Establishment of grasses on roadside debris slopes

K. C. Paudel[1], J. H. Howell[2] and B. P. Tripathi[3]

A factorial experiment was conducted to evaluate the effect of fertilisers and materials on the establishment of indigenous grass species on roadside debris slopes. Two debris slopes were used in the experiment: one on uncompacted fill and the other in an original cut slope. Performance of grass establishment was compared among three species: phurke (*Arunduella nepalensis*), kans (*Saccharum spontaneum*) and babiyo (*Eulaliopsis binata*); and four level of inorganic fertilisers: control, minimum (NPK 80:40:40), medium (NPK 120:80:80) and maximum (NPK 240:120:120). Soil analyses showed a poor nutrient status at both sites, with a high volume of stones (at least 50%). The overall survival of grass in the fill slope was 99% and in the cut slope was around 90%. No effects of inorganic fertiliser applications were evident on survival, plant height, ground coverage, or grass production. However, *Saccharum spontaneum* attained highest growth (128 cm), grass production (264 g DM/plot) and root development, when compared with both *Eulaliopsis binata* and *Arunduella nepalensis*. The latter had the poorest plant height (39 cm), grass production (19 g DM/Plot) and root development. Grass growth was better on the fill slope near Lumle, compared with the cut slope near Baglung. It is clear that *Saccharum spontaneum* and *Eulaliopsis binata* can be established successfully on roadside debris materials without the addition of inorganic fertilisers.

Keywords : *Arunduella nepalensis, Eulaliopsis binata, Saccharum spontaneum,* bio-engineering, road side stabilisation, NPK, Nepal.

The use of living vegetation, either alone or in conjuction with civil engineering structures, to reduce shallow-seated instability and erosion on slopes is called bio-engineering. It has been practised in the Nepali road sector for about fifteen years (Meyer, 1987; Howell *et al.*, 1991). Various techniques of using grasses have been developed specifically for local conditions. Studies on the rooting characteristics of grasses (Clark, 1992; Sunwar, 1993) have added to the general body of information on bio-engineering as described in standard works such as Coppin and Richards (1990), Morgan and Rickson (1995), and Schiechtl and Stern (1996).

Most of the studies worldwide have in fact concentrated on the physical characteristics of rooting in relation to slope stabilisation. Few have examined in detail the nutritional requirements, partly because this is a very site-specific characteristic. Some operations (*eg* IRI Research Institute, 1994) have used techniques of soil enrichment to great advantage in other parts of the world. In Nepal this has not been tried so far. The technique of mulching, while advocated by some manuals (*eg* ITECO, 1990), in practice rarely works on very steep slopes under intense monsoon rainfall (Howell *et al*, 1991).

The range of grass species used in the Nepal road sector (ERRM, 1995; Geo-Environmental Unit, 1998) concentrates on indigenous plants well adapted to the dynamic, heavily leached soils of the southern Himalaya. Most of the species are natural colonisers of bare and inhospitable sites, including semi-stable landslide debris. These species have to be common locally and are often widely used by villagers to make thatch, rope, brooms or other items. These are usually harvested from marginal land or forests. In such places the grasses are encouraged by farmers but are not directly cultivated. While these grasses appear to thrive naturally in poor sites, observations show that in certain locations very slow growth rates are experienced. Using only visual observation, it has not been possible to attribute the cause of this to any single factor. While rooting conditions, particularly the difference between "hard" natural undisturbed slopes and "soft", recently filled man-

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made slopes may be important, the role of nutrition is unknown. Site-soil studies of mountain forest soils (*eg* Howell, 1988) show little relationship between measurable soil nutrition parameters and plant growth. However, there are no records of trials where fertilisers have been added to improve the growth of grasses in such situations.

If the species selected for bio-engineering are to be used more widely than before, particularly on very poor and critical sites, it is necessary to build up a profile of their preferred site requirements. If the establishment and early growth (and therefore their contribution to soil conservation) can be significantly improved by adding nutrients, it would help to reduce the time between the grasses being planted and reaching a stage of effectiveness.

As well as being useful in controlling erosion, the better establishment of grasses on debris slopes and in other marginal areas can yield valuable additional products for farmers, thereby contributing to household incomes. Since an ultimate aim would be to carry out such activities at farmers' participatory level, a study of the effects of FYM might be desirable. However, since FYM is difficult to apply effectively to grass slips on steep slopes, and is variable in its nutritional content, inorganic fertilisers offer better potential for effective application.

This experiment was conducted as a collaborative project between the Nepal/UK Road Maintenance Project, Department of Roads, and the Forestry/Pasture Section of Lumle Agricultural Research Centre. The formal reference of the trial record has been published by Paudel, Howell and Tripathi (1998).

Methods

The trial was designed to test the performance of different grasses on two different debris (defined as "any material, disturbed by natural or human processes, which shows no soil formation features other than weathering") .slopes, under a range of fertiliser application regimes. Both slopes were unvegetated prior to the trial. One was a slope in the Humla section of the Lumle farm area, where debris from a slope failure above the road had been deposited downslope without compaction. The other was a cut slope on the higher side of the road, near the Bangechaur turning below Baglung. The Lumle site is at an altitude of approximately 1700 metres and receives an average annual rainfall slightly greater than 5000 mm; Bangechaur is at an altitude of about 800 metres near the Kali Gandaki river, and receives around 1800 mm of rain per year.

Native forest grasses with clump-forming habits are preferred for bio-engineering, and three species commonly used in the road sector were chosen: phurke (*Arunduella nepalensis*), kans (*Saccharum spontaneum*) and babiyo (*Eulaliopsis binata*).

The trial was designed as a factorial randomised complete block design with three replications in each site (fill slope and cut slope). As well as testing each of the three species separately, the fertiliser doses were also factored as follows:

(a)	Control (no fertiliser)	
(b)	NPK minimum dose	80:40:40
(c)	NPK medium dose	120:80:80
(d)	NPK maximum dose	240:120:120

Grass slips were prepared in nursery beds in advance of the trial. The slips were lifted, prepared and planted into drills as per the usual bio-engineering specification (Geo-Environmental Unit, 1997), once the summer monsoon rains had become continuous enough to ensure growth. Each replicate plot consisted of 24 planting drills at 25 x 10 cm spacings. There was a gap of at least 25 cm between plots. Fertiliser was added in the planting holes during plantation.

Standard soil analyses (particle size analysis, pH, N, P, K, organic carbon and exchangeable cations) were made for the sites, for each of three composite samples taken from each site at the time of establishment of the trial.

The observations recorded are as follows:

- Date of planting
- Survival/mortality count of each clump at three monthly intervals for fifteen months
- Slip height/length at survival count time
- Area cover of grass measured by size of clump foliage at measurement time
- Usable grass production dry matter weight three months after establishment
- Final total dry matter weight fifteen months after establishment
- Measurement of root systems fifteen months after establishment

The trial was run for fifteen months (June 1996 to September 1997) corresponding to two monsoon growing periods. The measurement of plant height was done using tapes, and root numbers and length through destructive sampling at the end of the experiment. The study on the effects of applied fertilisers on the rooting systems of planted grasses was carried out by counting the number of roots per clump and the length of the longest root per clump, both at the end of experiment in September 1997, by carefully uprooting the sample clumps (*ie* 8 clumps per plot). Although complete uprooting without disturbing the root system in debris materials was not possible, it gave a rough idea of the root systems of the plants.

Area coverage was measured in two ways. An ocular estimation of the spread of each planted grass clump was made against a scale of 1 to 5 (1 = <20%, 2 = 20 - 40%, 3 = 40 - 60%, 4 = 60 - 80% and 5 = >80%). A cover of 100% was recorded where two adjoining clumps touched at ground level. More specific measurements of ground area coverage were recorded by counting the total number of culms per slip planted, by sampling at the end of the trial. The eight middle clumps in each plot were counted, discarding all boarder rows. Analysis of variance was calculated using the package INSTAT.

Results

Survival of planted grass slips

The survival of the planted grass species at both sites was over 90% (Table 1). The effects of site on survival were found to be significant (P = 0.000). *Arunduella nepalensis* had a relatively low survival rate on the cut slope near Baglung. This site receives relatively low rainfall compared with the fill site at Lumle (which receives over 5000 mm/yr).

Any difference in the interaction between site and fertiliser application would be obscured by the distinct material and environmental variations between the two sites. No attempt was therefore made to analyse this interaction.

Table 1 : Survival rates of grasses by site after fifteen months

Grass species	Survival rates, %	
	Fill slope, Lumle	Cut slope, Baglung
Arunduella nepalensis	99	83
Saccharum spontaneum	100	93
Eulaliopsis binata	99	94

No effects of fertiliser were evident on survival rates at either site. The effects of the different doses of inorganic fertiliser on these species, in terms of survival, is presented in Table 2.

Plant height/length of grass slips

The height of the grasses four months after planting differed significantly (P = 0.011) kans had grown 58 cm compared to 53 cm for babiyo and 39 cm for phurke. These are shown in Table 3. The effect of the two sites was also significant (P = 0.034): the fill slope had better growth than the cut slope. But the effect of fertiliser application on growth was not significant (P = > 0.54).

The grass species were cut at ground level in late October 1996 to measure biomass and to avoid forest fire and grazing damage. The plant heights were re-measured at the end of the next growing season, in September 1997. The growth of all species was better on the fill slope (P=0.000). *Saccharum spontaneum* had a significantly better mean height (128 cm), followed by *Eulaliopsis binata* (93 cm) and *Arunduella nepalensis* (53 cm). However, as Table 4 shows, the effect of the fertiliser was not significant. It was obvious that the growth of the plants improved in the second growing season.

Table 2 : Effect of different fertiliser doses on survival rates (5 surviving) of grasses on both sites after fifteen months.

Grass species		Fertiliser dose				
		Control	NPK 80:40:40	NPK 120:80:80	NPK 240:120:120	Species mean
Arunduella nepalensis		87	99	89	90	91
Saccharum spontaneum		95	96	99	95	96
Eulaliopsis binata		97	95	96	96	96
Fertiliser mean		93	97	94	94	94
SEM (spp)	2.025	SEM (Fert)	2.338		SEM (Fert × spp)	4.049
SED (spp)	2.863	SED (Fert)	3.306		SED (Fert × spp)	5.726
SEU (59 df)	9.9					
CV	10.5					

Table 3 : Effect of fertiliser on grass growth (height in cm) after four months planting, both sites combined.

Grass species	Fertiliser dose Control	NPK 80:40:40	NPK 120:80:80	NPK 240:120:120	Species mean
Arunduella nepalensis	33.0	41.4	39.0	45.1	39.5
Saccharum spontaneum	54.4	62.7	60.1	58.6	58.2
Eulaliopsis binata	47.9	54.6	61.1	47.6	52.8
Fertiliser mean	44.08	52.9	53.2	50.4	50.1

SEM (spp)	4.348	SEM (Fert)	5.021	SEM (spp × fert)	8.696
SED (spp)	6.149	SED (Fert)	7.1	SED (spp × fert)	12.300
SEU (59 df)	21.3				
CV	42%				

Table 4 : Effect of fertiliser on height growth (cm) in the second growing season, both sites combined.

Grass species	Fertiliser dose No fertiliser	NPK 80:40:40	NPK 120:80:80	NPK 240:120:120	Species mean
Arunduella nepalensis	54	49.4	55.9	53.1	53.0
Saccharum spontaneum	124.0	141.6	119.6	126.6	127.9
Eulaliopsis binata	81.6	101.6	92.5	59.7	92.9
Fertiliser mean	86.4	97.5	89.3	91.7	91.2

SEM (spp)	4.888	SEM (Fert)	5.645	SEM (spp × fert)	9.777
SED (spp)	6.913	SED (Fert)	7.983	SED (spp × fert)	13.83
SEU (59 df)	23				
CV	26%				

Ground cover

Area coverage was influenced by site (P = <0.000) and species, but not by fertiliser (P = 0.879) or its interaction with species (P = 0.935) and site (P = 0.999). The greatest area coverage was attained by *Saccharum spontaneum* on both sites. It covered 98% on the fill slope and 66% on the cut slope. *A. nepalensis* and *E. binata* did not differ significantly in terms of ground area coverage in 15 month period.

The effect of fertilisers on new culm production (tillers) was not significant (P = 0.747). However, the number of tillers per clump was influenced by site (P = 0.000) and species (P = 0.001). *S. spontaneum* and *E. binata* developed 24 and 27 of tillers per clump respectively (from about 4 to 6 each at the time of planting), whereas *A. nepalensis* had only 16. The fill slope at Lumle showed much better grass growth, with an overall mean number of tillers per clump of 30, compared with 14 on the cut slope near Baglung. The interaction between site and species was not highly significant at the 5% level (P = 0.571). *Arunduella nepalensis* was clearly not suited at the Baglung site. Details of the number of tillers per clump are presented in Table 5.

Grass production

Usable grass production was recorded in October 1996 after one growing season, as well as at the end of the experiment in September 1997. Because of minor damage to the cut slope site, the grass production data for October 1996 were not analysed. However, total grass production (measured in grammes of dry matter per plot) recorded at the end of the trial showed that more biomass was produced on the fill slope (220 g/plot) than on the cut slope (165 g). The effect of fertiliser was not significant (P = 0.386) in grass production. The productivity of each of the species by site, irrespective of fertiliser doses, is shown in Table 6.

Rooting systems of grasses

The effect of fertiliser was not significant in terms of the number of roots formed or their lengths. However, all the species produced more extensive structures in the fill slope than in the cut slope. This could be due to either environmental conditions or soil compaction, or more likely, a combination of both. Kans and babiyo developed almost equal numbers of roots per clump (57 and 56 respectively), while phurke developed 45 roots per clump.

Table 5 : Mean number of tillers per clump at cut and fill slopes, fifteen months after planting.

Grass species	Site		Species mean
	Fill slope, Lumle	Cut slope, Baglung	
Arunduella nepalensis	25.8	6.5	16.8
Saccharum spontaneum	32.3	16.5	24.4
Eulaliopsis binata	33.4	19.9	26.7
Slope mean	30.5	14.3	22.6

SEM (Site)	1.585	SEM (spp)	1.941
SED (Site)	2.241	SED (spp)	2.745
SEU (57 df)	9.5		
CV	42%		

Table 6 : Dry matter grass production (means, g/plot).

Grass species	Site		Species mean
	Fill slope, Lumle	Cut slope, Baglung	
Arunduella nepalensis	149	34	91.5
Saccharum spontaneum	251	276	264
Eulaliopsis binata	261	186	223
Slope mean	220	165	192

SEM (spp)	15.79	SEM (site)	220.6	SEM (site × spp)	22.34
SEd (spp)	22.34	SED (site)	165.8	SEd (site × spp)	31.59
SEU (57 df)	77.3				
CV	40%				

Table 7: Mean number of roots per clump of grass species at both sites combined, fifteen months after planting.

Grass species	Fertiliser				Species mean
	No fertiliser	NPK 80:40:40	NPK 120:80:80	NPK 240:120:120	
Arunduella nepalensis	43.3	40.7	39.4	55.0	44.6
Saccharum spontaneum	67.5	55.1	43.5	64.0	57.5
Eulaliopsis binata	57.0	63.4	48.0	56.6	56.2
Fertiliser mean	56.0	53.1	43.6	58.5	52.7

SEM (spp)	3.548	SEM (fert)	4.097
SED (spp)	5.017	SED (fert)	5.794
SEU (57 df)	17.37		
CV	32 %		

Similarly, the mean lengths of roots observed were longest in kans (51 cm), followed by babiyo (42 cm), and was shortest in phurke (37 cm). The longest root recorded was over 100 cm in a kans clump on the fill slope. Details of the rooting systems are presented in Tables 7 and 8.

Soil analysis of trial sites

Physico-chemical properties of the soils at the two sites were analysed just before the trial was established. Both sites were poor in soil nutrient status and had high volumes of stones (at least 50%). The results of the analyses are presented in Table 9 and 10.

Conclusions

The sites used for the experiment were poor in soil nutrient status. Despite this, the application of chemical fertiliser to three species of grasses planted on both cut and fill slopes was not found to be effective, if applied at planting time. Grass growth was better on the fill slope at Lumle, compared to the cut slope near Baglung. This may be due to the better rooting conditions in the less compacted material of the fill slope. However, it may equally be the result of site conditions: Lumle, although cooler, has a much higher rainfall than Baglung.

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Table 8: Root growth (cm) of grasses at both sites combined, fifteen months after planting.

Grass species	Fertiliser				
	Control	NPK 80:40:40	NPK 120:80:80	NPK 240:120:120	Species mean
Arunduella nepalensis	38.1	32.0	38.0	41.2	37.3
Saccharum spontaneum	31.2	58.0	48.0	48.6	51.4
Eulaliopsis binata	39.1	45.3	40.5	44.0	42.2
Fertiliser mean	42.8	45.0	42.2	44.6	43.6
SEM (spp)	2.417	SEM (fert)	2.791		
SED (spp)	3.418	SED (fert)	3.947		
SEU (57 df)	11.8				
CV	27 %				

Table 9 : Soil chemical analyses (before trial establishment).

Analysis	Fill slope, Lumle	Cut slope, Baglung	Comments
pH	6.1	7.3	Baglung site unusually high for Nepal
Organic matter (%)	0.85	1.09	Very low
Organic carbon (%)	0.49	0.72	Very low
Total N (%)	0.01	0.02	Very low
Available P (ppm)	29.00	1.00	Lumle site high; Baglung site very low
Exchangeable K (me/100g)	0.08	0.06	Very low
Available B (ppm)	0.31	0.34	Low

Table 10 : Percent of stones in the fill slope material (Humla block, Lumle).

Species	Fertiliser			
	F1	F2	F3	F4
S1	58.1	56.9	53.4	62.4
S2	55.8	58.7	51.5	48.5
S3	49.0	50.2	54.8	49.8

Factor A (fertiliser dose):		Factor B (species):
F1 Control (no fertiliser)		S1 *Arunduella nepalensis*
F2 NPK minimum dose	80:40:40	S2 *Saccharum spontaneum*
F3 NPK medium dose	120:80:80	S3 *Eulaliopsis binata*
F4 NPK maximum dose	240:120:120	

Saccharum spontaneum showed the best growth and root system development at both sites, followed by *Eulaliopsis binata*. Phurke (*Arunduella nepalensis*) showed both poorer growth and a less extensive rooting system. Phurke tends to form smaller clumps and to be slower to develop. It was clearly not suited to the environmental conditions at the site near Baglung. The factors limiting later growth are still not clear, however. Certainly lack of moisture is the main limiting factor for much of the year, compounded by low temperature during the winter. Rooting conditions are poor in roadside debris sites, to the extent that the root growth even of hill pioneer plants may be physically restricted. Nutrition may become limiting during the monsoon, once the initial flush of nutrients has been leached. As the soil analyses in this trial have shown, there are few chemical sites for nutrients to reside on, particularly with such a small proportion of clay and a low fraction of organic matter. Even with the rapid release of nutrients normally expected during the warm, humid conditions of the monsoon, growth is likely to be slowed if nutrients are not abundantly available during this period.

This experiment appears to demonstrate that, within the correct climatic zones, kans and babiyo can be established successfully on roadside debris materials without the addition of fertilisers. Further research is needed to see if growth can be improved through application of a top dressing once grasses are established. This might be applied about one month after the onset of the monsoon. A straightforward and practical application might be to spray a solution of chemical fertiliser on to established plants. This could be undertaken even in steep and difficult roadside sites.

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References

Clark, J E, 1992. *Principles of Bioengineering with Reference to East Nepal.* PhD Thesis, Cranfield University, UK.

Coppin, N J and Richards, I G, 1990 (eds). *Use of Vegetation in Civil Engineering.* CIRIA, London.

IRI Research Institute, 1994. *Vegetation to Control Soil Erosion in Civil Works.* IRI Research Institute Inc, Connecticut, USA.

ERRM (Eastern Region Road Maintenance), 1995. *Guidelines for the Preparation of Bio-Engineering Contracts.* ERRM, Department of Roads, Kathmandu.

Geo-Environmental Unit, 1997. *Bio-engineering Information*, Second Edition. Department of Roads, Kathmandu.

ITECO, 1990. *Handbook for Bio-Engineering Methods in Gully and Landslide Stabilization Works.* Lamosangu-Jiri Road, Charnawati Rehabilitation Programme Phase III, ITECO/SDC/HMGN, Affoltern.

Howell, J H. 1988. Site and soil studies of xxx Soil Survey Report No xxx Forest Research and Information Centre, Kathmandu.

Howell, J H, Clark, J E, Lawrance, C J and Sunwar, I, 1991. *Vegetation Structures for Stabilising Highway Slopes.* Eastern Region Interim Project, Department of Roads, Kathmandu.

Meyer, W P, (ed), 1987. *Vegetative Soil Conservation Measures: a Field Manual.* Tinau Watershed Project, GTZ/Helvetas, Tansen, Nepal.

Morgan, R P C and Rickson, R J, (eds), 1995. *Slope Stabilization and Erosion Control: A Bioengineering Approach.* E & F N Spon, London.

Paudel, K C, Howell, J H and Tripathi, B P, 1998. Establishment of Grasses on Debris Slopes. LARC Working Paper No 98/5. Lumle Agricultural Research Centre, Kaski, Nepal.

Schiechtl, H M and Stern, R, 1996. *Ground Bioengineering Techniques.* Blackwell Science, Oxford.

Sunwar, I, 1993. *Comparison of Two Root Architectures for Bioengineering Purposes.* Diploma Thesis, Cranfield University, UK