots are then ready to take seeds or transplants.

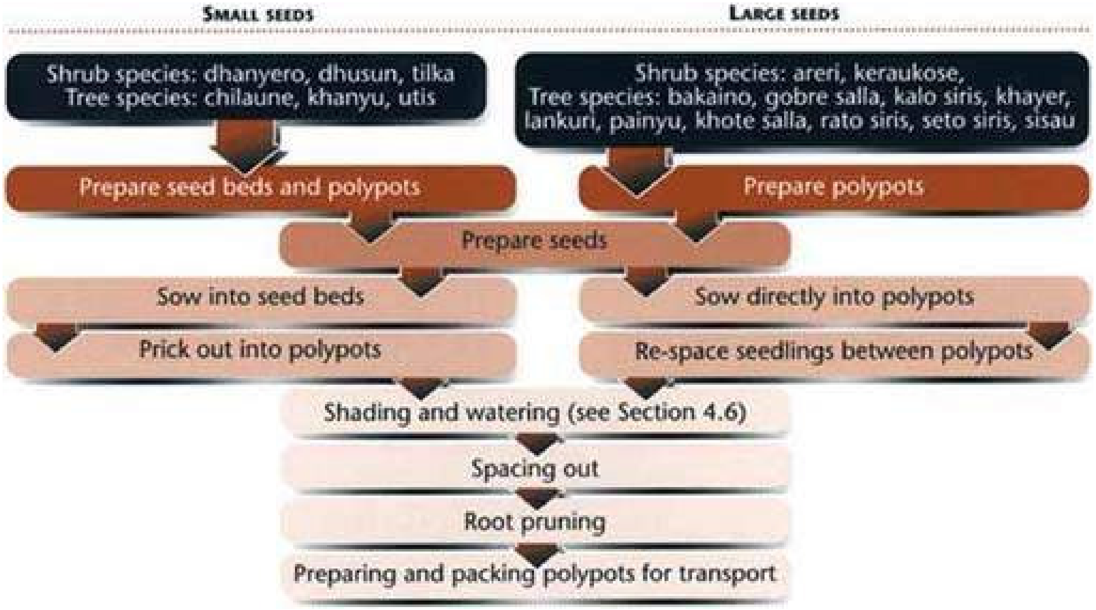


Figure 4.8: The main steps in producing polypot seedlings

Preparing seeds

Most species used for bio-engineering have seeds that will germinate quickly when sown. Others may take several months to germinate unless they are treated properly. Such seeds are said to be dormant. There are several ways to overcome dormancy, depending on the species. These are summarised in Figure 4.9.

Sowing small seeds in seed beds.

Estimate the sowing density so there will be about 4,000 seedlings per sq. m. Taking khanyu as an example, there are about 1,500,000 seeds per kg. Assume an effective germination of 25 per cent (the percentage is low because experience has shown that naikes have great difficulty in germinating very small seeds). If 25 per cent of 1 g of seed *(i.e.* about 1,500 seeds) germinates, we can expect 375

seedlings. Dividing the desired seedling density *(i.e.* 4,000/sq. m) by 375 gives the weight of seed to sow on 1 sq. m as 10.67 g.

Press down the soil with a small block and water it. The surface must be perfectly level. Mix small seed with two or three times its volume of clean, fine, dry sand. Then broadcast the seed/sand mixture over the surface. Distribute the seed/sand evenly by placing it on a flat piece of card, holding this just above the soil and tapping it lightly underneath. The seed bounces off, making it easier to control its distribution.

After sowing, cover the seed evenly with pure washed sand. Use just enough to cover the seed. Make the seed cover firm with a wooden block, cover lightly with a mulch of rice husks, pine needles or straw and water the tray with a watering can fitted with a fine rose. The mulch will prevent the seed from drying out. Protect the bed or tray from heavy rain with a strong shade.

Small seeds must not be allowed to dry out, so you must inspect the beds several times a day and water when necessary. However, too much water will also reduce germination.

When germination is nearly finished, remove the mulch and expose the seedlings to full light for a few hours each day. If the soil becomes too wet, or if damping off becomes a problem, allow them to dry out a little by reducing the amount of shade.

Polypots are filled with a fertile topsoil of loamy or sandy loam texture

Polypots are filled with a fertile topsoil of loamy or sandy loam texture and placed in standout beds

Pricking out

This is the process of transferring seedlings from the seed beds to polypots. It is a very delicate operation that should be done with great care, preferably by

experienced workers. Prick out shortly after germination, when the seedlings have only three or four primary leaves in addition to the cotyledons[1]. Pine seedlings can be pricked out three or four days after germination, when the seed coat is still attached to the cotyledons giving the appearance of a match-stick. Do the pricking out on a cloudy day or in the late afternoon or evening.

> **[1] Part of the embryo of a seed plant. The cotyledon often becomes the first photosynthetic (green, light-gathering) organ of the young seedling.**

When the seedlings have started to produce new leaves, start to remove the shade as explained in Section 4.6. Generally, after about a week no shade should be given.

Sowing larger seeds directly into polypots

Thoroughly water the pots the evening before sowing, and lightly water again immediately before sowing. Sow two seeds in each pot. Push the seeds into the soil surface in the centre of the pot and cover it with sand. Never sow seed deeper than twice its width and in any case not more than 5 mm deep. Shade the pots and water them again.

Re-spacing seedlings between polypots

After germination, pots will have 0, 1 or 2 seedlings each. When germination is almost finished, prick out plants from pots that have more than one into pots without any. This may still leave some pots with more than one seedling. Remove the extra plants, once germination and pricking out have been successfully

completed, by pulling them up or by breaking or cutting the stem near soil level.

Shading and watering

These are covered in Section 4.6.

Figure 4.9: Pre-sowing treatments for the main bio-engineering shrubs and trees

TREATMENT	SHRUB SPECIES	TREE SPECIES
No treatment required; just sow	Areri, bhujetro, dhanyero, dhusun, keraukose, tilka	Chilaune, gobre salla, khanyu, khote salla, utis
Soak in warm water for 24 hours before sowing	-	Bakaino, painyu, sisau
Chipping: cut off a small piece of the seed coat with nail clippers on the side of the seed opposite the hilum (the scar from which the seedling root emerges	-	Kalo siris, khayer, rato siris, seto siris
Avoid dormancy by sowing immediately	-	Lankuri (green)
Keep over a winter before sowing	-	Lankuri (brown)

Spacing out polypot seedlings

Plants growing close together in the nursery compete for moisture, nutrients and light. Their growth and form is affected and they become tall and thin, with weak, soft stems and poorly developed root systems. Plants grown in 4" × 7" pots to a

height of over 300 mm do not have enough growing space.

When plants reach a height of 300 mm, separate the rows of pots across the bed, leaving a space of up to 100 mm between them. You can make the spaces with wooden sticks, bamboo laths, bricks, stones, or old filled polypots without seedlings. Spacing between plants within the rows is not necessary. Spacing requires more bed area in the nursery and you must consider this in planning bed sizes. Where insufficient area is available, spacing only between pairs of rows is a reasonable compromise.

Root-pruning polypot seedlings

Root pruning prevents the formation of very long roots in the nursery, which would have to be cut when the plants are transferred to the field, increasing the shock to the seedling. It also reduces excessive shoot growth, increases the hardening of the stem and increases the development of lateral roots.

Check the need for root pruning by lifting a few pots; if roots are seen protruding from the bases, all the pots in the bed should be checked.

Roots should be trimmed off just below the pot, using a razor blade or a sharp khukuri. If root-pruning causes the plant to wilt slightly, it has been done at the right time.

Proper spacing of polypots minimises competition for moisture, nutrients and light

As with watering, root-pruning cannot be carried out according to a fixed timetable but must be done according to the needs of the plant, as ascertained by frequent checks.

Preparing and packing polypots for transport

These are covered in Section 4.6.

Hardwood cuttings

Rooting hardwood cuttings is the easiest and cheapest way of propagating plants vegetatively. Make cuttings from wood of the previous season's growth or sometimes of the one before. Never use older wood because this does not develop roots easily. Use material from branches in the lower part of the tree crown, but not from the main shoots or other outer parts of these branches. Even better, take cuttings from stool shoots produced in the nursery for this purpose (see below).

HOW TO PRICK SEEDLINGS OUT SUCCESSFULLY

Use the following procedure for good survival after pricking out:

1. One day before, thoroughly water the polypots into which the seedlings will be pricked out. Ensure that shades are erected and in good order.

2. Immediately before starting to prick out, lightly water the seedbeds.

3. Remove the seedlings from the seedbeds by inserting a flat stick under them and gently lifting. Take care to do as little damage as possible to the roots. Hold the seedlings by the leaves or cotyledons. Never touch the stem or roots.

4. Take just enough seedlings for about fifteen minutes pricking out, and keep them in a dish of water. Keep this shaded so that the water does not heat up rapidly in the sun and kill the seedlings. Do not let the roots dry out.

5. Make a hole in the soil, in the centre of the polypot, with a pointed wooden stick a little thicker than a pencil. The hole must be deep, and wide enough to contain the seedling's roots without bending them.

6. Hold the seedling's root in the hole with the root collar just below the soil surface. Do not bend the roots into a J or U shape. If any of the roots are too long, cut them to the desired length with your finger nails or a sharp blade. Do not leave the primary leaves in contact with the soil surface.

7. Insert the stick used for making the hole about 10 mm from the roots and close the hole around the root by levering the stick gently back and forth. Be careful to

close the hole throughout its depth, and not just at the top.

8. Lightly water the seedlings and ensure that the soil around the roots remains fairly moist but not saturated, as this would lead to rotting, by lightly watering tow or three limes a day for the next few days. Keep the shades on throughout this period.

9. Three or four days after pricking out, replace any plants that have died, by repeat-ting the above procedure.

Prepare cuttings just before the buds open, usually from mid-January to mid-April (Magh to Chaitra), from healthy vigorous stems or branches. Do not use weak stems. The cuttings should be about 150 - 200 mm long, 8 - 20 mm diameter, with at least two, and preferably three or four, nodes. Make a horizontal cut 10 to 30 mm above the upper node and a sloping cut just below the lowest node with secateurs, a sharp khukuri or similar blade. Avoid crushing, splitting or otherwise damaging the ends. Cut off all leaves and side branches.

Prepare the cuttings the same day you collect the shoots and set them immediately into pots or beds that have been prepared in advance. Cuttings that are allowed to dry out will not form roots.

You can root cuttings in large polypots (not less than 4" × 7"), or in previously prepared nursery beds (*e.g.* standard nursery grass beds).

In beds, set the cuttings 300 mm apart, in holes slightly larger than their

diameter, placing them so that only one bud, *i.e.* about 30 mm of the cutting, remains above the soil level. Firm the soil up so that there are no air pockets around the cutting. Use the same method for polypots, but finish by rolling the pot between your hands to firm up the soil.

Water the beds or pots and shade them immediately after setting. Keep them constantly moist, but not too wet, until well after root formation. If the soil becomes too wet, remove the shade for a few hours, but not long enough to permit the soil to dry out completely.

New shoots will develop a few weeks after setting, and will cause increased loss of water through transpiration. Maintain shade to minimise this loss until fully functioning roots have formed. Sometimes success is suggested by the development of healthy vigorous shoots, but they dry up and die if there is no equally vigorous development of roots. Remove the shade once the roots are well developed (*i.e.* when they start to grow from the bottom of the pots and you have to begin root pruning).

In nurseries at lower elevations, and with faster growing species, rooted cuttings reach the required size for planting by the beginning of the monsoon (five months after setting). In other cases it may be necessary to keep them in the nursery until the following monsoon.

You can produce young material ideal for hardwood cuttings in the nursery by establishing stool beds. Plant 20 to 50 plants of each of two or three species in a soil bed (i.e. a standard grass bed) and cut them back each year so they produce plants from which cuttings can be made. This makes collecting cutting material

easy, saves a lot of time, and ensures that juvenile material is used.

Stump cuttings

Stumps are a form of cutting used in the propagation of certain trees, notably sisau. The advantage of this technique is that the plant leaving the nursery is smaller and easier to transport.

Prepare the ground for the stump beds as for standard nursery grass beds. Sow the seeds directly into the beds, in lines 100 mm apart. Water to keep the soil moist. Shade the seedlings until they are well developed and about 50 to 100 mm tall. Once they have reached this size, thin them out to give a spacing of one plant per 150 mm in the lines. To thin the plants, gently uproot the unwanted seedlings or break them off at the root collar[1]. Take care not to disturb the plants that are to be left.

> **[1] The root collar of a seedling is the line below which the roots emerge. It normally corresponds with the surface of the soil and often shows a change of colour or a slight swelling.**

Allow the plants to grow on after the first monsoon. They will not need as much watering during the second dry season.

The stumps will be required for site planting during the second monsoon after sowing, when the plants are about 15 months old. Sisau should be 1.5 to 2.5 metres in height by this time.

To make the stumps, start by uprooting the plants carefully. Cut the tap roots about 300 mm below the surface level. Then make the stump cutting itself, using a sharp khukuri. Cut the stem about 50 mm above the root collar and cut the tap root about 250 mm below the root collar. Trim any side roots about 10 mm from the main root. Cuttings should be within the diameter range of 7 to 15 mm (between the thickness of a pencil and your thumb) at the root collar. Discard any badly misshapen or damaged cuttings. Wrap the cuttings in damp hessian for transporting to site.

4.5 Propagation of bamboos

Introduction: the methods of bamboo production

Bamboos are large grasses. They are relatively slower growing and harder to establish than the smaller grasses, and tend to grow in damper locations. But once they are established, the big bamboos form huge plants, which are especially useful for catching debris and supporting the slope.

Bamboos do not often seed and so they are normally propagated from big cuttings. To do this, there are two main methods used in Nepal (Figure 4.10 summarises these). The traditional method is commonly known in rural areas but is a big undertaking for large bamboos, and therefore expensive. Some species can be propagated from single-node culm cuttings, but this requires a long period in the nursery.

The traditional method of bamboo propagation does not involve a period in the nursery. This process is described in Section 3.9.

Propagation of bamboos from single-node culm cuttings

Rooted culm cuttings are relatively cheap, easy to transport and survive well after planting.

Equipment required

A sharp tool like a khukuri or hasiya is sufficient, but a handsaw and secateurs, for pruning branches, are useful if they are available.

Selection of materials

Only use choya/tama, dhanu or kalo bans for this method. Take cuttings from culms in their second year of growth. If such culms are not available you can use third-year culms. Culms less than one year old are not strong enough to give cuttings. Choose healthy culms with strong branches. Avoid damaging the dormant buds in the central branches at nodes. Select suitable culms one year in advance and mark them.

Time for taking cuttings

The best months for taking culm cuttings are February and March (mid Magh to mid Chaitra). Take the cuttings when the buds are ready to burst but before new growth starts. In hotter places take them earlier, generally in February (mid Magh to mid Falgun), whereas in cooler places March is best (mid Falgun to mid Chaitra).

Preparation of cuttings

Prepare the cuttings where you obtain the culms. Cut the culms midway between the nodes without splitting them, so that all the cuttings are single-noded. Cut off the leaves and small branches as close as possible to the culm. Reject material less than 40 mm in diameter from the tops of culms. Prune central branches off beyond the first node. You can take cuttings from culms whose buds are completely dormant or with undeveloped central branches. Dip the cuttings into water or sprinkle them with water immediately after preparation.

Transport

After you have prepared cuttings at the bamboo clump bring them to the nursery. Do not allow them to dry out during transport. If they are kept in a doko or any other container, pour water on them. Cover them fully with leaves and grass or wet sacks.

Preparation of beds

The best place to set culm cuttings is the coolest, dampest and shadiest part of the nursery. Prepare the beds as described for bamboo cuttings in Figure 4.5. Water the beds thoroughly before and after setting the cuttings. Good facilities for watering are essential. Provide shades all the year round.

Setting

Plant the cuttings horizontally with the large central branch, or the bud from which it will come, sideways at the soil surface. The main bud at the first node of the central branch should be facing upwards. Ensure that the ends of the culms are well covered with soil because all the water needed for the development of the

cutting enters through the cut ends of the culm for at least the first two months. If the ends are allowed to dry out, success rates will be reduced.

If the cuttings obtain enough water from the beds and do not dry out, shoots will develop in one to three weeks. Most of those shoots will grow to about a metre in height and produce leafy branches before beginning to root after about three months. The cuttings must be watered well and shaded throughout this period and beyond.

Setting a single node bamboo cutting in a saturated bed

Planting out

Below 1500 metres, keep the cuttings in the nursery for 16 months; above 1500 metres, keep them in for 28 months. After 16 or 28 months in the nursery, culm cuttings that have many rhizomes with more than three shoots will be ready for planting. This will be in June or July (Ashad), when the monsoon rain starts. The recommended height of bamboo plants is at least 2 m, but if the planting site is far away you can cut them back to 0.5 metre for ease of transport. Take precautions

to ensure that they will not dry out while being transported. Wrap the rhizomes well in a sack full of wet soil. Make sure the rhizomes are not damaged. Cut most of the remaining leaves in half to reduce transpiration.

Dig a large pit and plant the rooted cutting carefully. Add compost to the soil if it is available. Mulch the area around the plant well. If there is no rain, water it during the first few weeks after planting. See Section 5.3 (Mulching) for more details on mulching.

Survival rates of plants

Grasses propagated by slip should give a survival rate of almost 100 percent in the nursery and about 95 percent on site. If there are significantly more failures than this, then you should investigate the possible reasons. The most common reasons are that the slips were allowed to dry out at some stage during the transplanting process.

Grasses propagated by rhizome cuttings have a slightly lower survival rate. However, this should still exceed 95 percent in the nursery and 90 percent on site. Failures greater than these should be investigated.

Where grasses are grown from seed, it is almost impossible to estimate the survival rate. However, if the standard application rates are used, there should be a thick, even cover of grasses resulting. If this does not occur, the usual causes are from sowing too early or from seeds being washed off the surface.

Shrubs and trees have to be considered separately. In nurseries it is normal to plant more cuttings or to sow more seeds than are required because, however

good the nursery staff, there will inevitably be significant losses. The processes of taking from cuttings or germinating, transplanting and growing on, all take a toll on the young plants.

It is normal practice to allow four times the amount of seed for the final number of seedlings required.

It is normal practice to grow up 25 percent more seedlings than will be required, and to discard the poorer plants when they leave the nursery.

Therefore, for every 100 seedlings used on site, 400 seeds will have been sown and 125 seedlings will have been grown up.

Figure 4.10: Propagation methods for bamboos

PROPAGATION METHODS	DESCRIPTION	MAIN SPECIES
Traditional method	A section of rooted rhizome and an entire culm is cut out of an established bamboo clump. It is replanted with the culm cut off about 2 metres above the ground, leaving branches emerging from one or two of the nodes.	All bamboos
Rooted single-node culm cuttings	A single node of a bamboo culm is planted in a wet, well-shaded nursery bed and allowed to root over a period of at least one year. It is then transported for planting on site as a newly rooted plant.	Choya/tama, dhanu or kalo bans
Other methods	Bamboos can occasionally be grown from seed, but only if	

	seeds have been obtained (bamboos produce seeds only about once in 20 years). Other cutting methods and advanced techniques such as tissue culture have not proved successful in Nepal on a widespread basis.	

On site, the survival rates for shrubs and trees can vary considerably depending on the biophysical harshness of the site, the quality of the plants and the quality of the planting works. In forestry plantations in Nepal, survival of only 80 percent is considered acceptable, although it should be much more. The same rate should be used for bio-engineering works. If less than 80 percent survive, then a thorough investigation should be made. The usual causes of casualties are from careless handling and planting on site, and subsequent grazing damage.

4.6 Nursery management

The management of nurseries, beyond what has already been described in previous sections, consists of:

- **environment management (which means controlling shade and water);**
- **restriction of pests and diseases;**
- **preparing plants to leave the nursery;**
- **use of registers; and**
- **making and using compost.**

Shading

Plants in all nurseries in Nepal require shading at some stage. It is needed for a variety of reasons at different stages of growth, but must be done carefully. The

wrong use of shades can be damaging to young plants.

However, shading is only required on a very temporary basis. It is usually needed during germination, for protecting recently pricked out seedlings, and for protection against adverse climatic conditions such as excessively hot sun, heavy rain, hail, or frost.

Making shades

Make shades of locally available materials. They should be easy for one person to handle. They must be movable but capable of being fixed to prevent them blowing away in strong winds. The height of the shade depends on its use. It should be about 300 mm above seedbeds and recently pricked out seedlings, and 750 mm above ground level for protecting larger seedlings against hail, hot sun and heavy rain. Construct beds along an east-west line if possible and arrange the shade so that it slopes downwards from north to south.

The slope carries water off and the alignment gives maximum protection against the mid-day sun.

Complete shades can be made from woven bamboo matting, hessian cloth or the stalks of maize or wheat. They should be wide enough to overhang the bed slightly and can be up to two metres long. Longer lasting shades can be made from wooden or bamboo slats tied together with spaces between them to allow some light and air to penetrate. They can be rolled up for easy storage and unrolled very quickly when needed. They are heavy enough not to need fixing. Polythene sheets can be spread over them to make them waterproof when necessary.

Shading from hot sun

This is used for seeds and young plants. Shade helps germinating plants because it slows the drying out of the growing medium and the seed. It also prevents damage from rain. Shade over germinating seed should be waterproof. Polypot seedlings also require shade for a few days only after they have been pricked out, to protect them from the sun and to keep the soil moist. The amount of shade needed during germination and after pricking out varies with the weather. If it is used when it is not necessary, for example during spells of cool cloudy weather, the beds may become too moist and this often leads to the development of damping-off disease.

Removing shades from young seedlings.

Remove shades gradually, starting as soon as new leaf development is seen. At first, take the shades off for a short time in the morning and afternoon, keeping them in place at the hottest times.

All plants need shade at some stage of their growth. These shades can easily be removed when necessary

Gradually increase the time they are removed each day until after about a week the shade can be completely removed, without causing any damage to the plants.

Heavy rain

During the monsoon, shade for protection against the rain should only be used when it is actually raining heavily, or at night or during the day when staff are absent.

Hail

Hail usually occurs in the months immediately before the monsoon (Chaitra to Jestha) and during this period shades should be erected at night or when staff are absent from the nursery during the day. When the nursery staff are present they should only erect the shades when a storm is seen to be coming.

Frost

In higher altitude nurseries during the winter, if there is a danger of frost, erect shades each evening and remove them early the following morning. Do not leave them on all day at this season. Frost protection shades are most effective when they are just a few centimetres above the plants.

Shading bamboo beds

Bamboo culm cuttings need complete shade. This can be achieved by hanging sheets of hessian along the sides of the shade structures. The structures should also be higher, giving about 1.5 metres clearance above the soil, as the plants can grow to be quite large.

Cloches provide a warm, sheltered microclimate for growth early in the season

Cloches

Cloches are tunnels of clear polythene that are placed over nursery beds to raise the temperature during cooler weather. They are constructed by placing semi-circular hoops, made from split bamboo or the branch of a tree, every one to two metres along the bed. The polythene is then stretched over the hoops and weighed down at the sides and ends using stones or soil.

On sunny days the micro-climate inside the cloche can become very warm. The danger is that it can also become very humid and airless. For this reason, cloches must be opened out for at least one hour, twice per day, to ensure that fungi do not thrive inside them.

Cloches are often used in horticulture for speeding up the rate of vegetable production. They are extremely useful in higher altitude nurseries, as they can increase the growing season greatly at very little cost.

Watering

Watering in most small nurseries is done with 8-litre watering cans or a hose pipe with a watering rose, fed from a raised tank. These are the most appropriate and efficient methods. Careless watering can severely damage young plants.

There are no rules for watering, as the amount and frequency of watering required varies with weather conditions, species, the stage of development of the plants, soil type, and nursery management such as the use of shade. An inexperienced naike cannot be expected to know how often and how heavily to water. It is far better to teach the naike the basic principles of plant water requirements; a good naike will quickly learn from experience.

Keep seedbeds and recently pricked-out seedlings moist but never allow them to become saturated. This often means frequent, small applications of water, sometimes two or more per day. However, shading and mulching reduce the need for frequent watering. In cool, cloudy weather, water may not be required at all on some days. Check the beds periodically so that decisions can be made on the needs of the seeds or plants. Remember that the object is to keep the seeds or the seedling roots moist but not soaking wet. Always check the soil to the required depth before and after watering, to see if watering is required and if enough has been applied. Too much water can cause just as many problems as too little.

Weed, pest and disease control

Weeds

Weeds compete with plants for moisture, nutrients and light, and must be carefully controlled in the whole of the nursery area. If beds are weeded frequently, weeds will not have the chance to grow and weeding will take much less time. Their removal complete with roots is easy, and damage to the plants is minimised. Water the beds or pots before you start to weed, and pull the weeds out with their roots. If the roots cannot be pulled out, weeding has been started too late.

Keep the fence line, unused areas and paths free of weeds. Never leave weeds to flower and seed in any part of the nursery as this creates more problems and work later on. Weed throughout the year.

Insect and mammal pest control

Serious losses from insect damage are less common than losses from disease, but they are occasionally severe in some nurseries. Once again, prevention is better than cure.

Damage by insect larvae can lead to serious losses, especially just after germination. Some types live in the soil and come out to feed at night. They usually cut the stem of the young plant close to the soil surface, and they may also eat the leaves. Other types just eat the leaves. Where possible, it is best to control larvae by carefully examining the beds each day, picking off any that are found and squashing them. Insecticides containing methyl parathion, such as Metacid and Paramar are effective. Make a 0.05 per cent solution *(i.e.* mix 1 ml with 2 litres of water) and apply this with a watering can with a fine rose. You need to measure the very small quantities of chemical needed accurately, with a 4 ml hypodermic syringe.

Ants and 'white grubs[1]' will occasionally eat seed or attack seedlings. If this is a problem, sprinkle the area lightly with Aldrin dust. In the case of larvae, cultivate the Aldrin into the soil. However, Aldrin is a very hazardous chemical; do not use it unless you have to. When its use is unavoidable, take every possible care to minimise the risk of physical contact with the chemical.

> **[1] Insect larvae that live in the soil and eat plant roots: they are large, thick, white larvae, usually C-shaped, and may be more than 30 mm long.**

Rodents, cattle, goats, pigs, dogs and chickens must be completely excluded from the nursery by constant maintenance of the fence or wall and use of the normal deterrent and trapping methods.

Fungal diseases control

Two fungal diseases are important in nurseries in Nepal: damping-off and brown needle disease. The latter affects only pines, which are not used very widely in bio-engineering nurseries. Napier and Robbins discuss it in *Forest Seed and Nursery Practice in Nepal.*

'Damping-off' affects young seedlings. It may be caused by many different fungi, which are always present in soils. Good nursery management involves stopping them from killing seedlings. There are three types:

- **pre-emergent damping-off, in which the fungus attacks the seed and the newly developing root before the shoot emerges from the soil. It can easily be confused with poor germination that is due to the seed having poor viability;**

- **post-emergent damping-off, in which the fungus attacks the base of the stem or roots after the seedling has emerged from the soil. The plant falls over and rots quickly. This usually occurs within 2 - 3 weeks of germination, while the stem is still soft. It is easy to recognise, but can be confused with insect damage to roots and the seedling stem-base. It often occurs in patches on the seedbed, with the most recently affected plants at the outside of the patch. It can spread very rapidly unless corrective action is taken as soon as it is noticed; all the plants in a seedbed can be killed within 48 hours;**

- **root rot affects older seedlings than the other two types. The first signs**

are yellowish (chlorotic) foliage in the upper leaves. This is followed by the wilting, discoloration and death of the shoot, after which the lower leaves may show signs of secondary fungal attack. Some of the roots will be seen to be soft and rotten or already dead. A good test is to see if the outer root layer can easily be pulled away from the inner core. Also, when healthy roots are broken, a sharp snap should be heard, but this will not happen if they are affected by root rot. Unfortunately, the first visible symptom of root rot, chlorosis, can be caused by many other problems such as a shortage of nutrients, too much or too little watering, or insect or nematode damage.

In bio-engineering nurseries, where soil sterilisation and extensive use of fungicides are not normally practised, prevention and control of damping-off depends on good nursery techniques. Damping-off fungi thrive in warm, moist, shady conditions and the most common cause is excessive moisture. This can be controlled. The naike should prevent damping-off by:

- **not over-watering;**
- **removing shade as soon as it becomes unnecessary;**
- **not sowing seed too deep;**
- **where possible, sowing in the dry season;**
- **ensuring free air circulation over the beds;**
- **keeping the nursery free of weeds and old unmanaged seedlings;**
- **not including compost or fertilisers in the sowing medium;**
- **using a well drained, sandy medium;**
- **using pure sand as a seed cover;**
- **avoiding transplanting damage by always handling seedlings carefully, by**

the cotyledons or leaves and not by the stems or roots and, where possible, by sowing seed directly into polypots or stand-out beds.

Grass slips must be prepared carefully for use on site

If damping-off occurs, reduce watering, remove shade and, if possible, protect the plants from rain by moving the seed trays under cover, or covering the beds with plastic sheets, during heavy showers. Once the disease is established it is very difficult to control. Try to prevent it altogether, but if it does happen, act quickly to prevent it spreading.

If fungicides are available, they can be used to help prevent damping-off spreading to other plants but they will not have much effect once it is well developed. Mix 25 g of Blitox (a blue powder) with 5 litres of water, and apply to the affected plants with a watering can twice a week.

Preparing plants to leave the nursery

Hardening-off

In a nursery we try to produce ideal conditions for plant growth. When the plants are planted out on site, they often face conditions that are far from ideal. They may face strong competition from weeds. They may receive excess rain or suffer from an interruption in the rains. In the nursery we must get them accustomed to, and able to tolerate, more difficult conditions. This is achieved through the process known as 'hardening-off'. Its main features are:

- **removal of shade at an early stage;**
- **spacing;**
- **reduction of watering.**

Culling

There will always be some plants that are not good enough for planting out. Planting out poor seedlings is a waste of money and opportunity. It is perfectly normal to reject as many as 20 per cent of the plants in a bio-engineering nursery because they are not suitable for planting and you should have taken this into consideration in planning the annual production (see Section 4.1).

Sort the plants out so that only those suitable for planting, and with a good chance of survival, are used. Cull thoroughly, following a previously planned specification that includes size, health, no distorted growth and lack of any damage. Keep the specification easy to apply. This should make it much easier to introduce the idea to naikes who are unfamiliar with it and may be reluctant to throw apparently sound plants away. Reject all plants that do not meet the specification.

Destroy all shrubs and trees that are not of a good enough standard to be used on site. Do not keep them for next year in the hope that they will be better.

Preparing and packing grass slips for transport

Lift grass clumps carefully, keeping the root ball intact so that the roots are not damaged. Wrap the root ball in wet hessian. Split them out on site. Trim the roots and stems to length, as for nursery planting. Wrap bundles of slips in wet hessian until they are needed for planting by the site labourers. Do not let them get exposed to direct sun because this will dry out the grass slips rapidly. At every stage, encourage labourers to treat the grasses as if they are slips of millet or rice, which are being transplanted.

Preparing and packing polypots for transport

Thoroughly water plants in polypots 2 to 3 days before they are to be transported and, again, lightly water them the evening before planting. Soil that is too wet or too dry tends to break up and this can damage plant roots. Thorough watering in advance is very important because it helps the plant withstand dry periods immediately after planting (one of the major advantages of using polypot plants).

Handle the plants by the container, not by their shoots; the stress caused by the transfer from nursery to plantation is great enough, without adding to it unnecessarily. When you are handling and transporting seedlings, ensure that the soil around the roots is not broken or damaged. Pack them vertically and close together so that they cannot shake about or fall over during transport. However, in packing them closely together do not force them as this will also break the soil

cone and damage the roots.

If possible, transport the polypots in trays made of metal or wood. A 400 × 250 mm tray, with sides 100 - 120 mm high, containing about twenty-four 4" × 7" polypots, weighs about 12 kg and can be safely handled by one person. Paint numbers on the trays to make it easy to keep track of them and ensure they all come back to the nursery.

Although not ideal, you can also use dokos for carrying plants. Fill the bottom of the doko with straw or some other light material to form a firm level base for the plants to stand on. Pack the seedlings so that they are vertical and will not shake about. About 40 plants in 4" × 7" polypots can be transported at a time. This makes a normal load of 20 to 25 kg. Place the plants into the doko individually. Never allow the pots to be bundled together and tied with string. It breaks the soil root ball and damages the roots of all the plants on the outside of the bundle.

Preparing and packing other plants for transport

Stumps are easy to transport; which is their major advantage. Wrap them in wet jute cloth, tie the bundles with string and keep them in a cool shady place. Do not let them dry out.

Dig up bare-root plants carefully, shake the soil off their roots, cull and then make up bundles of 100 to 300 with only the roots wrapped in saturated jute cloth. Do this work quickly and in the shade. Bare-root seedlings can also be transported in plastic buckets with their roots submerged in a mixture of 1 kg clay in 1 litre of water.

Never take more planting stock to site than can be planted that day. With a bit of experience staff can judge the requirements and ensure that surplus stock is not kept on site overnight.

Care of planting stock on site

Once the nursery stock is on site, treat it carefully. There will often be a delay before it is planted. Plants treated carelessly can be badly damaged on site and this can make the entire bio-engineering programme useless.

Keep bare-rooted plants and slips in damp hessian. Do not stack them in damp bundles in big heaps, as they will soon start to rot. Assign one person to the task of repeatedly checking the plants and ensuring that they are in good condition. This person can move them as necessary and add water when they start to become dry.

Ensure that all labourers know that they must lift polypot seedlings by the pots, not by the stems. They should be moved in strong trays or a few at a time in the hands.

Always handle plants, slips and cuttings carefully. Always keep them moist and in the shade, and never let them dry out. Destroy plants that have dried out, as they are certain to die.

Use of registers

There are four registers used in bio-engineering nurseries. They are all given in Annex C.

- **Grass slip hardwood cutting register.**
- **Seedling register.**
- **Seed identification register.**
- **Seed collection calendar.**

The purpose of each of these is described below.

Grass slip/hardwood cutting register

This provides a simple method of keeping track of grass and cutting stocks in a nursery. It allows the Overseer and Engineer to check on the amounts of material available when calculating site requirements. It also permits checking of likely problem areas if plants fail on site.

Seedling register

This does the same for plants produced from seed in the nursery. Their progress is checked from the time of germination onwards. It allows monitoring of technical problems in plant production, since it will be clear if the seedlings have fared particularly badly at any stage of development.

Seed identification register

It is important that seeds are kept in good condition and that they do not stay too long in the nursery. This register provides the information required to track problems resulting from poor germination, and to ensure that seed sources are of adequate quality.

Seed collection calendar

This is not a formal register. Instead, it serves to remind staff of the seeds that must be collected to provide future plants in the nursery. It has to be filled out locally, since it depends both on the particular bio-engineering programme and the availability of seeds in the area. It lists, month by month, the seeds that must be collected and the places from which they can be taken.

Making and using compost

Compost is produced from the breakdown of organic materials by micro-organisms in a warm, moist, aerated environment. The bacteria responsible for this require moisture, oxygen, carbon, nitrogen, and other nutrients. The energy they use is given off as heat.

Compost is added to the beds in nurseries to enrich the soil and help to retain moisture.

Good compost is black and crumbly, and you cannot distinguish the original plant parts. If standard farm 'mull' is used, you must check that it is in this condition, which means that it has decomposed fully.

You can make compost out of almost any organic material that is easily available. This includes weeds, forest litter, crop residues, animal bedding and dung. Weeds such as ban mara are plentiful during the monsoon, which is the best time to start compost making. Crop residues and pine needles take much longer to compost than recent weed growth and litter from the forest floor because they contain too much carbon and not enough nitrogen. When you compost them you can speed up

the process by adding liquid manure and larger amounts of recent weed growth. Chop up large material such as maize straw before you compost it.

You can make compost in a compost bay, a simple heap or a pit. Compost bays or heaps are best because pits are easily water-logged in the monsoon. Make the volume between 1 cu. m and 4 cu. m with a maximum height of 1.5 to 2.0 metres. In order to ensure good aeration, start with a layer of brushwood, old branches or rocks. Then pile the compost materials on top, ensuring that there is a good mix of different sizes and types. Apply components that are in short supply, such as farmyard manure, animal bedding and liquid manure (1 part dung mixed with 10 parts water), in thin layers every 200 - 300 mm. Add layers of a good loamy soil every 200 - 300 mm. If the components are dry before starting the heap, wet them for a few days beforehand. Layers of lime at a rate of 0.5 kg/cu. m will help promote the decomposition of acid components such as pine needles.

When the heap is finished, cover it with a large polythene sheet. This will prevent the compost from getting too wet, will conserve heat and, after the monsoon, will prevent it drying out. Two to four weeks later the heap should have heated up to its maximum and will need turning. Check the temperature by pushing a thin metal rod into the middle of the heap; if it becomes too hot to touch, the heap is ready to be turned. Simply dig it up and make a new one alongside it. This serves to aerate the components and to mix in the outer parts of the heap, which do not heat up as much as the inside. Inspect the heap occasionally to ensure that decomposition is taking place. You can find information on poor decomposition in the *Reference Manual.*

Compost making may take only 2 - 3 months in the Terai but may take more than 6

months above 2,000 metres. Other factors, however, are more important than altitude, in particular the attention paid to correct techniques, and the type of material used.

When the compost has been made, pass it through a soil sieve before mixing it into beds or potting mixtures. The larger components, which will not pass through the sieve, can be used for starting up another heap, as they will introduce bacteria to it. Add compost to every bed at least once per year. This is best done when the bed is empty and about to be cultivated. Make sure it is mixed well with the soil.

About 20 dokos (70 litres) of fresh green vegetation, such as ban mara, each weighing 20 - 30 kg with the material piled up above the rim of the doko, are needed to make one doko of compost, weighing 35 kg with the compost level with the rim.

Figure 4.11 Nursery troubleshooting chart

PROBLEM	DIAGNOSIS	ACTION IF "YES"	ACTION IF "NO"
SEEDS			
Seeds not germinating	Has the weather been cold?	Wait for warmer weather and check again Alternatively place cloches over the beds and monitor carefully.	Consider other possibilities.
	Is the bed waterlogged?	Allow the bed to dry until it is just slightly moist check the seeds are not rotten be very careful not to over water.	Consider other possibilities.
	Are the	Remove the seeds from the seed beds	Consider other

	Are the seeds rotten?	Remove the seeds from the seed beds replace the top layer of soil/sand re sow the seeds be very careful not to over water Remove cloches if they have been used.	Consider other possibilities.
	Do the seeds seem healthy?	The seed may no longer be viable Obtain new seeds and re sow.	The seed may have been stored badly Obtain new seeds and re sow.
GRASSES			
Grasses are growing abnormally slowly	Has the weather been cool or lacking in sun?	Wait for warmer weather and check again Alternatively place cloches over the beds and monitor carefully.	Consider other possibilities.
	Is the soil in the beds mostly dry?	Increase the rate of watering.	The soil in the beds may be poor If there are still several months before site planting transplant to a new bed with better soil If there is little time add fertiliser.
Grasses are very yellow	Is the soil in the beds	Reduce the fate of watering.	Add a nitrogen based fertiliser.

SHRUBS AND TREES	very wet?		
Poor growth	Has the weather been cool or lacking in sun?	Watt for warmer weather and check again.	Consider other possibilities.
	Does the soil in the polypots feel hard?	The pots may have been over compacted when filled or there may be too much clay in the potting mixture Loosen the soil with a pointed stick taking care not to damage the plant roots and water regularly.	Consider other possibilities.
	Is the soil in the polypots mostly dry?	Increase the rate of watering.	The potting mixture may be poor If the plant is small transplant it to a new pot with a better mixture If it is big water dilute fertiliser on to the plants using a watering can.
Plants become	Are the plants kept	Reduce or remove the shades.	Increase the spacing between the plants.

long and thin	under shade?		
Plants have yellow leaves	Is the soil in the polypots very wet?	Reduce the rate of watering.	Add a nitrogen based fertiliser.
Plants have wilting leaves	Is the soil in the polypots dry?	Increase the rate of watering.	Consider other possibilities.
	Have the roots just been pruned?	Wait a week and check again.	Consider other possibilities.
	Have there been gusty winds recently?	Wait a week and check again.	Consider other possibilities.
	Are there signs of attack by insects or fungus?	Spray with the most appropriate insecticide.	The potting mixture may be poor If the plant is small transplant it to a new pot with a better mixture If it is big add fertiliser.
Small plants	Does it look like damping	Reduce watering and shading.	Consider other possibilities.

suddenly start to die off	off described in Section 4.6 (p104)?		
	Is there evidence of other fungal attacks (white hairs growing on the plants)?	Reduce watering and shading.	Consider other possibilities.
	Is the soil very wet?	Reduce watering.	Consider other possibilities.
	Do the plants look rotten?	There may not have been enough ventilation leading to excessive humidity on hot days Ensure that air can flow under the sides of the shades Remove the shades more.	Look for signs of insect damage to the roots and treat the plants accordingly.
Excessive growth	Are roots growing into the ground below the bed?	Prune the roots level with the bottom of the pots.	Reduce the amount of water and increase the amount of shade.
BAMBOOS			
More than 25 percent	Is the soil moist and	Look at other possibilities.	Increase the amounts of water and shade.

of cuttings fail to grow	shady all the time?		
	Are there signs of insects especially termites attacking the cuttings?	Re plant with new cuttings flood the beds again and check carefully every day for the next week If the termites or other insects persist excavate the cuttings carefully and sprinkle Aldrin dust around the cutting Reduce the watering and observe carefully over the next week If all is well then increase the watering again. **Take care: Aldrin is highly poisonous.**	The nutrient status of the bed may be poor Improve the depth and quality of soil in the bed and re plant the failures.
Poor growth	Is the soil deep and stone free?	The nutrient status of the bed may be poor Add fertiliser.	Improve the depth and quality of soil in the bed and re plant the cuttings.

Troubleshooting

All nurseries, however well run, experience difficulties at some stage. To assist in detecting problems, a troubleshooting chart is given in Figure 4.11. While this covers the most common problems, always bear in mind that there are exceptional circumstances. If you cannot resolve a problem, call the Geo Environmental Unit for specialist advice.

4.7 Seed collection, treatment and storage

Seed collection, treatment and storage are a skilled business. Care has to be taken in order to ensure that you get material of good quality as a basis for a bio-engineering programme.

Seed collection: basic considerations

Start by choosing carefully the location and actual plants from which you collect seeds.

- **Collect seeds from plants growing in sites similar to the ones you are going to plant the seedlings on.**
- **Collect seeds from plants with the characteristics you want (*e.g.* good rooting): seedlings grow like their parents.**
- **All seed plants should be healthy and growing vigorously.**
- **Always collect seed from at least 10 plants, to increase the genetic diversity.**

If you have to order seed from elsewhere, give as many details as possible about the planting site (altitude, rainfall, soil) and also how many seedlings will be needed. Ask the supplier to match these considerations as closely as possible.

Keep a register of all sources of seed within your working area, with details of the species, area of the stand (or number of plants), and location. This register will help you plan seed collections. A form for this is given in Annex C.

Keep seed from very different sources separate, *i.e.* sources that are several kilometres apart. Never mix new collections with seed from previous years. Label every seed lot properly with species name, date of collection, location, and the number of seed plants.

Calculating how much seed to collect

Because of natural uncertainties, you need to obtain and sow many more seeds than the actual number of seedlings required. If the seed collectors manage to collect more seed than is needed, do not waste it by sowing too much in the nursery, or storing it carelessly. Seed supplies are always difficult and there may be other nurseries that could use it. Tell the Geo-Environmental Unit, the Regional Director's Office, and other Divisions and Projects. Someone else may well be able to use it.

Calculation of grass seed requirements

It is normal in bio-engineering to sow grass seeds at the rate of 25 g per sq. m. This covers all expected natural losses. However, in case the first seeding fails, it is normal to ensure adequate supplies for a separate complete seeding. Therefore aim to collect seed according to this equation:

Seed required (kg) = area to be seeded (sq. m)/20.

Calculation of shrub and tree seed requirements

It is normal practice to grow 25 per cent extra seedlings and discard the poorer plants when they leave the nursery. It is also normal to allow four times the

amount of seed for the total number of seedlings to be grown. Therefore, for every one seedling to be used on site, five seeds should be obtained and sown.

Figure 4.12 shows as an example the quantity of seeds required to grow 5,000 each of utis and khote salla trees.

The tables in Annex B give the average numbers of seeds per kilogramme for all the bio-engineering species. Once you know the number of seeds required, you can easily calculate the weight of dry seeds to be collected.

Collecting and treating grass seeds

In bio-engineering it is normal to collect and use the whole seed head of grasses. The procedure is as follows:

- **Collect the seed heads when they are ripe. Bring them back to the camp or nursery in dokos or hessian sacks. If you use polythene bags, empty them out as soon as possible so that they do not go mouldy.**

- **Spread the seed heads out to dry in sheltered, sunny places, on a clean concrete or hard earth floor.**

- **Separate them from stems and other unwanted parts in the ways normally used for grains. Since the seeds of bio-engineering grasses are mostly very fine, take great care when winnowing.**

- **Store them in hessian or polythene bags in a dry, well ventilated place. If you use polythene bags, make sure that the heads are completely dry or**

they will go mouldy.

- **Most grass seeds will remain viable[1] for several years, but you should use them within one year if possible.**

  [1] Viability is the length of time that the majority of seeds remain able to germinate. After a certain period of storage, seeds will not germinate once sown. This varies for each species, and approximate viability periods are given in the tables in Annex B.

Collecting shrub and tree seeds

Tree climbing

Climbing trees to collect seeds is dangerous and must be done carefully, so as to avoid accidents. Falling from trees is a common accident and your collectors should be especially cautious while collecting seeds. Local methods can be safe if properly supervised. Follow these guidelines for safety:

- **only employ seed collectors if they like climbing;**
- **only use strong and healthy collectors;**
- **collectors should work in twos; then if one needs help, the other can go and get it;**
- **only healthy trees with strong branches should be climbed;**
- **while picking fruits, the climber should be tied to the tree whenever possible;**
- **proper fruit cutting tools with long handles (see below) should be used,**

so that there is no need to cut off large branches.

If seed must be collected from very large trees that are dangerous or difficult to climb by local methods, contact the Geo-Environmental Unit or the local Department of Forests office for advice. Special equipment (spurs, safety belts and ropes) and trained seed collectors may be available. It may be useful for someone in your area to receive such equipment and training, which is sometimes given by the Department of Forests.

What fruits to harvest

Collect only ripe fruits. If fruits are collected too early, the seed may be immature and weak. If you delay collection too long, the seed may be eaten by birds, or attacked by insects or fungi. Pick fleshy fruits just as they turn from green to their ripe colour. Pick dry fruits that open just before they open. Test the ripeness of seed by cutting the fruit open and looking at the inside of the seeds. They should be firm and white, and completely fill the seed coat. The seed coat should usually be dark and hard.

Do not collect fruits that are unhealthy or attacked by insects. For this reason avoid fruits that have fallen to the ground.

How to harvest the fruits

Harvest the fruits without damaging the tree, so that it can produce again in the following years. Whenever possible, take only the fruits or the small twigs bearing them. Try not to tear them off, but cut or break them cleanly. Unless it is absolutely necessary, do not allow seed collectors to cut whole branches with a

khukuri or hasiya.

Good seed-collection tools include:

- **A hook for bending branches towards the collector. Fix a metal hook to a wooden handle 2 m long. Provide a 2 m length of rope so that the climber can tie the hook and the branch to himself, so that he has both hands free to pick the fruits and put them in the collecting bag, A strongly made hook can also help in climbing the tree.**

- **If it is necessary to break off the ends of branches with the fruits attached, a 'wedge knife' will work well. This can be made in any large bazaar. It should be bolted or tied with wire to a light, long wooden or bamboo pole (up to 4 m). The collector places the tool over the branch end and pulls it. The branch may slice off easily, but if it is woody, the knife may have to be twisted to snap the branch.**

- **A collecting bag can be made from a strong hessian sack, which has been made shorter and has a draw string to close the mouth easily. When full, the bag is closed and thrown to the ground.**

Figure 4.12: Example of tree seed calculations

S No	DETAIL	UTIS	KHOTE SALLA
[1]	Number of plants needed	5,000	5,000
[2]	Number of plants to be produced: [1] × 1.25	6,250	6,250
[3]	Number of seeds needed: [2] × 4	25,000	25,000

[3]	Number of seeds needed: [2] x 4	25,000	25,000
[4]	Seeds/kg	1,350,000	10,000
[5]	Seeds/g	1,350	10
[61	Grammes of seed required: [3] / [5]	18.5	2,500
[7]	Seed order	20 g	2.5 kg

Wait for seed to ripen properly before picking it from the tree

The best material for long handles is one-inch aluminium tube with thick walls, which can be purchased in large bazaars. Otherwise, use well dried wooden or bamboo poles.

If it is difficult to gather the fruits by hand in the tree, they can be allowed to fall to the ground and be gathered by an assistant. Clearing the ground of vegetation may help. The assistant should wear a strong hat as protection from falling fruit and twigs. It is safer to wait until the climber has finished his work.

Transport and storage of fruits

Store and transport fruits in cloth or hessian sacks. Do not put them in polythene bags, as they will get warm and mouldy very quickly, spoiling the seeds inside. Always store the sacks in the shade. Keep them cool, dry and off the ground by placing them on planks of wood, or by hanging them.

When to collect seeds

You need to know the dates for seed collection in order to get good results. Details are given in the tables in Annex B, as far as they are known, for all of the bio-engineering species. Remember that these give an approximate guide only, and there is always some local variation. Every month, you should check which species are due to ripen, so that you do not forget to arrange for their collection.

As part of the routine planning of a bio-engineering programme, you should establish a seed collection calendar for your Division or Project. A form for this purpose is given in Annex C.

Before the collecting season of a species starts, the person responsible should keep a regular check on how the fruits are ripening. In some years, fruits will ripen earlier than usual, and in other years they may ripen later. As a general rule, fruits tend to ripen later in the west than in the east, and are also later at higher altitudes.

Processing and storing shrub and tree seeds

Seed processing following collection

Most seeds need to be removed from their fruits before sowing or storage.

Separate them carefully to avoid damaging the seeds. Although they may look inert and tough, heat, moisture, physical breakage, fungi, insects, etc can easily damage them. Try to extract the seeds as soon as possible after collection, unless recommended otherwise.

The pods of many leguminous species (*e.g.* sisau, khayer, areri and the siris species) are brittle and split easily once they have been dried in the sun. The seeds must be carefully separated from all the pod fragments that result.

Some species (*e.g.* bakaino) have a stone inside a fleshy fruit. The flesh must be removed before storage. This is best done by soaking in water and then rubbing the soft fruits together so that the flesh comes away. Once cleaned, the seeds must be properly dried in the sun.

Fleshy fruits containing many small seeds (*e.g.* khanyu) are separated in the same way, but much more care has to be taken because the seeds are much smaller and more delicate. Again, once cleaned, the seeds must be properly dried in the sun.

Storing seed

If you are sowing the seeds immediately after processing (within a few days), put them in a cloth bag and keep them cool. Never use a sealed container such as a polythene bag, glass jar or tin, as the seed will be too moist and will quickly get warm and mouldy.

If you are keeping the seeds for more than a week (often several months or even a year may be required), store them properly to avoid loss of viability. When the seeds have dried sufficiently, leave them in the sun until the afternoon, and then

put them immediately into a container that can be properly sealed, thus keeping them dry. Do not leave packing until the morning, as the seeds will absorb moisture overnight.

The simplest container is a thick polythene bag, or two thin ones, one inside the other. Squeeze out the excess air, and then tie the neck tightly with string or wire. It is often a good idea to put the bag in a tin box to protect it from being punctured and from rodents that may try to eat the seed. Label and number the containers of seed.

Keep the containers in a cool, dry room. The best place is a well-ventilated ground-floor room on the north side of a two-storey building. Keep the containers off the ground, preferably on shelves half way up the wall. Do not put them in the eaves of a roof, as this will become warm during the day; or directly on a ground floor as this may be damp.

Recalcitrant seeds

Most seeds have to be dried before storage and are called 'orthodox'. But some species have seeds that must be kept moist if they are to remain viable. They are called 'recalcitrant'. If they are dried they will quickly die. These seeds are often found in species that have fleshy fruits which do not dry out on the tree, and which are dispersed just before or during the rains. The species used for bio-engineering which fall into this category are badahar *(Artocarpus lakoocha),* champ *(Michelia champaca),* chiuri *(Aesandra butyracea),* dhale katus *(Castanopsis indica),* chuletro *(Brassaiopsis hainla),* khasru *(Quercus semecarpifolia),* kutmero *(Litsea monopetala),* musure katus *(Castanopsis*

tribuloides),* okhar *(Juglans regia),* patle katus *(Castanopsis hystrix)* and phalant *(Quercus lamellosa).

Always sow this type of seed as soon as possible. If it has to be stored for more than a week, use the following method. Extract the seed from the flesh, do not dry it, but mix it with twice its volume of damp sand. Put this mixture in a tin with a lid, whose sides and bottom have at least 20 small holes (2 mm diameter), made with a nail. After putting in the sand/seed mixture, fill it to the top with damp sand. Dig a hole 1 m deep in a sheltered and well-drained place. Cover the bottom with a layer of damp sand, and put the seed containers on it. Then cover with more damp sand, and fill the rest of the hole with the excavated soil. Mark the spot with a stick. When you require the seed, dig it out. Remove the seed from the sand carefully, as some of it may have started to germinate.

Dry seeds thoroughly before storing them in a container that can be properly sealed

4.8 Assessing the quality of bio-engineering nurseries

The following are some simple indicators for assessing the quality of bio-engineering nurseries. They are not comprehensive.

Grass beds (slip and rhizome cuttings, and grass seeds) and hardwood cutting beds should be:

- **composed of good, fertile, well aerated soil;**
- **kept moist at all times;**
- **showing even growth;**
- **well weeded;**
- **kept with a porous, uncapped soil surface.**

Grass plants should be:

- **a healthy green colour;**
- **growing vigorously, with long new shoots;**
- **showing no signs of wilting;**
- **attack.**

Shrub and tree seed beds should be:

- **composed of good, fertile, well-aerated soil and fine, clean sand;**
- **kept moist at all times;**

- **well shaded;**
- **showing even growth;**
- **well weeded.**

Polypot seedlings should be:

- **a bright, healthy colour;**
- **showing no signs of wilting;**
- **growing fast, with long new shoots;**
- **kept with roots pruned; kept moist throughout the soil cylinder;**
- **well weeded;**
- **without signs of discoloration on the leaves;**
- **without signs of insect attack on the leaves or shoots (*e.g.* holes eaten in the leaves);**
- **without any obvious signs of disease;**
- **undamaged.**

Whole nurseries should be:

- **kept tidy and clean;**
- **weeded throughout;**
- **well maintained;**
- **protected properly at all times.**