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Impact of vegetative cover and slope on runoff, erosion, and water quality for field plots on a range of soil and spoil materials on central Queensland coal mines

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Abstract

In 1993, a field study commenced to determine the impact of vegetative cover and slope on runoff, erosion, and water quality at 3 open-cut coal mine sites. Runoff, sediment, and water quality were measured on 0.01-ha field plots from 3 slope gradients (10, 20, 30%), with pasture and tree treatments imposed on soil and spoil material, and 2 soil and spoil plots left bare.

The greatest soil erosion occurred before pasture cover established, when a large surface area of soil (>0.5 plot area) was exposed to rainfall and overland flow. Once buffel grass (*Cenchrus ciliaris*) colonised soil plots, there were negligible differences in soil erosion between slope gradients. On spoil, Rhodes grass (*Chloris gayana*) reduced *in situ* soluble salt content, and reduced runoff electrical conductivity to levels measured in surrounding creeks. Where spoil crusted there was poor vegetative growth and unacceptably large runoff and erosion rates throughout the study.

Introduction

Draglines are used in most open-cut coal mines in Australia, with the result that landscapes after mining generally consist of a series of parallel spoil piles, with slope angles of approximately 75%. The cost of recontouring these spoil piles represents a major cost in rehabilitation of mined land. A small change in the degree and length of slope can have a major impact on the cost of recontouring the landscape.

Zingg (1940) found erosion rates on agricultural soils increased with slope gradient, whereas, Warrington *et al.* (1989) reported a rapid increase in erosion at slopes >10%, but only a small increase between slopes of 25% and 30%. Gilley *et al.* (1977) found a similar response on disturbed mined land, and observed that increasing slope steepness caused only a small increase in erosion rates on sodic spoil material. Likewise, where spoils crusted, Schroeder (1987) found little difference in erosion rates from different slope gradients. Crusting also causes poor seedling establishment and reduced plant water use efficiency (Naidu 1992), and leads to unsuccessful rehabilitation.

Other factors such as pasture and mulch cover also modify the effect of slope, preventing macropores from being sealed, enhancing infiltration, and reducing runoff and erosion and, hence, the impact on water quality (Wilcox and Wood 1989; Eldridge and Rothon 1992). On steeper slopes more cover is required to control erosion, and rapid establishment of vegetation on reclaimed mine land is suggested as a way to reduce erosion and prevent both on-site and off-site transport of sediment (Meyer *et al.* 1970; Schroeder 1987).

Compared with pasture, trees have a slower growth rate and provide less surface cover to prevent erosion. Agricultural soils in central Queensland are most vulnerable to erosion when they are bare and have low vegetative cover, often a scenario caused by the

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variability of the region's rainfall (Carroll *et al.* 1997). It is for this reason that we focus on the impact of pasture rather than trees for stabilising slopes on coal mine rehabilitation.

There is little information in Australia on erosion rates from open-cut coal mine rehabilitation, particularly from natural rainfall events. Most erosion research has been conducted for agricultural soils and land use, and on lower slope gradients than are commonly found on mine rehabilitation. Undertaking erosion research under natural rainfall conditions is labour-intensive, time-consuming, and costly. In this study 3 coalmines were selected with a range of soil and spoil materials that are commonly encountered on central Queensland coal fields.

In this paper we describe a 6-year field study to determine, under natural rainfall: (i) runoff and sediment loss for a range of soil and spoil material, (ii) the trend in sediment loss with an increase in pasture cover, and (iii) the impact of pasture cover on runoff, sediment loss, and salt transport from 3 slope gradients.

In further research we will use regression analysis to explore the temporal changes to soil and spoil erodibility, and undertake a comparison with erodibility parameters determined from field rainfall simulation.

Materials and methods

Location and experimental layout

The experimental sites were at the Curragh (23.29°S, 148.50°E), Oaky Creek (23.04°S, 148.28°E), and Goonyella/Riverside (21.51°S, 148.58°E) coal mines in Central Queensland.

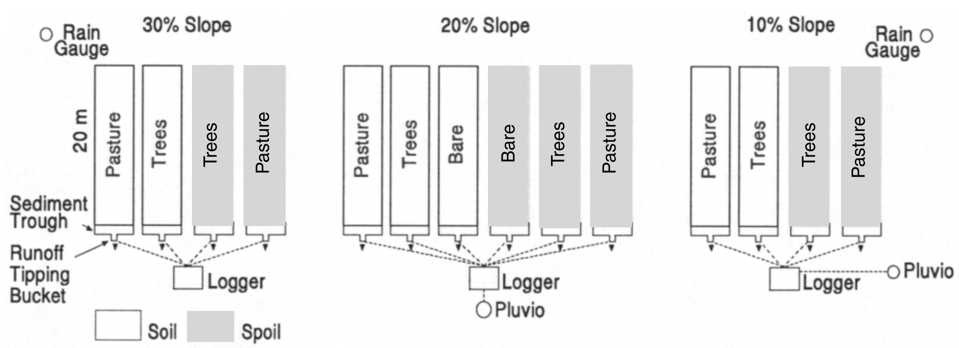

Fig. 1. Experimental layout.

Three slope gradients (approximately 10, 20, and 30%) were formed using a D9 size dozer (Fig. 1). A depth of soil (20–30 cm at Curragh and Goonyella/Riverside, 10 cm at Oaky Creek) was then laid over the spoil and ripped at 1-m intervals across each slope. Pasture and tree treatments were imposed on soil and spoil material, and on the 20% slope, single soil and spoil plots were left bare as a comparison with the vegetated treatments. Sediment and runoff were measured from 14 bounded plots, each 0.01 ha (20 m by 5 m) in size (Fig. 2). The field study at Goonyella/Riverside terminated in year 4 when subsidence caused slumps and cracks to appear on the plots. Data from the 20% slope are reported for the site.

Soil and spoil

Chemical and physical properties of the soil and spoil (mean of 7 soil and 7 spoil plots) materials at the 3 sites are given in Table 1. In each plot, 8 surface samples (0–50 mm) were randomly collected and bulked and a single subsample was taken for chemical and physical analysis.

Particle size analysis and cation exchange capacity (CEC) for soil and spoil material showed little variability within sites, but large differences between sites. At each location spoil material had higher pH, electrical conductivity (EC), and exchangeable sodium percentage (ESP) than soil materials. There was

Fig. 2. Erosion plot and runoff tipping bucket; suspended sediment collected in 20-L plastic drum, via 1-mm slot in 10-cm upright copper pipe (left of tipping bucket).

notable variability in spoil EC at Oaky Creek and Goonyella/Riverside sites. Oaky Creek soil exhibited some variability in EC where ripping caused spoil to be mixed with the overlayed soil material.

Chloride salts contribute 90% of the soluble salt content of Goonyella spoil, with sulfate the main contributor with Oaky Creek spoil. Oaky Creek spoil on the 10% slope had greater EC, chloride, and sulfate (maximum values in Table 1) than the 20% and 30% slopes (data not identified), and this caused salt encrustation on these plots.

Pasture and trees

A mixture of species was sown on the pasture plots: *Chamaecrista rotundifolia* and *Stylosanthes hamata* (Amiga and Verano) at 3 kg/ha, and *Bothriochloa insculpta*, *Cenchrus ciliaris*, and *Chloris gayana* at 4 kg/ha. Ten tree species were planted on the tree plots: *Acacia harpophylla*, *A. holosericea*, *A. salicina*, *A. saligna*, *Casuarina glauca*, *Eucalyptus citriodora*, *E. crebra*, *E. drephanophylla*, *E. populnea*, and *E. tereticornis.* Trickle irrigation tape was installed at Goonyella/Riverside in Year 2 and in Year 4 at Curragh to help establish pasture and trees. The tape was laid at 1-m intervals across each slope at a depth of 50 mm.

Rainfall

At each site rain was recorded at 1-min intervals by 2 pluviometers situated on the 20% and 10% gradients, and recorded on data loggers. Two rainfall gauges were installed on the 10% and 30% gradients to measure daily rainfall (Fig. 1).

In the first 2 years of the study all 3 sites experienced 50% less rainfall than the long-term median rainfall (Table 2). Most of the rainfall during this period was from rainstorms, with several monthly rainfalls larger than the median (Fig. 3). Highest annual rainfall at Curragh and Oaky Creek was in Year 6 (1998–99) of the study.

Runoff and sediment

Runoff was measured using a tipping bucket (7.47 L capacity) (Fig. 2). Total runoff and runoff rates were determined by recording the number of tips per min on a data logger. Total tips were also recorded on a mechanical counter.

Sediment erosion was measured as 2 components: bedload and suspended sediment in runoff. Bedload was deposited in 5-m-long troughs and was weighed after each rainstorm event and dry weight calculated. A 10-cm copper pipe with a 1-mm vertical slot collected a small sample of runoff (0.01% flow) from one side of the tipping bucket, and this was stored in a 20-L plastic drum. Suspended sediment, pH, and EC were determined from a runoff subsample.

Table 1. Chemical and physical properties for seven soil and spoil plots at Curragh, Oaky Creek, and Goonyella/Riverside sites for Year 1

CS, coarse sand (0.2–2.0 mm); FS, fine sand (0.02–0.2 mm); S, silt (0.02–0.02 mm); C, clay (<0.002 mm)

	pH	EC (mS/cm)	Cl (mg/kg)	SO_4-S (mg/kg)	Ca (cmol/kg)	Mg (cmol/kg)	CEC (cmol/kg)	ESP (%)	Particle size analysis (%) CS	FS	S	C
						Curragh soil						
Mean	8.6	0.43	219	31	26	9	38	7	5	22	16	59
Range	8.8–8.5	0.6–0.30	413–82	39–21	28–21	10–9	40–33	8–6	7–4	25–20	17–15	62–54
s.e.	0.05	0.03	39	3	1.1	0.1	0.9	0.3	0.4	0.7	0.2	1.0
						Curragh spoil						
Mean	9.6	0.6	519	39	7	8	20	28	19	31	19	33
Range	9.9–9.4	0.7–0.4	741–219	51–27	10–5.1	9–8	23–17	36–22	24–16	35–28	22–17	38–31
s.e.	0.1	0.0	61	3	0.6	0.2	0.7	1.7	1.2	1.0	0.7	0.9
						Oaky Creek soil						
Mean	7.3	1	274	753	4	6	9	10	11	62	9	19
Range	7.8–7.0	1.7–0.7	367–139	1180–241	5–4	7–5	10–8	14–7	14–8	64–59	10–8	22–16
s.e.	0.1	0.1	31	121	0.1	0.3	0.4	0.8	0.9	0.6	0.3	0.9
						Oaky Creek spoil						
Mean	8.3	3.3	583	3371	4	12	8	15	24	46	14	15
Range	8.7–7.9	6.3–1.5	916–394	7000–1040	5–3	25–7	10–6	30–6	28–20	50–44	18–13	26–11
s.e.	0.1	0.7	67	813	0.2	2.6	0.6	4	1	1	2	2
						Goonyella/Riverside soil						
Mean	7.6	0.3	394	11	6	5	15	11	19	22	9	51
Range	8.5–7.0	0.4–0.2	496–183	12–10	7–6	6–3	16–13	15–5	24–14	24–19	11–8	58–44
s.e.	0.2	0.0	42	0.2	0.2	0.4	0.4	1.3	1.2	0.7	0.5	1.8
						Goonyella/Riverside spoil						
Mean	8.0	2.2	3299	3	2	9	20	38	11	16	13	61
Range	8.3–7	2.6–1.7	4385–1227	7–1	2–1	10–8	21–18	41–35	13–9	18–14	14–12	64–59
s.e.	0.2	0.1	389	0.2	0.2	0.2	0.4	0.7	0.6	0.5	0.3	0.6

Table 2. Annual rainfall (mm) and year number for Curragh, Oaky Creek, and Goonyella/Riverside sites, and long-term median rainfall

Year	Year no.	Curragh	Oaky Creek	Goonyella/Riverside
1993–94	1	369	407	279
1994–95	2	362	531	316
1995–96	3	479	608	507
1996–97	4	694	610	604
1997–98	5	596	568	n.a.
1998–99	6	824	772	n.a.
Long-term median		567	584	530

n.a., not available, monitoring terminated.

Sediment in the bedload trough and sediment in the runoff were used to determine total sediment movement.

Vegetative cover

Sallaway *et al*. (1988) described the photographic technique used to quantify vegetative cover. Three photographs were taken at 5-m intervals along each plot, and covered an area of 30 m^2. In Year 6, standing dry matter was determined on the soil plots at Curragh and Oaky Creek by cutting and drying samples taken from 5 quadrats (0.25 m^2).

Surface roughness

Plot linear roughness was determined by taking 2 measurements: the horizontal length of the plot (straight), and length along the surface relief (rough). Surface relief was measured by laying a tape measure along and over undulations caused by ripping the plots. The rough/straight ratio was used to calculate a numeric expression of linear (1-dimensional) surface roughness:

$$\text{Linear roughness} = [(\text{rough/straight}) - 1]\ 100 \qquad (1)$$

Saleh (1993) has used a similar technique using a chain instead of a tape measure to measure surface roughness.

Soil and spoil strength

A torvane gauge was used to measure surface strength of soil and spoil for a range of moisture conditions. Strength measurements were conducted on bare soil and spoil plots that had been wet with deionised water. Ten measurements were taken at each sampling, with moisture samples taken to depth of torvane penetration. In addition strength measurements were taken at Curragh in rills during a rainfall event on 30 April 1996.

Results and discussion

Sediment loss from all soil and spoil material was large (>70 t/ha) when there was low surface cover. When pasture colonised plots, erosion rates declined to negligible levels (<0.5 t/ha), even on steeper slopes. Where pasture did not establish, due to surface crusting, rates remained very large (>200 t/ha) throughout the study.

Impact of soil and spoil on runoff and sediment loss

Bare plots at the 3 sites are used to compare the inherent differences in hydrology and erodibility of the soil and spoil material.

Curragh soil was the most erodible material, with more sediment transported per unit volume of runoff. Although Curragh spoil had lower sediment concentration, runoff was more than double, which resulted in spoil having an overall greater sediment loss than soil at this site (Table 3).

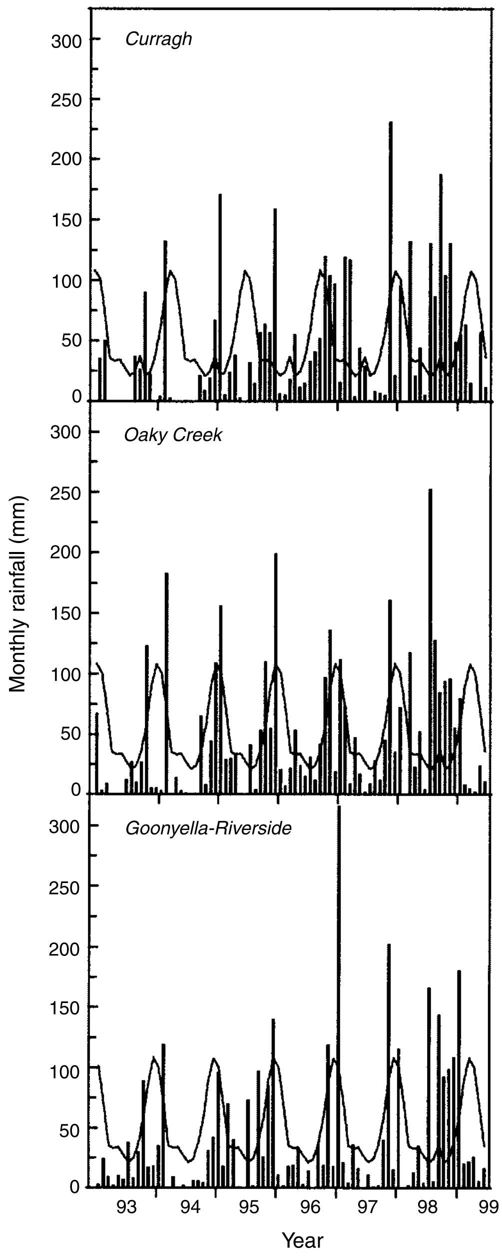

Fig. 3. Monthly rainfall bars for Curragh, Oaky Creek and Goonyella/Riverside sites (1993 to 1999), and long-term median rainfall.

When dry, the Curragh spoil formed a hard dispersive crust (Fig. 4), which resulted in low infiltration and large runoff losses, with a runoff coefficient (c) of 0.69 (Fig. 5). Curragh spoil consistently had low infiltration and high runoff and erosion rates throughout the 6-year study. When bare, Curragh soil had a relatively high runoff coefficient (0.43), but this was greatly reduced once vegetation established, as discussed later.

In contrast to Curragh, sediment concentration from Goonyella/Riverside soil was half that from bare spoil, with runoff twice that from spoil. Hence, Goonyella/Riverside soil had slightly larger total sediment movement than the spoil material (Table 3).

Table 3. Curragh, Oaky Creek, and Goonyella average sediment concentration, total runoff and sediment loss, and average annual sediment loss from bare soil and spoil, 20% slope (Years 1–4)

Site	Average sed. conc. (g/L)	Total runoff (mm)	Total sed. loss (t/ha)	Av. annual sed. loss (t/ha.year)
		Soil		
Curragh	192	495	954	238
Goonyella/Riverside	58	598	345	86
Oaky Creek	49	1050	514	128
		Spoil		
Curragh	107	1047	1119	280
Goonyella/Riverside	123	255	314	78
Oaky Creek	51	623	318	79

Goonyella/Riverside soil and spoil were both hard-setting (Fig. 4). However, very little runoff was initially generated on the Goonyella/Riverside spoil, giving a runoff coefficient of 0.02. Water entry was via small pipes that formed in the dispersive spoil. Once spoil water content increased, the runoff coefficient increased to 0.18 after 500 mm cumulative rainfall (Fig. 5). Goonyella/Riverside soil had an overall runoff coefficient of 0.53, with a slight reduction in Year 3 when cracks appeared on the plot.

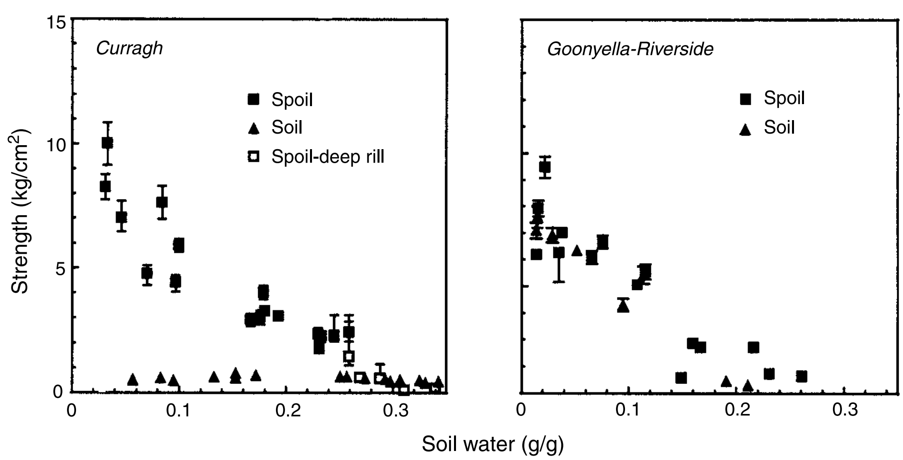

Fig. 4. Curragh and Goonyella/Riverside soil and spoil surface strengths.

On Oaky Creek soil a thin surface seal formed and caused low hydraulic conductivity and a high runoff coefficient (0.69), similar to the Curragh spoil (Fig. 5). Oaky Creek soil and spoil had similar sediment concentrations, with soil having greater runoff and overall greater sediment loss than spoil.

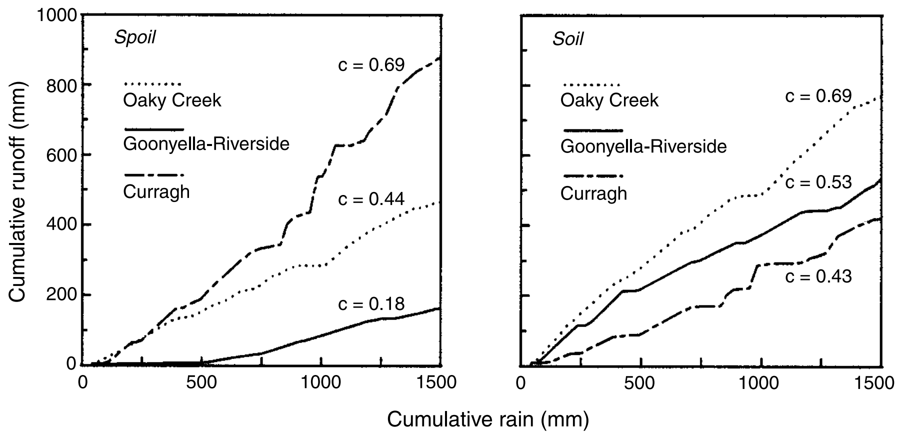

Fig. 5. Cumulative runoff and rainfall, runoff coefficient (c) for soil and spoil at Curragh, Oaky Creek, and Goonyella/Riverside, Years 1 to 3.

Impact of vegetative cover on erosion

Low and sporadic rainfall in the first two years of the study resulted in poor establishment of vegetation at all sites. Buffel grass (*Cenchrus ciliaris*) colonised soil plots, whereas the more salt-tolerant Rhodes grass (*Chloris gayana*) only sparsely established on spoil material at the 3 sites.

The effect of vegetative cover on erosion dominated across all sites, despite large differences in soil and spoil properties shown in Table 1. Any small differences within soil and spoil had a smaller effect on runoff and erosion. Vegetative growth ameliorated the hardsetting nature and surface sealing of Goonyella/Riverside and Oaky Creek soil, and improved hydraulic conductivity, and reduced runoff and erosion rates. Curragh and Oaky Creek soil in particular had a dramatic reduction in runoff and sediment movement once pasture established.

At Curragh, soil erosion rates rapidly declined once buffel grass covered more than half the plot (>0.5 soil exposure) on the 20% slope (Fig. 6), with >1200 t/ha more erosion from the bare plot by the end of the study. The greatest erosion on the pasture plot was in Years 1 and 2 when grass cover was low and there was a large proportion of soil exposed to the erosive forces of rainfall and runoff. Vegetation, particularly grass cover, protected the soil from rainfall impact which disrupts and detaches soil aggregates and causes macropores to block, infiltration to decline, and erosion and runoff to increase. Loch and Orange (1997) observed that wetting patterns on rehabilitated areas were closely associated with root channels, which developed stable macropores and a gradual increase in aggregation. Infiltration on the Curragh soil was further enhanced where buffel grass dried and cracked the soil. The impact of vegetative cover was also seen at Goonyella/Riverside and Oaky Creek sites where increasing vegetative cover progressively reduced erosion (Fig. 7), a similar relationship to that found by Carroll *et al.* (1997) on an agricultural soil in central Queensland.

Tree establishment was poor on soil material initially due to low sporadic rainfall, then later to invasion of weeds, particularly buffel grass. Better tree growth occurred on Oaky Creek and Goonyella/Riverside spoil where there was less competition from weeds. However, tree seedlings provide little or no surface cover, consequently erosion rates tended to be higher than the pasture plots (Fig. 8).

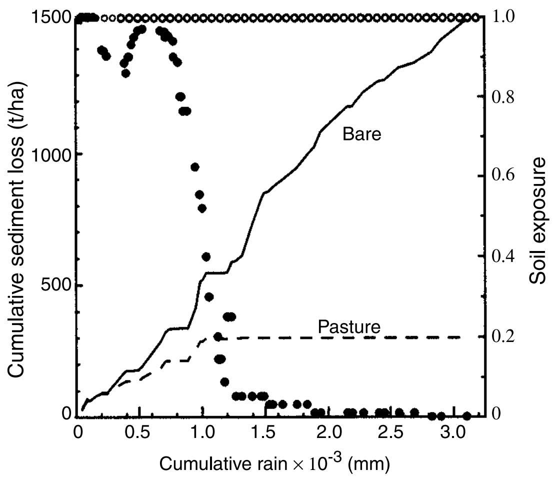

Fig. 6. Effect of soil exposure on cumulative soil loss for pasture (●) and bare plot (○). Curragh soil 20% slope, Years 1–5.

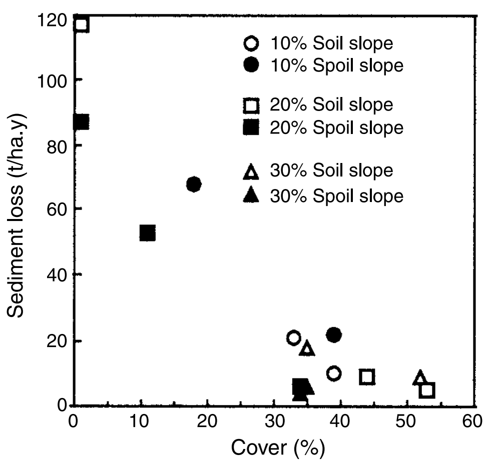

Fig. 7. Year 4 annual sediment loss *v.* pasture cover, Oaky Creek soil and spoil.

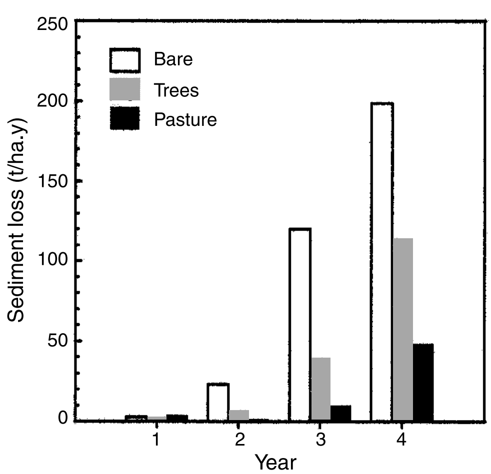

Fig. 8. Annual sediment loss from bare, tree and pasture plots, Goonyella/Riverside spoil, 20% slope, Years 1–4.

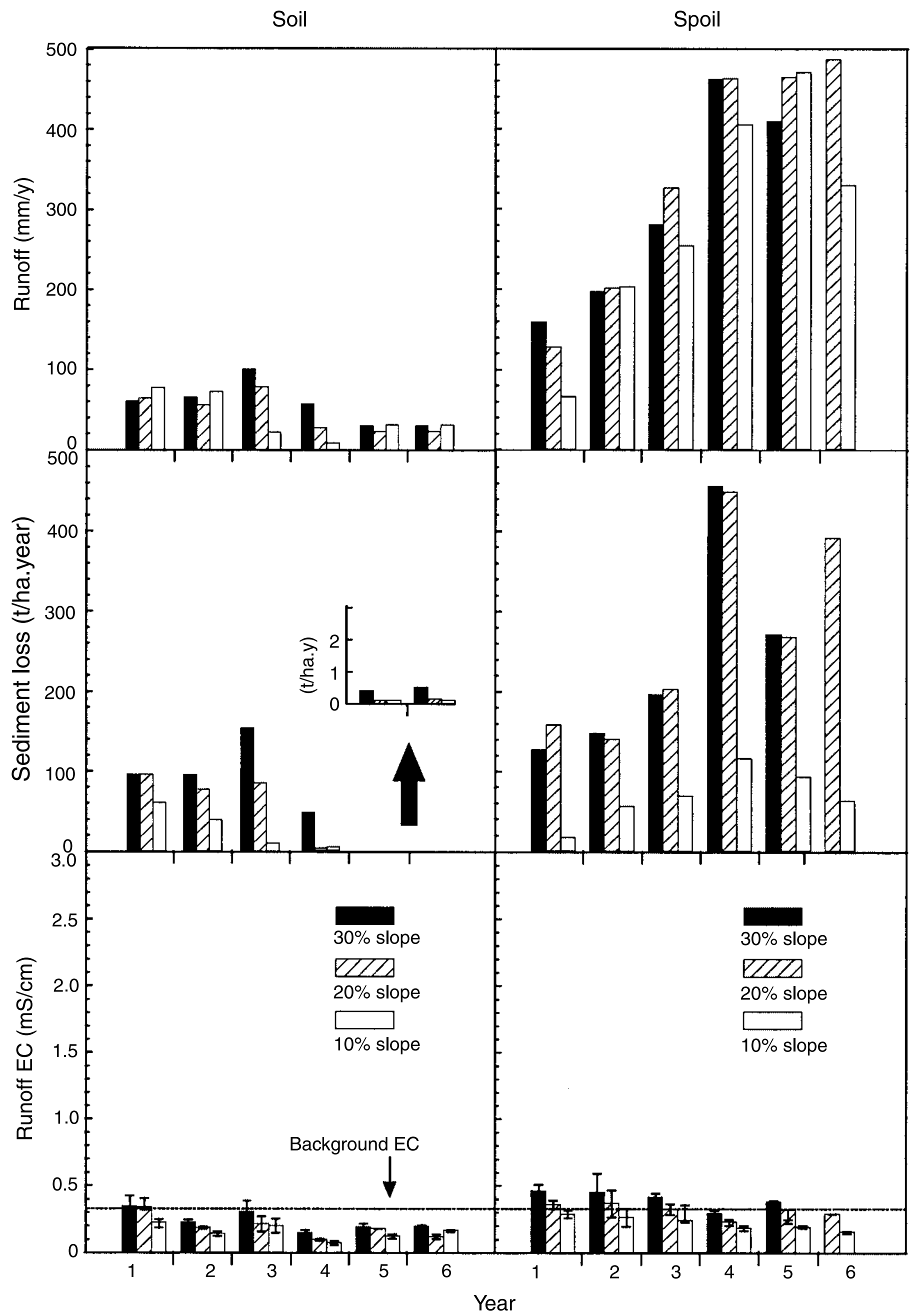

Fig. 9. Curragh annual runoff, sediment loss, and average runoff EC (with standard error) for soil and spoil pasture plots on 10, 20, 30% slope.

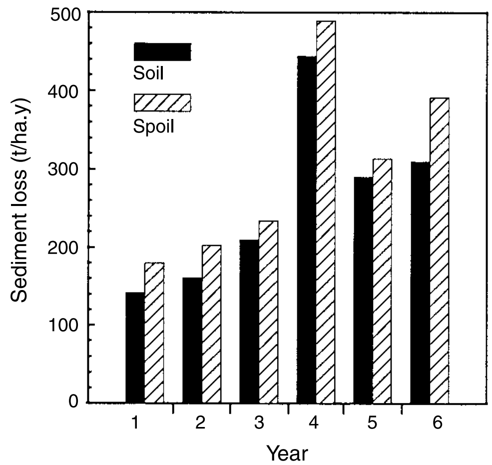

Fig. 10. Annual sediment loss for Curragh bare soil and spoil, Years 1–6.

Impact of slope and vegetative cover on runoff, erosion, and water quality

Curragh

Sediment loss peaked in Year 3 on the 30% slope with 154 t/ha compared with 85t/ha and 10 t/ha on the 20% and 10% slopes, respectively. Runoff and sediment loss declined as buffel grass continued to colonise soil plots, until Years 5 and 6 when soil erosion was negligible (<0.5 t/ha) from all 3 slopes (inset Fig. 9). The negligible erosion on the pasture plots is in direct contrast with the bare soil plot where sediment loss doubled between Years 1 and 6, with >280 t/ha in the last 2 years of the study (Fig. 10). In Year 6, buffel growth had produced >10 t/ha dry matter (Table 4), and a 5–10-cm-thick mulch layer that protected the soil from erosive forces of rainfall and runoff.

Table 4. Standing dry matter (t/ha) for Curragh and Oaky Creek soil plots on 30%, 20%, and 10% slopes (Year 6)

Slope (%)	Curragh	Oaky Creek
30	13.3	4.8
20	10.8	4.4
10	10.3	7.6

On the spoil, Rhodes grass only sparsely established (30% cover) on the 10% slope, and not at all on the 20% and 30% slopes. Greater vegetative cover on the 10% slope caused an 80% reduction in sediment loss when compared with the 20% and 30% slopes. However, both runoff and sediment losses were still unacceptably high (369 mm, 63 t/ha) on the 10% slope after 6 years of rehabilitation (Fig. 9).

On the Curragh spoil where a dispersive crust formed, there was little difference in runoff and sediment movement between the 20% and 30% slopes, a finding similar to that of Gilley *et al.* (1977) and Schroeder (1987). On the steeper slopes, rills formed and tended to cut progressively deeper rather than wider, with spoil with low cohesive strength being preferentially eroded by concentrated flow from the bottom of rills

(Fig. 4). This caused rills to become increasingly deeper, with the potential to eventually form gullies.

Both Curragh soil and spoil had average runoff EC levels below or close to background levels measured in local creeks (0.3 mS/cm) (Fig. 9).

Oaky Creek

Ripping of plots to create a rough surface was shown to reduce runoff and erosion during the early stages of rehabilitation when vegetative growth was slow and risk of erosion was high. The effectiveness of ripping and the degree of surface roughness tended to be greater on steeper gradients (Fig. 11), and lasted until rills formed. Surface roughness on Oaky Creek soil plots had a pronounced impact on runoff in the first 2 years of the study, with the greatest roughness on 30% slope resulting in less runoff than the 20% and 10% slopes (Fig. 12).

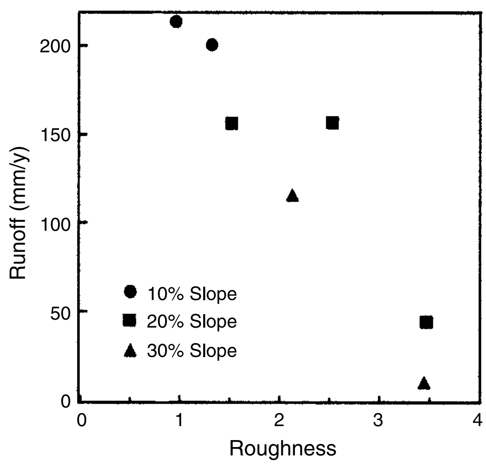

Fig. 11. Effect of surface roughness on total runoff, Oaky Creek spoil, Year 4.

As at Curragh, establishment of buffel grass varied across the soil plots. Initially, buffel grass established best on the 20% soil plot, and this, along with greater surface roughness, meant the 20% slope had consistently lower runoff and sediment loss than the 10% slope, with the 30% slope producing the greatest erosion. But as at Curragh, the difference in erosion rates between slopes declined (Fig. 12) as buffel grass colonised soil plots, and by Year 6 the 10% slope had the greatest pasture matter (Table 4) and the least erosion. In Year 6, soil loss from the pasture plots was 0.6, 0.9, and 4.2 t/ha, respectively for the 10%, 20%, and 30% slopes, compared with 76 t/ha from the bare soil plot. Pasture growth on Oaky Creek spoil also caused sediment loss to decline during the study, with losses in Year 6 of 34, 12, and 16 t/ha from 10, 20, and 30% slopes, respectively, compared with 66 t/ha from the bare spoil plot.

The greatest runoff, sediment, and salt transport was from the 10% spoil plot at Oaky Creek, where salt encrustation occurred (Fig. 12). Following drying, the crust disintegrated leaving a layer of salt-enriched erodible sediment which caused greater interill erosion and much higher average runoff EC than from the 20% and 30% slopes (Fig. 12). Singer and Warrington (1992) and Zhang and Miller (1993) have observed similar salt encrustation processes and wetting and drying effects on erosion rates.

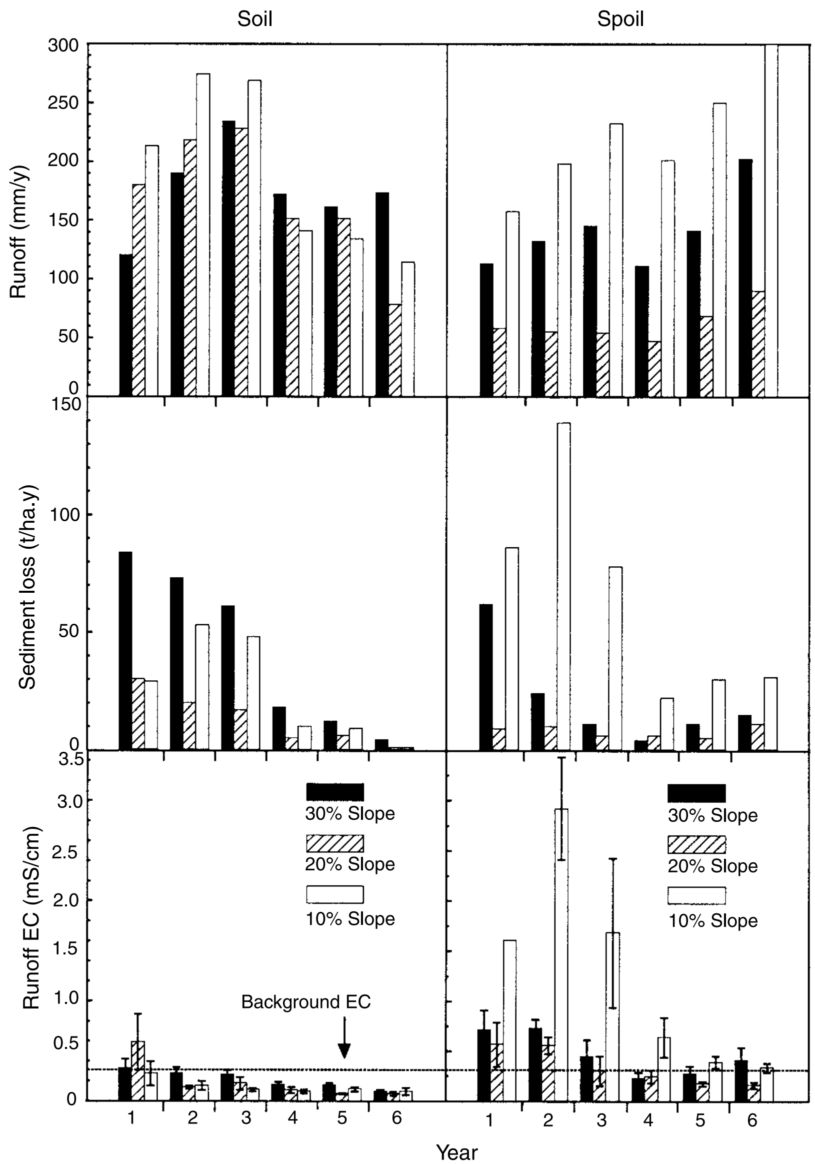

Fig. 12. Oaky Creek annual runoff, sediment loss, and average runoff EC for soil and spoil material on 10, 20, and 30% slope.

As Rhodes grass colonised the spoil plots, sediment loss and runoff EC declined, particularly on the 10% slope where there was an 8-fold reduction in average runoff EC, from a peak of 2.9 mS/cm in Year 2 to 0.3 mS/cm in Year 6 (Fig. 12).

Temporal change to erosion and water quality

In situ soluble salt content of Oaky Creek spoil declined as pasture established during the study (Fig. 13), with a similar trend on Goonyella/Riverside spoil. As discussed previously, *in situ* soluble salt content peaked in Year 2 on the 10% spoil at Oaky Creek,

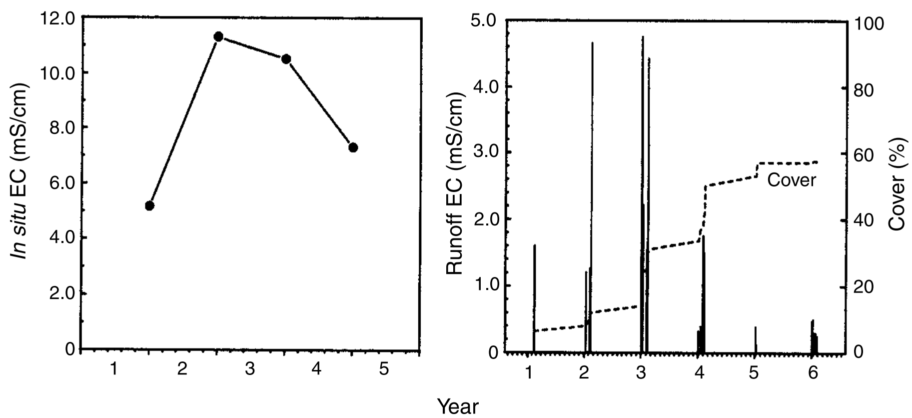

Fig. 13. *In situ* electrical conductivity (EC) of Oaky Creek spoil pasture plot, and runoff EC (Years 1–6).

and began to decline in Year 3 as Rhodes grass colonised the plot. A reduction in runoff EC coincided with a reduction in *in situ* soluble salt content (Fig. 13). The large fluctuations in runoff EC in the first 3 years of the study suggest a cycle of stripping, replenishment, and stripping of salt-enriched material. The cycle continued until the start of Year 4 when Rhodes grass began to establish, causing runoff EC to decline to levels similar to surrounding creeks. Leaching and depletion of salt enriched spoil material are other explanations for the reduction in runoff EC.

Conclusions

The greatest window-of-erosion risk was before vegetation established, when a large proportion of surface area was exposed to the erosive forces of rain and runoff. During this period rills formed, particularly on steeper gradients, and once formed persisted until a dense sward of grass colonised and stabilised rills. Vegetative growth also reduced soluble salt concentrations at the surface of spoil material, and reduced the risk of salt movement on-site and off-site.

The study showed there was little difference in soil erosion rates between slope gradients once a dense sward of buffel grass established on soil plots. However, caution should be shown when rehabilitating steep slopes. Post-mining land use and management will determine the long-term success of erosion and water quality control from steep slopes. For example, should grazing be the preferred post-mining land use, the amount of pasture utilised by cattle should be strictly controlled. If over grazing should occur and insufficient vegetative cover was retained, then erosion rates and water quality are likely to return to levels experienced before slopes were rehabilitated.

Successful establishment of vegetative cover is the key to reducing runoff and erosion, and improving water quality. In a semi-arid environment, rainfall is a major limiting factor for successful rehabilitation. In such an environment rainfall needs to be fully utilised and unnecessary runoff losses should be minimised. Physical and chemical characteristics of soil and spoil material determine how much rainfall infiltrates and how successfully and quickly vegetation is established. Where spoil was crusted there was poor seedling establishment and vegetative growth; as a result unacceptably large runoff and erosion rates occurred throughout the study.

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