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RUNOFF AND SOIL LOSS FROM FOUR SMALL CATCHMENTS IN THE MULGA LANDS OF SOUTH WEST QUEENSLAND.

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ABSTRACT

This study investigates the relationship between pasture production, runoff and soil loss from four small catchments in the mulga lands of south west Queensland over a three year period. The mulga lands of south west Queensland are degrading under current land use practices. In areas that are over-utilized as much as 80% of a storm can be lost as runoff. Losses of this order cause severe erosion and place the area in an artificial drought situation.

A positive linear relationship has been found between soil loss and rainfall and a dependent negative cubic relationship between soil loss and vegetation cover. Landholders within the mulga lands could theoretically reduce infiltration losses to 10% of the average annual rainfall compared to the current 40% by doubling the residual vegetation canopy cover after grazing. By doubling the residual vegetation canopy cover soil loss would be reduced to one tenth of that currently experienced. The infiltration losses estimated to be occuring in the mulga lands equates to potential production losses of dry matter of in excess of 400kg/ha. The implications of the relationships derived by this study for management are discussed and the relationship modelled. Losses of preferred plant species through overgrazing were negligible for the three years of the trial.

INTRODUCTION

The mulga lands of south west Queensland have been grazed by domestic livestock for just on 100 years and concern has been expressed for the gradual yet constant decline in productivity (Gasteen, 1986). Rainfall in this area is both spatially and temporally variable (Fleming, 1978) and economic productivity is dependent on maximising the benefit from each rainfall event. Declining vegetative cover levels have resulted in major changes in the surface hydrology of the area with exponential increases in stream flows recorded for the Paroo River since 1960 (Miles, 1988). Drought records indicate that one of the major shires in the mulga region (Paroo) has been drought declared 75% of the time since 1964. Rainfall records show no major shift in rainfall pattern to account for this (Miles, 1988). Surface runoff appears to be correlated.

The understanding of surface hydrology in the semi-arid rangelands of Australia is limited. This understanding given the spatial and temporal variability of rainfall in semi-arid environments is critical to the development of sustainable land use practices.

Runoff and soil loss investigations in the mulga lands have been largely limited to a few rainfall simulations on small plots (Pressland and Lehane, 1982; Pressland, 1976; Glanville and Mills, 1987; Miles and Glanville, 1990) with a few infiltrometer studies (Gifford, 1978, Miles and Glanville, 1990).

Generally point infiltration has been shown to increase with vegetative cover using rainfall simulation (Thompson, 1968, Wood and Blackburn, 1981). Pressland and Lehane (1982) reported that biomass levels of > 2000kg/ha are necessary to reduce runoff below 60% in small simulation plots in the mulga lands of south west Queensland. Reductions in sorptivity and hydraulic conductivity on red earths in the northern territory were found by Bridges *et al.* (1983) to be correlated to heavy grazing pressure.

This study recorded total runoff and soil loss on an event basis over a three year period from four small catchments in the mulga lands of south west Queensland. Both vegetation cover and composition along with antecedent soil moisture were recorded. Two catchments were located on hard stoney red earths (hard mulga) and two on soft loamy red earths (soft mulga), in an attempt to provide some understanding of the relationship between rainfall duration/intensity, vegetation cover, runoff and soil loss in the mulga lands.

MATERIALS AND METHODS

Site description.

Four hillslopes were selected on both hard and soft mulga land systems (Dawson, 1974) in the mulga lands west of the Warrego River, south west Queensland. The hard mulga hillslopes were located on Croxdale station 15km west of Charleville and the soft mulga hillslopes were located on Mayfield station 47km west of Charleville. The four hillslopes were surveyed with a dumpy level on a 5m grid pattern and 1.0 to 1.2 ha. catchments identified on each site.

Soils of the hard mulga catchments range from shallow to moderately deep (30-60cm), acid, loamy red earths with ironstone gravel throughout the profile. Textures grade from sandy/clay loam at the surface to light clay at depth (Gn 2.11, Gn 2.12; Northcote, 1965). Soils of the soft mulga catchments are moderately deep (>60cm), loamy red earths with ironstone shot throughout the profile, textures grade from sandy clay loam at the surface to light clay at depth (Gn 2.11, Gn 2.12 (Northcote, 1965). All sites were of uniform relief with slopes of less than 1%.

Equipment.

The catchments were bordered by a 30cm high earth mound to eliminate possible runon and runoff induced by the channelling of water by sheep pads when grazing. Each catchment was equipped with two 50 metre V shaped earth trenches coated with bitumen draining through San Dimas flumes with dimensions calculated to accommodate 100% runoff from a greater than 1 in 100 year event using rainfall intensity duration data provided by the Australian Bureau of Meteorology.

The San Dimas flume uses lateral contraction plus a 3% slope in its floor to create supercritical flow. Head measurements are made in supercritical flow in the throat and critical depth occurs upstream. Because of this discharge ratings are independent of upstream and down stream disturbances. Variations in approach conditions have little effect on the ratings. The flumes were constructed with two stilling wells equipped with a capacitor-frequency height recorder and a clock driven float and chart manual height recorder. Pluviometers were used to record rainfall intensity duration.

Five metre Gerlach troughs were also installed on each catchment draining through tipping buckets and equipped with a vertical profile suspension sampler and weir for bed load measurements. The capacitor frequency height recorder, tipping buckets and pluviometer were coupled to an 1802 data logger calibrated to a 3 minute recording interval. All sites were serviced with a network of standard 6" rain gauges.

Data collection and analysis.

Data collection commenced in January 1987 for the hard mulga sites and in June 1987 for the soft mulga sites. Data collection ceased in April 1990 for all sites and records were collected for 51 separate rainfall events on the hard mulga catchments and 37 on the soft mulga. All sites were serviced weekly and the capacitor frequency height recorders cleaned with hydrogen peroxide and re-calibrated to minimise recording errors due to organic residue. After each event loggers were down loaded with an Epsom HX20 and data transferred to an IBM PC for analysis. Height recorder charts were removed and digitized. Calibration for the San Dimas flumes was based on the general equation for free flow.

$$Q = 6.35W^{1.04} H^{1.5-N}$$

where

Q = cubic feet per second
H = height of water (ft)
W = width of flume (ft)
N = $0.179\ W^{.32}$

Gravimetric soil moisture (expressed as % OD) was measured 24 hours after rain followed by three days, seven days then weekly on a continuous basis. Soil moisture was sampled in 10cm depth increments to bed rock on the hard mulga sites (30cm) and 60 cm on the soft mulga soils with three replicates on each of the four sites. Bed load and suspension samples were oven dried and weighted. Moisture content of the total soil profile was measured to study the dry down phase and the retention of moisture in the lower horizons.

Penetrometer readings and soil surface temperatures were recorded at 1.00pm daily in vegetated and non vegetated areas for three months of summer at the outset of the trial only. Three replicate measurements were taken at each recording. These measurements were taken to determine changes in crust strength and soil surface temperatures in the post event period between areas with a canopy cover of grass and bare areas.

Vegetation basal area, percentage cover, biomass and species composition were recorded using both dry weight rank techniques and step point methods (Tidmarsh and Howenga, 1955). Recordings were made on a three monthly basis and 4-6 weeks after a major rainfall event. Dry weight rank measurements were based on 100 x 0.25m^2 quadrants per 1.0 - 1.2 ha site. Vegetative cover was assessed using 3000 step points per catchment and was defined as the sum of the projected foliage cover and litter.

Catchment condition and use.

Catchments were selected on the basis of condition and geomorphic uniformity. The catchments were considered comparable in terms of their topography. One catchment on each soil type was regarded as in poor condition i.e. low levels of biomass and minor woody weed invasion while the remaining two sets were considered to be in better condition with higher coverage of grass. The events recorded on each catchment covered a range of conditions such as antecedent soil moisture and vegetation cover levels. Grazing of the catchments was managed such that the range of conditions could be obtained.

The strategies ranged from overstocking to spelling and native animal grazing and control programmes.

The catchments were identified as Croxdale good/poor and Mayfield good/poor. The catchments called poor were managed with stocking rates that typified the upper regional stocking levels with native animal grazing (kangaroos) while the catchments called good were either conservatively stocked or spelled. Some native grazing control was employed though only when the grazing by kangaroos was seen as significantly affecting cover levels.

RESULTS.

Vegetation.

Vegetative cover on the four catchments ranged from five percent canopy cover in November, 1988 to 53 percent cover in April, 1987. Cover generally increased during the summer wet season and declined through winter. Basal area similarly fluctuated from 0.2% to 4.8%. Basal areas below 2% are extremely difficult to measure accurately and therefore should be regarded as approximate only. Cover levels on the conservatively stocked and spelled catchment never fell below 22%. On the heavily grazed catchments cover levels never exceeded 24% (Table 1).

Table 1. Vegetation cover levels and biomass for eight catchments on the soft and hard mulga land systems of south west Queensland.

	YEAR											
	1987				1988				1989			
Condition maintained in	GOOD		POOR		GOOD		POOR		GOOD		POOR	
1.Hard Mulga (Croxdale)	Min Apr	Max Sept	Min Sept	Max Apr	Min Nov	Max May	Min Nov	Max May	Min Jan	Max Mar	Min Jan	Max Mar
Biomass (kg/ha)	724	726	38	113	502	726	35	51	620	703	37	127
Cover(%)	38	53	18	21	37	44	5	10	40	33	6	11
area(%)	2.75	2.8	0.60	2.25	2.8	3.4	0.2	0.4	3.0	2.6	0.3	1.8
2.Soft Mulga (Mayfield)	Apr	Sept	June	Sept	Nov	June	June	Nov	Jan	Mar	Jan	Mar
Biomass (kg/ha)	N	740	N	367	564	659	240	253	400	405	120	133
Cover(%)	N	39	N	24	32	36	16	23	22	22	16	17
Basal area(%)	N	4.0	N	2.2	2.0	1.8	0.2	0.8	1.3	1.4	0.3	1.6

* N = no data as site recording started mid year.

Plant species composition varied considerably dependent on climatic conditions and time of year, however pasture assessments showed no discernible changes to species composition either between catchments or over time (P> 0.05).

Runoff.

Runoff varied considerably between catchments and was noticeably higher on the heavily grazed catchments. On the hard mulga sites monitoring of runoff commenced on January, 1987. Since that time the runoff, on the heavily grazed catchments with an average cover of approximately 18%, has represented 46% of the total rainfall. Runoff from the conservatively stocked catchments represented only 9.6% on the hard mulga. The results on the soft mulga while only available from late 1987 are not significantly different from the hard mulga on the conservatively stocked areas (9.9%, $P>0.05$) and slightly lower on the poorer area (36%, $P<0.05$). The difference in runoff from the poor catchments on soft mulga areas is probably a function of slightly higher average cover (20%) and greater soil depth (< 2m).

Comparison of the multiple regression analysis of runoff from the four catchments for the factors antecedent soil moisture, plant basal area, percentage vegetation canopy cover, rainfall intensity, duration and quantity showed no differences ($P>0.05$). Pooling the data and using multiple regression provided a simple insight into runoff and the factors which strongly influence it. A model was defined using vegetation canopy expressed as a percent cover, soil moisture expressed as percent oven dry, amount of rainfall in millimetres and the duration of storm in minutes. For the analysis data was transformed by taking the arc-sine square roots of percentages to ensure the data was continuous and normally distributed. The model accounts for 87% of the variation of the dependent variables with an adjusted squared multiple R of 0.72.

The model has the following form :

$$Y = 0.402*R - 0.010*C^2 + 0.084*D - 2.6035*S$$

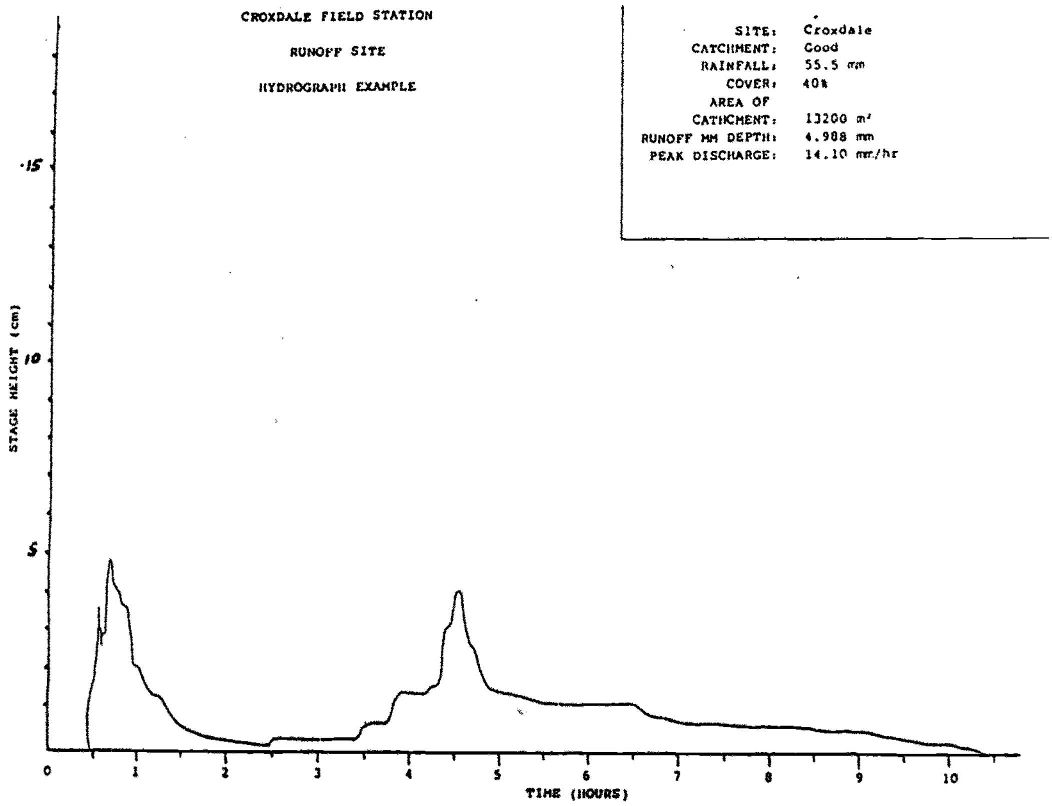
Where

Y	=	runoff (mm depth)
R	=	rainfall (mm)
D	=	duration of storm (minutes)
S	=	antecedent soil moisture (OD%)
C	=	vegetation canopy cover (%)

A limitation of the model is that it describes runoff conditions on loamy, red earths Gn 2.1 for catchments with average slopes of < 1% bulk densities between 1.44 to 1.55. These soils represent the major soil type and slope characteristics of the mulga lands.

Storms with peak rainfall intensities greater than 73mm/hr generated as much as 80% of the rainfall as runoff on soils with less than 20% cover. Whereas soils with greater than 40% cover lost less than 10% of rainfall as runoff (Figure 1.).

When soils were below field capacity (i.e. 12% gravimetric water content) peak rainfall intensities of approximately 7mm/hr generated runoff on the poor catchments (approx. 20% cover). On the catchments in good condition



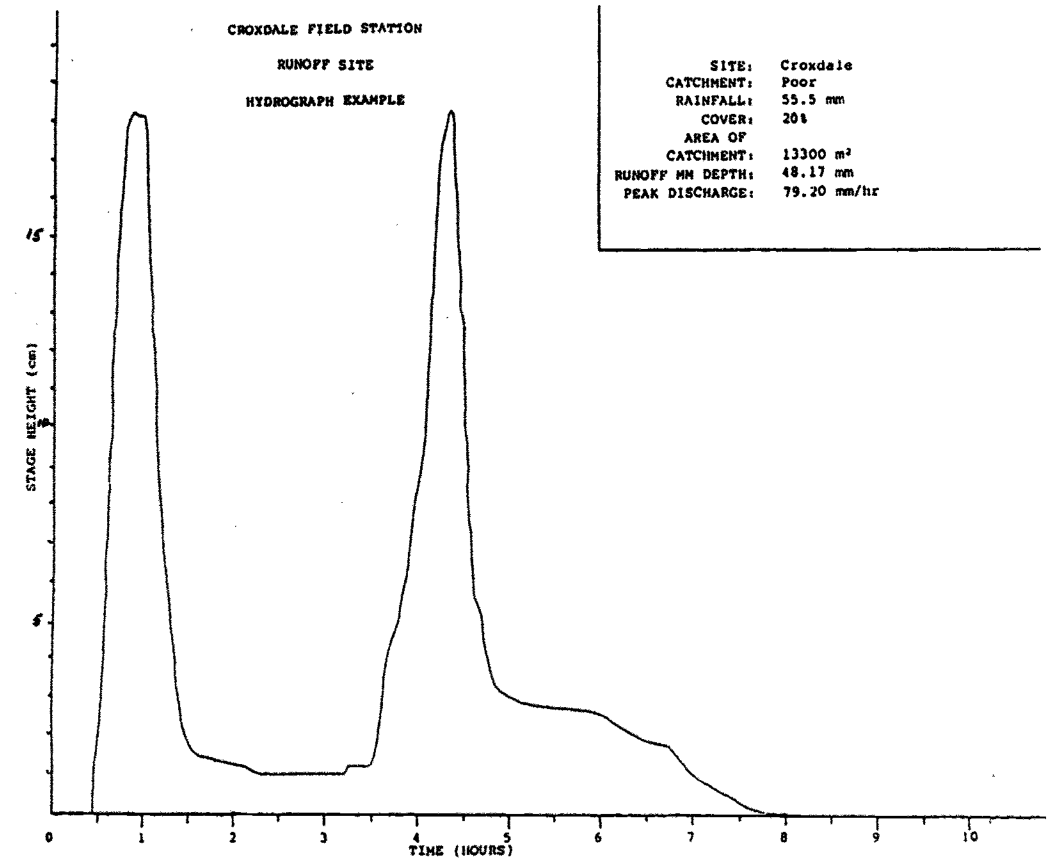


Figure 1. Runoff hydrographs of a single storm for two 1.2 hectare catchments, demonstrating the effect of vegetation cover on runoff in the mulga lands of south west Queensland.

(40% cover) peak rainfall intensities of > 21mm/hr were required before runoff occurred.

Soil moisture.
Field capacity and wilting point expressed as gravimetric soil water content (%) were found to be 12 and 4% respectively for the catchment soils. Average soil moisture after each rainfall event was consistently higher on the catchments with the greatest grass cover (Figures 2 and 3). However, soil moisture declined at a greater rate in the catchments with higher cover levels (40%), possibly due to higher levels of evapotranspiration. The rate of change in soil water levels is also reflected in the depth of soil with the soft mulga sites (with deeper soil profiles) having lower rates of decline particularly on catchments of lower cover levels.

The number of days in which average soil moisture exceeded wilting point for the catchments maintained at 20% and 40% cover was; for Croxdale 240 and 345 days out of 780 respectively and for Mayfield 322 and 349 days out of 570 respectively. The cooler months of Autumn and Winter account for the major period of time in which soil moisture exceeds 4% (Figures 2 and 3).

The rate of decline of soil moisture is reduced in the catchments once soil moisture falls below 4% (Figure 4). This supports the laboratory determination of 4% gravimetric soil moisture as wilting point for these soils.

The relationship between soil depth and soil water with time (Figure 4) indicates that the first ten centimetres responds rapidly to evapotranspiration. The response curve is similar on all sites. Below ten centimetres depth soil moisture declines less rapidly in the sites of lower cover than in the sites of higher cover levels. This suggests that the areas of higher cover are experiencing greater losses from transpiration. The plant roots appear to be effectively tapping the soil moisture to a depth of at least 50cm.

The effect of transpiration on soil moisture is governed by the density of plant material and this needs to be considered in the prediction of growth periods from available soil moisture. Areas of high cover receive greater infiltration and rapidly utilize this available soil moisture. On the other hand lower levels of cover are associated with lower levels of infiltration and the lower plant biomass means that available soil moisture is maintained for longer periods due to differences in total transpiration loss per unit area.

Soil loss.
Soil loss varied considerably between the catchments with total annual losses exceeding 3.57 tonnes per hectare from the hard mulga sites with 20% cover and 0.37 tonnes per hectare on the site with 40% cover and on the soft mulga 2.38 tonnes on the site with 22% cover and 0.63 tonnes on the site with 40% cover. Differences between the sites are due principally to rainfall patterns and cover levels at the time of events. Soil loss was most strongly correlated with rainfall ($P< 0.01$) $r=0.72$) and negatively related to cover ($P<0.01$) $r=0.68$). Variables such as intensity of rainfall and soil moisture

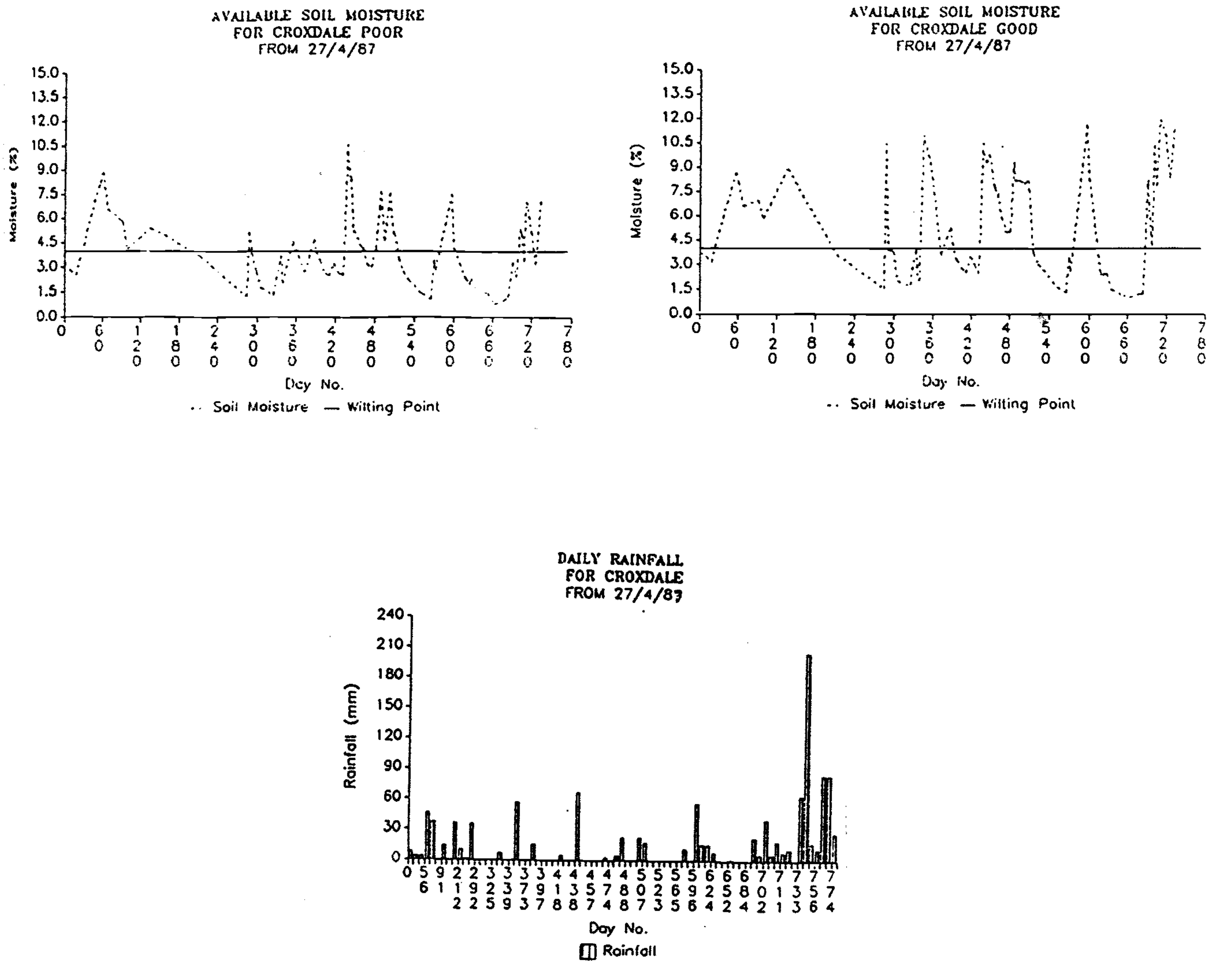


Figure 2. Relationship between rainfall and soil moisture on two catchments of differing cover levels in the hard mulga lands of south west Queensland.

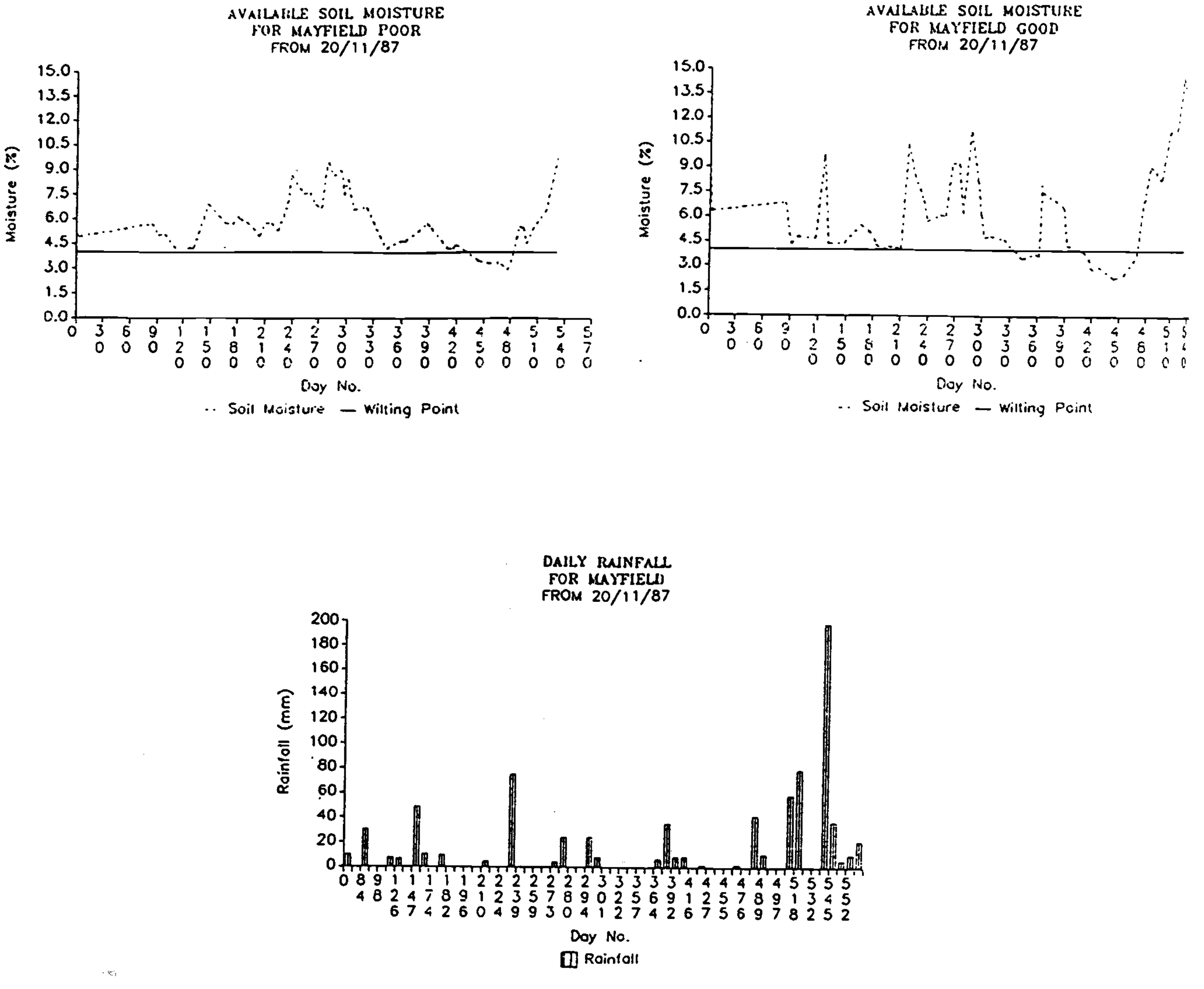


Figure 3. Relationship between rainfall and soil moisture on two catchments of differing cover levels in the soft mulga lands of south west Queensland.

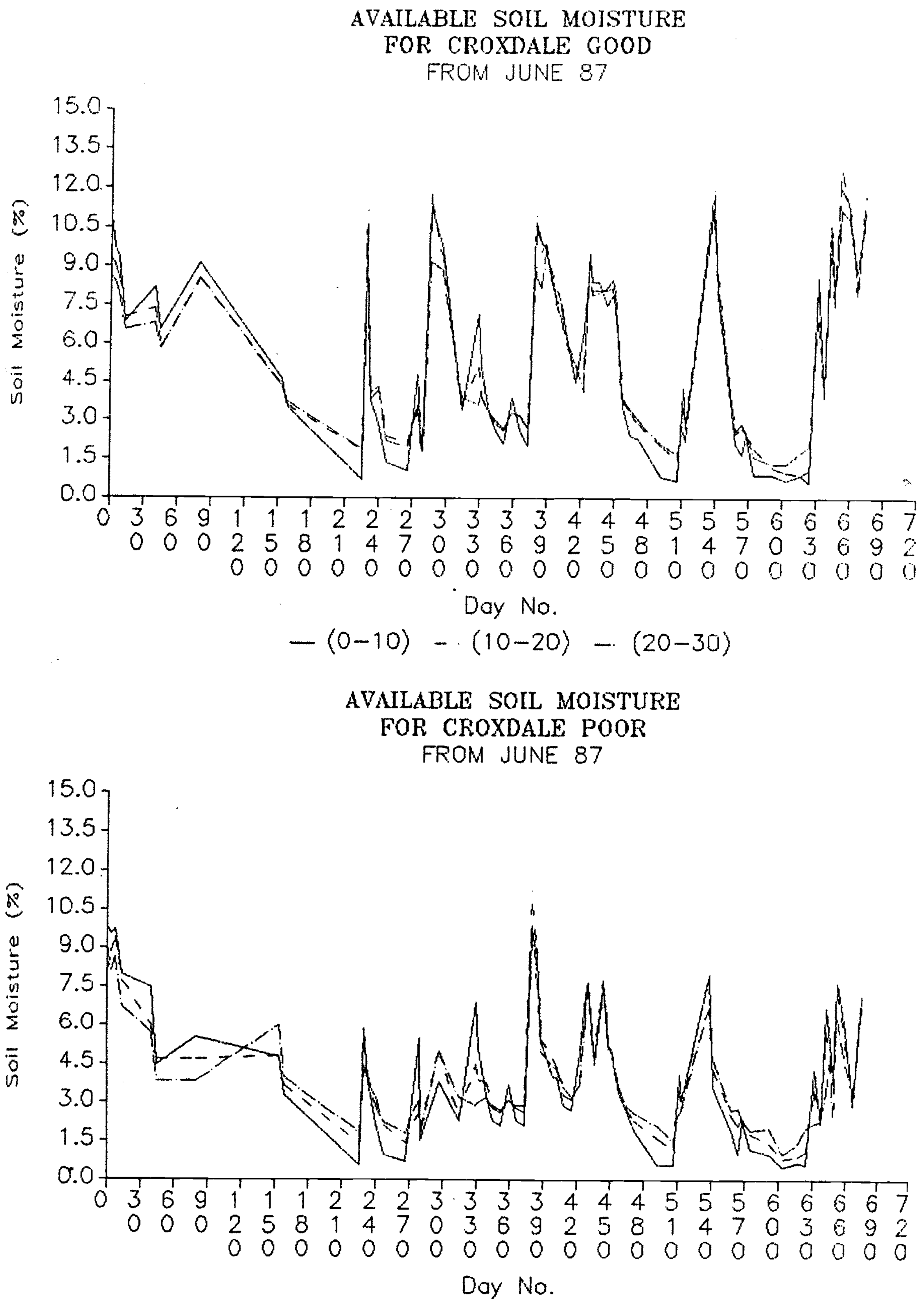


Figure 4. Relationship between soil moisture and soil depth over time for four catchments in the hard mulga lands of south west Queensland.

were also positively correlated while duration of rain was negatively correlated ($P<0.05$).

Multiple polynomial regression was used to define a model to predict soil loss combining both hard and soft mulga. The model defined includes only cover and rainfall, while other variables improved the fit they failed to significantly ($P>0.05$) improve the model. Model improvement through the inclusion of the additional variables was of the order of 5%. The model has the following form.

$$Y = 8.098R - 0.228C^2 \quad (SE=73.29)$$

where
Y = soil loss (kg/ha)
R = rainfall (mm)
C = grass canopy cover (%)

The model accounts for 83.9% of the variation in soil loss experienced on the catchments since 1987 with an adjusted squared multiple R of 0.683. Over this period of time peak storm intensities never exceeded 72mm per hour on the catchments. The model is not valid for falls of less than 10mm, which generally produce very little or no runoff. From the data set no differences were evident between the soft and hard mulga sites for similar cover levels. Losses of suspended sediment were 44% of the total soil loss. These values are consistent with the particle size analysis with silt and clay representing 46% which indicates that soil erosion caused by water is not particle size selective.

The highest loss recorded was from a 55.5mm fall with a 67mm peak intensity and duration over three hours 17 minutes on the hard mulga site with 5% cover. 288.25kg/ha were recorded for suspended load with 297.89 kg/ha of bed load. The peak discharge from a rainfall event was substantially attenuated by increasing cover levels. High vegetative cover levels reduced runoff velocity which in turn reduced energy levels of the runoff water and lowered its ability to carry sediment. While cover reduced peak discharge it also extended the duration of discharge (Figure 1).

Surface temperatures and penetrometer readings.

Surface temperatures on bare soil were recorded as high as 65°C in the first centimetre of soil at 38.5°C air temperature. For the same air temperatures under the grass canopy cover the temperatures of the first centimetres of soil was only 31°C. At these temperatures seedlings on the bare areas were rapidly burnt off and died while on the grassed areas they persisted and established to maturity.

Surface crust strengths provided little insight as to the differences in infiltration between the catchments relative to cover. Drop cone penetrometer readings showed an increase in surface crust strength with time since rainfall ($P<0.05$), though variations between and within different types of cover prohibited any meaningful interpretation ($P>0.05$).

DISCUSSION

The results have quite clearly shown that both runoff and soil loss increased with lower levels of vegetative cover. The implications of this from a productivity point of view are important. Not only is there reduced soil moisture content for plant growth with lower levels of cover but the erosion has the potential to drastically affect productivity through lost nutrients. Recent findings of Miles and Baker (in press) supported by Charlie and Cowling (1968) and Friedel (1984) indicate that minor soil loss in lateritic red earths is critical to plant growth. In the mulga lands of south west Queensland 70% of the soil nutrients are found in the first two centimetres and 90% are accounted for in the first three centimetres (Miles and Baker, in press). Soil loss from the catchments with 20% vegetative cover are of the order of 0.5mm per year however much of the mulga lands of western Queensland have cover as low as 2% for the majority of the year. These are predicted by the model to give soil losses of 0.8mm year. While these levels are still relatively low the rate of soil loss is sixteen times that experienced in areas of good cover (40%).

The soil loss coupled with runoff means that styles of management that create low cover have also reduced productivity through limited available soil moisture and reduced nutrient status. Potential soil moisture is reduced by 40% on 20% cover whereas 40% cover realizes only a 10% loss of infiltration through runoff.

If we assume no loss of nutrients due to runoff then the work by Rickert and McKeon (1982) provides a comparison of the potential loss of plant growth through rainfall. The relationship for a mulga community, between rainfall and primary productivity of the pasture if assumed linear, is equal to 2.04 times the rainfall (kg/ha). Charleville receives a 500mm average rainfall the maximum potential plant growth for the 40% cover site would therefore be 922 kg of dry matter production annually, given the 10% loss due to runoff. On the site with low levels of cover the potential production based on the 40% loss of rainfall is 520 kg/ha of dry matter production. These are based on the assumption that there are sufficient plants to exploit the available soil moisture. Basal areas of 4% represent the basis of the model. The basal areas of the runoff sites were 3.4% maximum on the Croxdale good catchments and 4.0% maximum on the Mayfield good catchments. The biomass measured at the end of the growth period (March)(Christie and Hughes 1983) was 726 and 740kg/ha respectively. At the same time the dry matter yields were 367kg/ha for the Mayfield poor catchment with a basal area of 2.2 and on the Croxdale poor catchment 35 kg/ha for a 0.2% basal area.

Domestic and native animals on the catchments had consumed some of the biomass before the end of summer measurement was taken for this comparison. A small part of the vegetation dry matter recorded, particularly on the good catchments, was seasonal carry over material. Considering these anomalies the example adds support to the pasture production model of Rickert and McKeon (1982).

Based on this information stocking conservatively to maintain vegetation cover at levels of 40% or better will provide a more sustainable and higher level of productivity than higher levels of stocking where vegetation cover is reduced below 20%. The differences in productivity through higher rates of infiltration alone is 77%. The additive and possibly multiplicative affect of soil and nutrient loss would widen the gap between the productivity of these two grazing strategies. Preliminary results of a pot trial by the author assessing the effects of soil loss on plant growth in the mulga lands indicate that a 1cm loss of soil reduces by half above ground production. The trial is based on a non limiting water supply and undisturbed soil cores of soft mulga soil. Previous studies by Pressland and Cowan (1987) in the mulga lands used two levels of soil removal, five and ten centimetres, to predict the effect of soil loss on productivity . Their data suggested a linear relationship existed between productivity and soil loss, and a total above a below ground reduction in productivity of 50% for the 5cm soil loss. That study however was based on disturbed and mixed soil material. Such an approach influences the distribution of soil nutrients.

The lateritic red earths of the Mulga Lands are inherently self sealing. The removal of vegetation rapidly results in a collapse of the soil surface and sealing. The exposed surface is rapidly colonised with cryptogams and this further reduces infiltration and impedes soil loss (Greene and Tongway 1988). This characteristic is possibly principally responsible for low soil losses in areas of low cover. The question that this raises hinges on the role of natural erosion. Do geomorphic factors outweigh the influence of man's activities ? Pickup and Chewings (1987) report that the mulga lands comprise of a series of erosion cell mosaics and that the cells comprise of deposition, transition and erosion areas. Pickup and Chewings (1987) suggest that the size or proportion that each cell represents in an area changes with time. The data of Mills, Cattabiano and Turner (1989) suggest that the erosion cells are increasing in size with pastoral activities and that the deposition areas are declining. Work by Miles and Campbell (in press) using the radio active isotope Caesium 137 to measure erosion over the last 30 years in the mulga lands of south west Queensland suggest that erosion products are generally removed from the catchments and not relocated within the catchments. On the basis of this data and the comparisons between the good and poor catchments it is evident that man's activities are accelerating the erosional processes and that careful management can prevent this.

On the basis of the findings reported here it is apparent that the maintenance of vegetation cover is a critical factor in maximising production in the mulga lands. More importantly it is the maintenance of cover that will lead to the sustainability of that production. At present graziers in the mulga lands of south west Queensland make extensive use of browse trees *(Acacia anuera)* in dry times to maintain stock numbers (Mills 1986). This is at the expense of the grass cover. When droughts break stock numbers are high and cover levels low.
This results in high levels of grazing pressure on re-establishing pastures. New seedlings are damaged and older grasses are eaten off before they have a chance to set seed. As a consequence soil seed reserves decline and basal area diminishes with time (Dawson and Boyland, 1974). If graziers are to maximise and sustain production by reducing runoff and erosion then changes in current management strategies are required. There is a need to develop education programmes which will demonstrate the importance of flexible and conservative stocking strategies. This paper has clearly demonstrated the

importance of cover in minimising runoff and erosion and the substantially high levels of productivity that it provides. Unless changes in management strategies are adopoted that will minimise runoff and erosion there is little point in attempting to reclaim the extensive degraded areas of the mulga lands as reported by Mills (1986) and Mills *et al.* (1989).

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