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Effects of vegetation cover on runoff and erosion under simulated rain and overland flow on a rehabilitated site on the Meandu Mine, Tarong, Queensland

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Abstract

This research was carried out to quantify the role of vegetative cover in reducing runoff and erosion from rehabilitated mined land. Duplicate plots 1.5 m wide and 12 m long were prepared on a rehabilitated area of the Meandu Mine, Tarong, with vegetative cover of 0, 23%, 37%, 47%, and 100%. The area had a uniform 15% slope, and there were no rill or gully lines present. Simulated rain equivalent to a 1 : 100 year storm was applied to the plots, and runoff and erosion were measured.

Infiltration totals and rates increased strongly with increasing vegetative cover. There was visibly greater infiltration under vegetation. Erosion from the simulated storm was greatly reduced by vegetative cover, declining from 30–35 t/ha at 0% vegetative cover to 0.5 t/ha at 47% cover. Reductions in erosion at lower levels of vegetative cover were greater than predicted by the cover/erosion relationship used in the USLE. The dominantly stoloniferous growth habit of the grass at this site may have increased the effectiveness of vegetative cover in this study.

To allow the data to be extrapolated to slopes longer than 12 m, a series of overland flows were applied to the upslope boundaries of the plots, simulating flows on slopes up to 70 m long. Detachment and transport of sediment by applied overland flow was similarly reduced by vegetative cover, and results from the overland flow study also indicate that for slopes up to 70 m long with grass cover of 47% or greater, erosion rates will be minimal, even under extreme rainfall/runoff events.

Additional keywords: mine rehabilitation, erosion processes, sediment size, infiltration, USLE, *C*-factors.

Introduction

Environmental management policy for mining in Queensland (Department of Mines and Energy 1995) seeks 'to achieve:

- acceptable post-mining land use capability/sustainability
- stable post-mining landform(s), and
- preservation of downstream water quality'.

Establishment of vegetation on land disturbed by mining is widely perceived as a major factor in achieving these objectives. Studies of runoff and erosion in agricultural and pastoral areas have shown that vegetative cover greatly reduces runoff and erosion (Mannering and Meyer 1963; Freebairn *et al.* 1986; McIvor *et al.* 1995), and similar benefits of revegetation could be expected for minesites. However, because of the considerable costs involved in re-shaping land for rehabilitation, there is considerable potential advantage in being able to quantify the potential impacts of vegetative cover, and in being able to identify the most effective forms of vegetative cover.

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Reductions in runoff have been attributed to a combination of soil water depletion by growing plants (Freebairn *et al.* 1986), protection of the soil surface from raindrop impact and surface sealing (Foley *et al.* 1991), and the role of plant roots and soil fauna in creating pores for water entry into the soil (Bridge *et al.* 1983; Loch and Orange 1997). Reductions in erosion are attributed to growing plants and plant residues providing protection of the soil surface from raindrop impacts and overland flow, and to binding together of soil by roots.

A relationship between cover and soil loss ratio (ratio of soil loss from a soil with cover to soil loss from an equivalent bare soil slope) was developed for the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). That relationship is used in soil loss prediction for a wide range of soils and in a range of erosion models including CREAMS (Knisel 1980) and AGNPS (Young *et al.* 1987). The relationship between cover and soil loss ratio is used to estimate *C*-factors for the equation. However, experience in eastern Australia indicates that the USLE cover/soil loss relationship may underestimate reductions in erosion associated with vegetative cover, especially in the range 0–30% (Freebairn *et al.* 1989; Rosewell 1990). There is little information on the effects of vegetative cover on runoff and erosion for rehabilitated mined land that would enable assessment of *C*-factor estimates for that situation.

This study of effects of vegetative cover on runoff and erosion was carried out on the Meandu Mine, Tarong, to provide quantitative information on the impacts of vegetative growth on runoff and erosion from rehabilitated mined land for a site with relatively well-structured, low-clay topsoil.

Methods

Location

The study was carried out on the Meandu Mine, Tarong (26°31′S, 151°55′E), in southern Queensland. The experimental site selected was on the King 1 area of the mine, where vegetation had been established in the spring of 1993. The site had been topsoiled, using a grey sandy loam with approximately 27% clay and 12% silt, developed on sandstone. Topsoil depth ranged from 15 to 30 cm. The underlying material was a sandstone spoil. The study site was a uniform 15% slope.

Vegetative cover

Vegetation established on the slope studied was dominantly grass: Rhodes grass (*Chloris gayana*) and kikuyu (*Pennisetum clandestinum*) being the dominant species. Some tree seedlings and weeds were also present. After 2 growing seasons since rehabilitation, vegetative cover was close to 100%, and at the time of the rainfall simulator study, measurements of standing dry matter at the site ranged from 5.9 to 7.3 t/ha.

To enable study of a range of cover levels, an area of visually similar vegetation (and therefore, probably uniform soil) was selected, and plots were marked out. Levels of cover lower than 100% were created by removing different proportions of vegetation from the plots, and tilling the areas where vegetation was removed to destroy any macropores that may have been formed in those areas. Seedling growth on bared areas was controlled using herbicide during the period October 1994 to April 1995 to allow the areas that had been disturbed to consolidate under rainfall. Monthly rainfalls from plot preparation through to the experimentation in early April were: October 40.1 mm, November 10.4 mm, December 30.3 mm, January 166.3 mm, February 166.3 mm, and March 178.2 mm.

At the time of experimentation, the range of plant cover available on the plots that had been prepared was (approximately) 23%, 37%, 47%, and 100%. These cover levels were higher than intended, with the increased cover being due to growth of grass seedlings on the bared areas on all plots, with Rhodes grass stolons being particularly noticeable. There had been little consolidation by rain of soil tilled in October 1994, which was consistent with the observed minimal consolidation of soil on areas undisturbed since rehabilitation in 1993. To create a bare (reference) treatment, 2 plots were freshly tilled and raked at the time of rainfall simulation to remove grass stems and roots and were used as a 0% vegetative cover treatment (they had 3% surface cover by stone). For considerations of soil erodibility for the USLE, the ‘standard’ surface condition is defined as continuous fallow, free of weeds, and this was clearly interpreted as representing a freshly tilled surface (see methods described by Barnett 1977). Logically, this same freshly tilled surface free of weeds represents the ‘bare’ condition on which soil loss ratios (or *C*-factors) in the USLE are based.

Rainfall/runoff simulation

Simulated rain and overland flow were applied to duplicate plots of each treatment. The rainfall simulator produced ‘rain’ from flat fan Veejet 80 100 nozzles, with oscillation of a manifold causing the fan sprays to sweep to and fro across the plot. Kinetic energy of the ‘rain’ produced was approximately 29.5 J/m^2.mm rain (Duncan 1972), which is consistent with the energy of natural rain at intensities greater than approximately 40 mm/h (Rosewell 1986; Kinnell 1987). A total of 6 simulator modules were combined to cover a plot 12 m long and 1.5 m wide.

The rainfall/runoff simulation procedure had 3 components:

1. Simulated rain at 130 mm/h was applied to plots 12 m long and 1.5 m wide for 30 min. Measurements included runoff rate and concentration of sediment in runoff. This ‘storm’ is equivalent to a natural storm for the area with a return period of approximately 100 years. [An Intensity Frequency Duration (IFD) program developed by the Department of Conservation and Land Management, NSW, estimates a 1 : 100 year, 30-min intensity of 125 mm/h for the Nanango/Tarong area, using input data from Australian Rainfall and Runoff (Pilgrim 1987).]
2. Immediately following the first ‘storm’, simulated rain at 130 mm/h was applied to the bottom 2.7 m of the same plot for a 10-min period. Runoff rates and sediment concentrations in runoff were measured. This gave a measure of the contribution of raindrop-driven (or interrill) erosion to the sediment concentrations in runoff measured on the 12-m-long plots.
3. Immediately following the interrill study, a series of increasing rates of overland flow was applied to the 12-m-long plot, and runoff and sediment concentrations were measured. Flow rates applied ranged from 0.5 to 3.0 L/s, effectively simulating runoff on plots up to 70 m long, thus assessing whether the results obtained are valid at longer slope lengths. Depending on observed erosion, the number of flow rates applied ranged from 2 to 4.

The only variations to this procedure were for the plots with 100% cover, where rain was continued until steady infiltration rates were reached, at 40 and 50 min for the 2 plots, and the interrill measurement was omitted. Raindrop impact is essential for interrill erosion to occur, so for the 100% cover plots interrill erosion was extremely unlikely.

The relatively high rainfall intensity applied was selected partly to ensure that runoff was generated on all plots. It was also selected because relatively large storms dominate erosion under field conditions in this region and, therefore, will also dominate long-term responses of erosion to surface cover and other management inputs. For example, Edwards (1987) reviewed field erosion plot studies in New South Wales and concluded that ‘10% of the runoff events….contributed 90% of the total observed soil loss’. Similarly, for a 14-year erosion study on the Darling Downs, Queensland (some 150 km to the south-west of Tarong), Wockner and Freebairn (1991) found that 7% of the runoff events caused 70% of the total soil erosion. The other benefit of using higher rainfall intensities was that erosion processes such as rilling would be more likely to develop on the relatively small rainfall simulator plots. This ensured that results were more representative of erosion on (larger) field-sized areas, thus yielding more representative soil erodibility parameters (Loch *et al.* 1989).

Derivation of curve number

Curve number (CN) is a parameter used in USDA runoff prediction models, with a value of 100 indicating total runoff, and runoff decreasing as curve number decreases. Curve number (2) (CN_2) is the value of CN for ‘average’ conditions, usually taken as an initial condition where the soil is at 50% of plant-available water capacity (PAWC). (CN_1 refers to soil where initial plant-available water is zero.) The values of CN_2 were derived by deriving a CN for each plot on the basis of total infiltration, similar to the approach of Littleboy *et al.* (1996), adjusting for soil water content to derive CN_1, and then adjusting CN_1 to CN_2.

Antecedent soil water contents

Gravimetric soil water contents prior to application of simulated rain showed a marked effect of surface cover. Both 0–5 and 5–10 cm layers were wetter under higher levels of cover (Fig. 1), with a similar, though less marked, trend for the 10–20 cm layer.

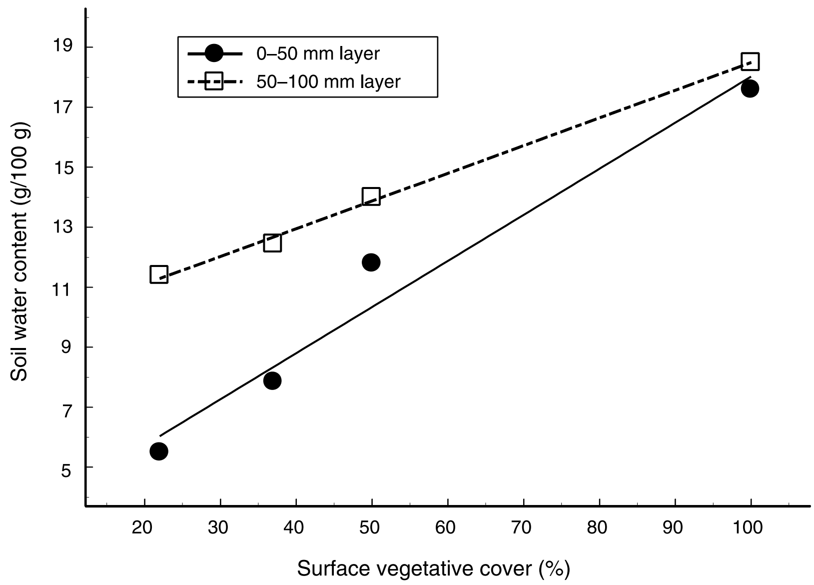

Fig. 1. Effects of surface cover on gravimetric water contents of surface soil prior to application of simulated rain, King 1 area, Meandu Mine, Tarong.

Results

Runoff and infiltration, 12-m-long plots under simulated rain

Surface cover greatly increased steady infiltration rates (Fig. 2). The 100% cover treatment was the only treatment to show considerable variation between duplicates. The plot with a higher infiltration rate had noticeable faunal macropores up to 2 cm in diameter, whereas the other plot lacked macropores. The plots with the 2 lowest levels of cover were visibly water-repellent, which would have further restricted infiltration for those treatments. Plots with the lowest surface cover also had the lowest antecedent water contents in the 0–5 cm layer (Fig. 1), which would have increased the potential for water-repellence to be significant.

Excavation of the surface layer of one of the vegetated plots following rain gave strong visual evidence of increased infiltration under grass clumps, due either to reduced surface sealing or to pores in the soil formed by, or associated with, plant roots (Fig. 3).

Consistent with the differences in steady infiltration rates, curve number also showed a large response to surface cover (Fig. 4). Maximum decreases in CN due to surface cover shown by the fitted lines in Fig. 4 (0–100% cover) were 50 units for CN_1 and 34 units for CN_2.

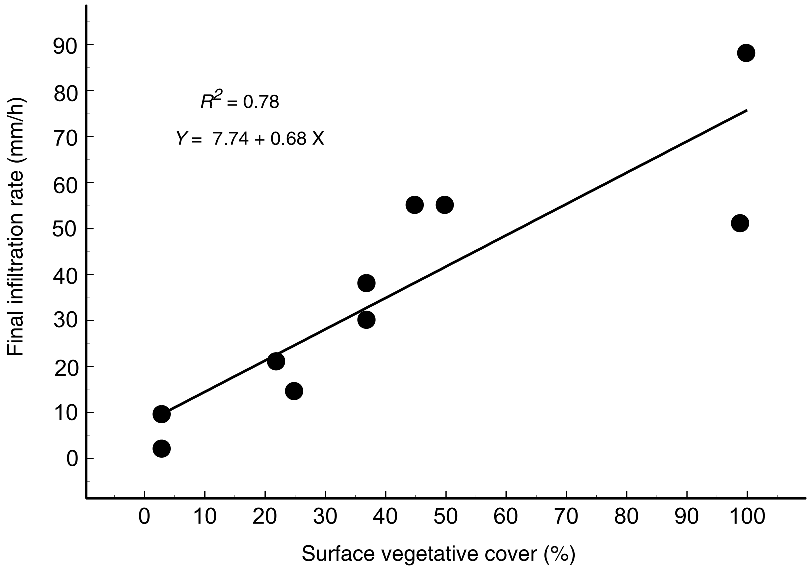

Fig. 2. Effects of surface cover on steady infiltration rates of simulated rain, King 1 area, Meandu Mine, Tarong.

Fig. 3. Restricted water entry on bare soil contrasting with deep penetration of water under a grass tussock, King 1 area, Meandu Mine, Tarong.

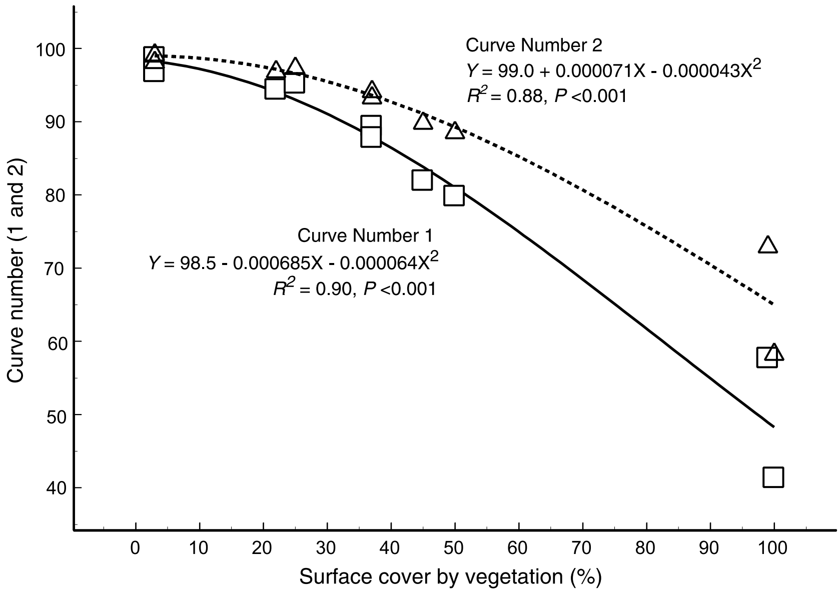

Fig. 4. Effects of surface cover on curve number, King 1 area, Meandu Mine, Tarong.

Effects of cover on erosion, 12-m-long plots under rain.

Plant cover greatly reduced measured erosion (Fig. 5). For the duplicate plots with 100% cover, erosion from the applied 'storm' was 0.1 and 0.01 t/ha, compared with erosion of 30–35 t/ha from the bare plots.

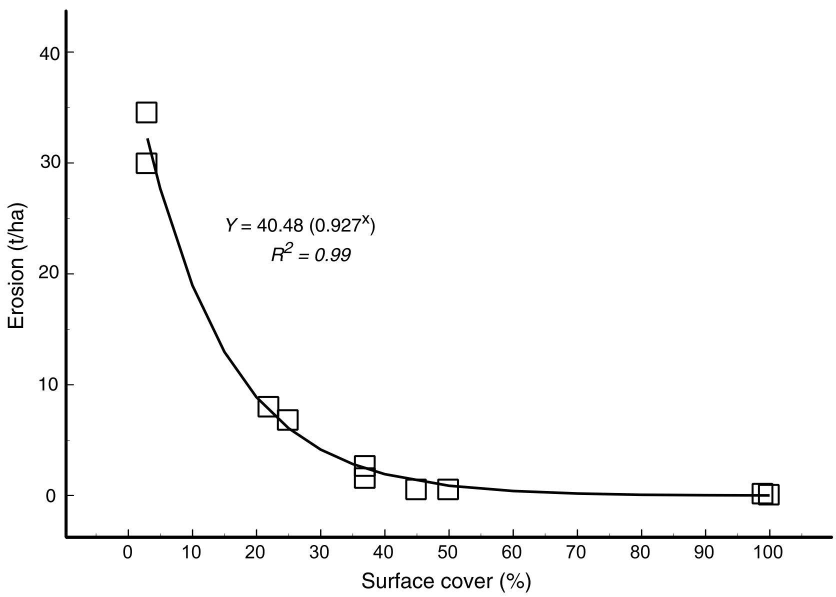

Fig. 5. Effects of surface cover on erosion from 12-m-long plots under simulated rain, King 1 area, Meandu Mine, Tarong.

The relationship shown between cover and erosion was expressed as a soil loss ratio (ratio of soil loss from a vegetated plot to soil loss from equivalent bare plots), which is the basis of the USLE relationship between erosion and contact cover. The relationship obtained (Fig. 6) is similar in form to that used in the USLE, but shows greater reductions in erosion at nearly all levels of cover, particularly at intermediate cover levels (20–60%).

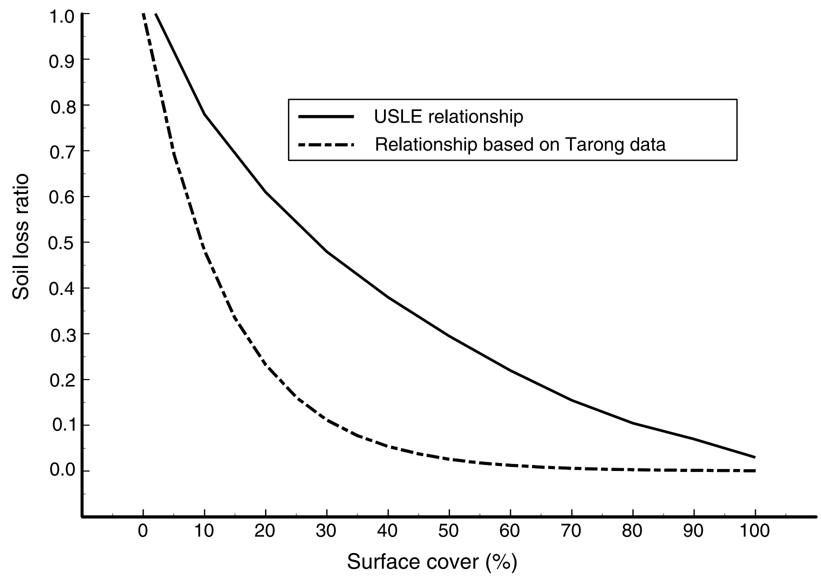

Fig. 6. Comparison of soil loss ratios (*C*-factors) from USLE and from the rainfall simulator study at Meandu Mine, Tarong.

Interrill erosion

Interrill sediment concentrations were compared with concentrations from the 12-m-long plots to assess the proportion of sediment from the 12-m-long plots under rain that was contributed by interrill erosion (Fig. 7). The results show that interrill erosion accounted for virtually all erosion from all 12-m-long plots except for those of the bare disturbed treatment. Detachment and transport by overland flow only made a significant contribution to erosion from the 12-m-long plots for the bare disturbed treatment. Development and incision of rills was observed only on the bare disturbed treatment, illustrating the effectiveness of vegetative cover in preventing rill development.

Erosion by overland flows

Results of the overland flow study (Fig. 8) show trends in sediment concentrations on a log scale so that it is possible to discern differences between the low concentrations produced by plots with higher levels of cover. However, the log scale also tends to accentuate small changes in sediment concentrations at the lower end of the *Y*-axis.

For the plots without any vegetative cover, the initial increase in discharge caused increases in sediment concentration. For both plots, sediment concentrations increased by 20–40 g/L as flow rates increased, effectively doubling the sediment concentrations measured for interrill erosion. At the highest flow rates, sediment concentrations declined

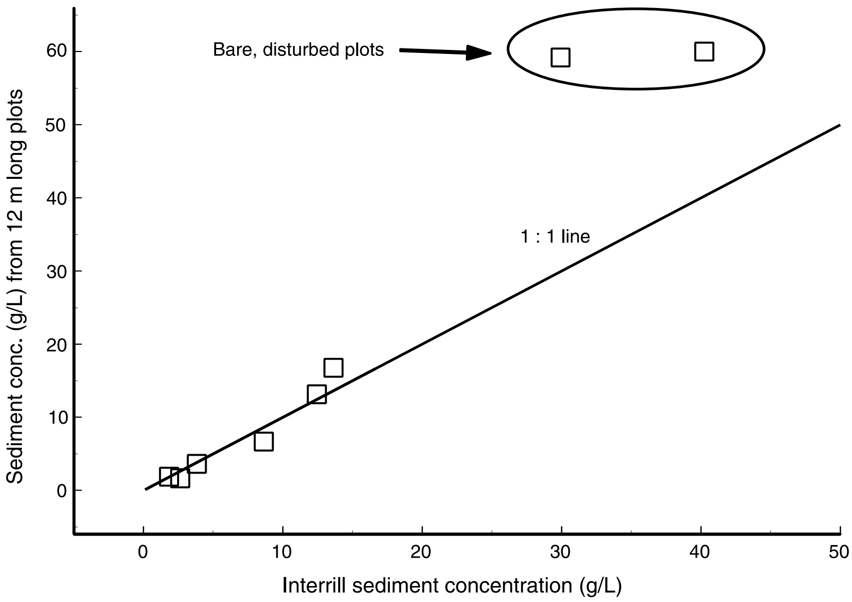

Fig. 7. Comparison of average sediment concentrations from interrill erosion (2.7-m-long plots) with average concentrations from 12-m-long plots under simulated rain, Meandu Mine, Tarong.

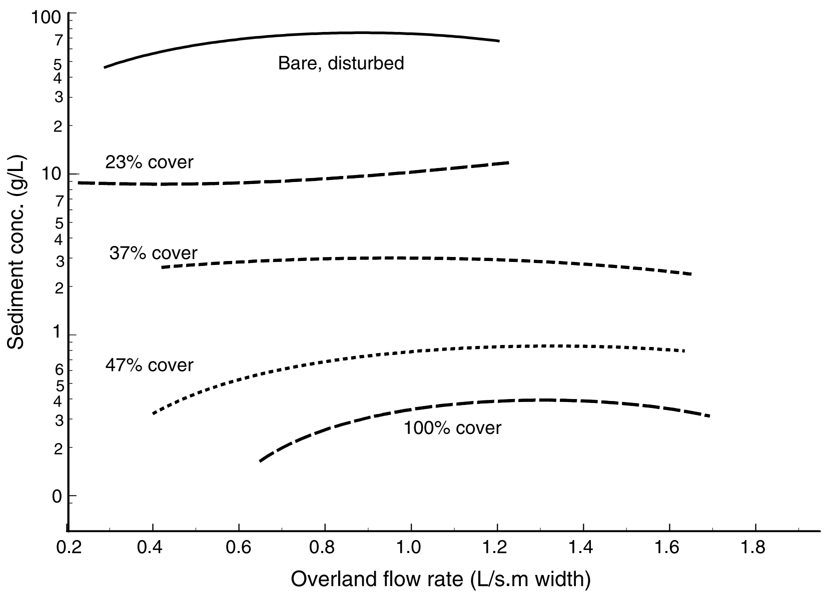

Fig. 8. Effects of cover on average sediment concentrations carried by various rates of overland flow, Meandu Mine, Tarong.

slightly, possibly due to depletion of sediment available for erosion. These were the only plots on which incision of rills was observed.

For the plots with 23–100% cover, calculation of an average sediment concentration for each flow rate applied was not an entirely satisfactory procedure, as sediment concentrations varied greatly through time (Fig. 9), with increases in flow appearing to cause rearrangement of the small amounts of detached sediment on the plots, and resulting in short-lived increases in sediment concentration. As the sediment concentrations were low, the short-lived increases appear large, but have little real significance.

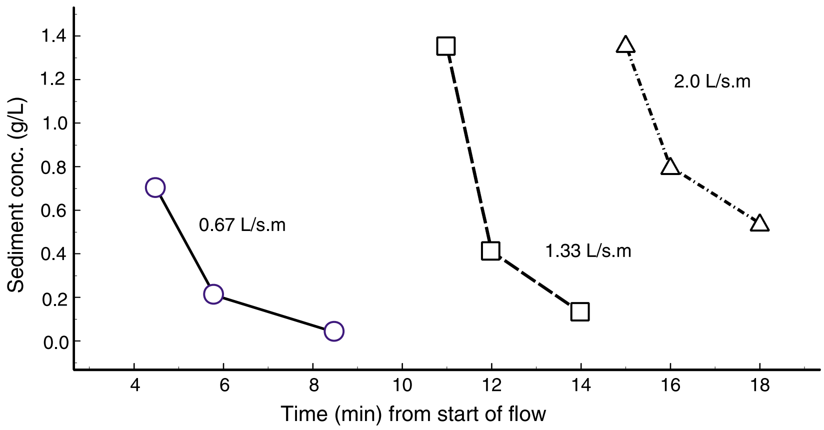

Fig. 9. Effects of successive overland flow rates (L/sec.m width) and time on sediment concentrations from Rep. 1 of plots with 47% cover, Meandu Mine, Tarong.

For the plots with vegetative cover, however, there was little or no effect of discharge (and therefore, of slope length) on average sediment concentrations carried by the various discharges over a wide range of discharges (Fig. 8). The data in Fig. 8 also indicate extremely low concentrations of sediment in overland flow for cover levels of ≥47% The maximum slope lengths simulated by the highest discharges applied to each plot varied slightly, depending on plot runoff rates, but were generally equivalent to a length of 60–70 m receiving the same 1 : 100 year rainfall event applied to the 12-m-long plots. From this it can be concluded that the soil loss ratios shown in Figs 5 and 6 are valid for slope lengths up to 60–70 m under extreme erosive events, and would apply to longer slopes for less extreme rainfall events. For 60–70-m-long slopes, erosion from areas with greater than 50% cover can be expected to be negligible.

In situ and eroded sediment sizes

Samples were taken of the soil surface after rainfall wetting to gain a measure of size distributions of sediment (aggregates and primary particles, with no distinction made between them) in the surface layer available for detachment and transport. The sediment size distribution data showed little variation between the various plots, and showed quite low proportions of fine particles (Fig. 10). For example, Loch and Foley (1994) reported size distributions after rainfall wetting for 21 Queensland soils. Proportions of fine (<0.125 mm) material ranged from 13 to 79%, with only 2 soils having <20% of particles at the surface <0.125 mm, and relatively few soils having 20–30% of particles <0.125 mm. This compares with the 19.8% <0.125 mm found at the King 1 site. (The lower the proportion of fine particles, the higher the steady infiltration rates.)

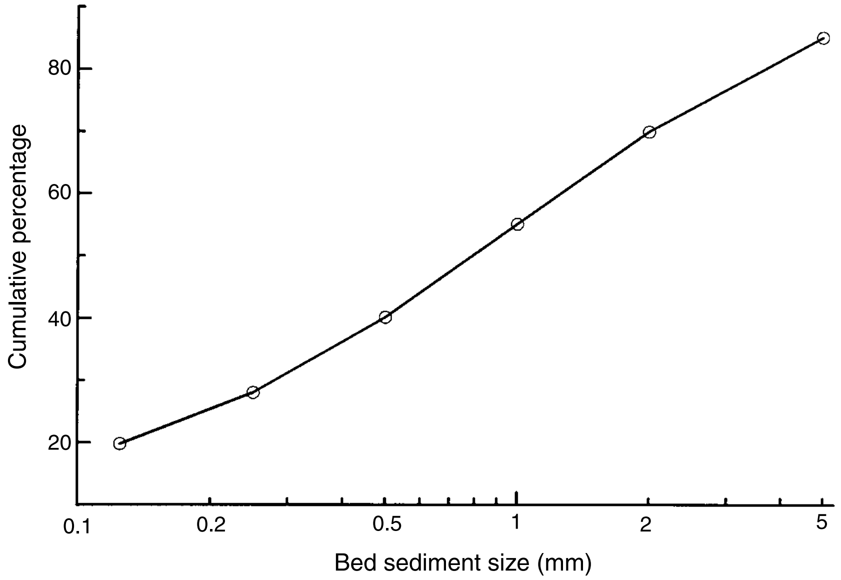

Fig. 10. Size distribution of particles at the soil surface after rainfall wetting of the bare disturbed plots, King 1 area, Meandu Mine, Tarong.

The low infiltration rates into bare soil measured in this study are not consistent with the relatively low proportion of particles <0.125 mm that was measured, but are explained by the visible water-repellence of the bare soil.

The proportions of suspended sediment in runoff (particles <0.02 mm) varied consistently through time, and are also not high (Fig. 11). (A flush of finer sediment in the early stages of runoff is common.) The bulk of the sediment eroded from this soil was carried as bedload, and therefore, sediment transport would have been quite sensitive to flow velocities and to any factors (such as vegetative cover) that reduced those velocities.

Discussion

Effects of vegetation on infiltration

Increases in infiltration associated with vegetation cover are most probably related to effects on water-repellence at lower cover levels and on both reduced surface sealing and increases in stable macropores at higher cover levels. Water-repellence was only visible on the drier (bare) surfaces. Evidence of the importance of surface cover and macropores comes from observations of the soil after rain showing preferential water entry associated with grass tussocks (Fig. 3), and from increases in soil macropores due to revegetation measured by Loch and Orange (1997) at this site.

The measured effect of cover on curve number—with the fitted lines showing a reduction of 50 units between 0 and 100% cover for CN_1, and 34 units for CN_2—is large,

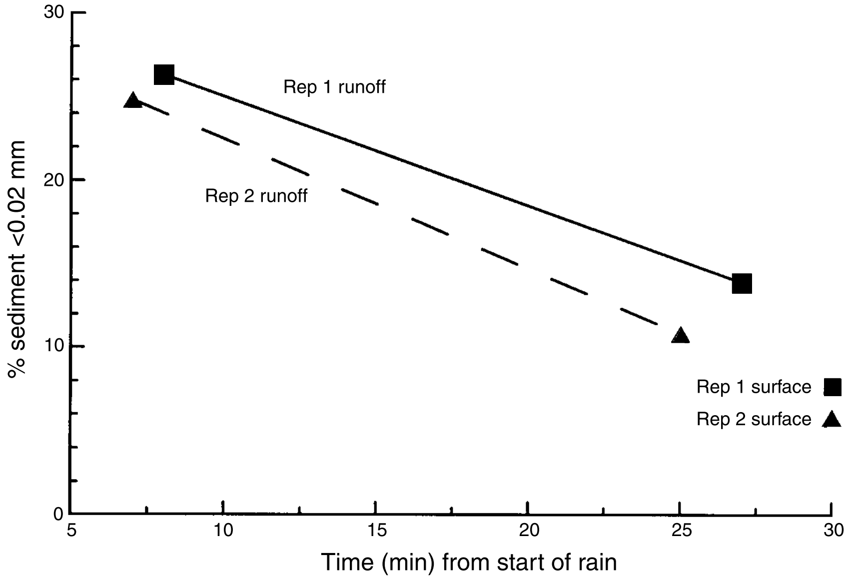

Fig. 11. Comparison of the proportion of particles <0.02 mm in runoff from 12-m-long plots under rain with that measured in the soil surface after 30 min simulated rain, bare disturbed treatment, King 1 area, Meandu Mine, Tarong.

but not inconsistent with other data. An even larger decrease of 42 units in CN_2 was found for a degraded solodic soil under pasture in central Queensland (Yee Yet 1994). A maximum decrease in CN_1 of 25 units was found by rainfall simulator studies on a tilled, hardsetting red brown earth at Hyderabad (India) by Littleboy *et al.* (1996), and a maximum decrease in CN_1 of 27 units was reported for a reclaimed minesite in North Dakota (US) by Schroeder (1994).

Although Littleboy *et al.* (1996) found a linear relationship between straw cover and CN, data from this study show the lower levels of cover to be somewhat less effective, giving a more curvilinear response. This may result from the small cover units (stolons, and small seedlings) that predominate at the lower levels of cover being less effective in increasing infiltration than the larger tussocks and clumps that predominate at the higher levels of cover.

For the Meandu Mine, the reductions in CN with cover indicate that revegetation will greatly reduce annual runoff.

Effects of vegetation on erosion

The soil loss ratio/cover relationship shown in this report indicates much larger effects of cover on erosion, compared with the relationship developed for the USLE, largely due to impacts of cover on sediment transport. Both cover/erosion relationships show curvilinear responses of erosion to cover. The curvilinear response is undoubtedly due (largely, if not entirely) to the impacts of cover on erosion processes, with rilling (and high rates of erosion) at very low levels of cover, and interrill erosion only at the higher levels of cover. The response to intermediate levels of cover will then depend on (*a*) their effectiveness in preventing rill development, and (*b*) their effectiveness in reducing interrill erosion.

It appears that in both this experiment and others (Freebairn *et al.* 1989; Rosewell 1990) intermediate levels of surface cover have been more effective in reducing erosion than in the experiments on which the USLE is based. The USLE plots carrying stubble mulches were probably tilled up and down the slope, and it is likely that the mulch in that situation would have provided less impediment to overland flow than in this study (where surface cover by the stoloniferous Rhodes grass occurred in clumps 0.5–1.0 m in diameter), and the work reported by Freebairn *et al.* (1989) (where tillage on the contour arranged mulch at right angles to overland flow).

It can be inferred that effects of cover on erosion will vary depending on the physical arrangement of the cover, and on the size of the cover elements. As the data in this paper illustrate, impacts of cover type on erosion can be considerable in the cover range 20–60%, with up to a 6-fold variation in predicted erosion rates depending on the response curve that applies (Fig. 6). As the levels of vegetative cover achieved at many mines would range from 20 to 60%, the potential impacts of cover type (and therefore, the species selected for revegetation) are likely to be important for a significant proportion of minesites.

Soil properties may have also affected the response to cover found in this study. The topsoil at Meandu Mine produced dominantly coarse sediment, for which cover would have been particularly effective in causing deposition of particles entrained in overland flows. Vegetative cover could be expected to be less effective on, for example, dispersive soils producing predominantly fine sediment.

Conclusions

Reductions in runoff and erosion due to vegetative cover were large. Particularly for lower cover levels (10–50%), reductions in erosion were greater than predicted by the soil loss ratio curve used in the Universal Soil Loss Equation. Low levels of cover were sufficient to prevent rill development. Studies using overland flow showed little effect of simulated slope lengths on erosion for all vegetated plots. The overland flow studies indicate that the effects of vegetation cover on erosion measured at this site should apply to slope lengths of at least 60–70 m and, for areas with close to 100% cover, probably to longer slopes as well. (For simulated slopes of 60–70 m, not even the plots with 23% cover showed any signs of rill development.)

For plots with ≥47% cover, soil losses from the simulated storm were <0.5 t/ha. As the storm simulated was equivalent to a 1 : 100 year event, it can be concluded that soil losses of even 0.5 t/ha will be rare on similar areas with >47% cover. Similarly, sediment movement by the range of overland flows applied was extremely low for cover levels >47%, and it appears that, *as a simple rule of thumb*, a level of 50% grass cover could be set as a target for stable rehabilitation (at least where stoloniferous grasses are a major component of the vegetation

The period in the mine rehabilitation process when the soil is bare and vulnerable to erosion by surface runoff represents a significant ‘window of risk’. The results from this study indicate that establishment of even small quantities of vegetative cover can close that window, highlighting the importance of rapid and reliable plant establishment in mine rehabilitation.

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