LAND AND VEGETATION DEGRADATION BY SOIL EROSION AND SALINIZATION IN THE WESTERN AUSTRALIAN WHEAT BELT

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Abstract In the W.A. Wheat Belt, there are serious soil erosion and salinization in farmlands. Field studies were carried out in 1983 to observe soil erosion, salinization and related environmental changes caused by European settlement and to consider their interrelationships. Soil erosion seems to be related to the spread of soil salinity. Both effects have been caused by the replacement of native vegetation with agriculture. Soil erosion appears to begin with the instability of the surface layer on relatively gentle slopes with high content of cations and phosphorus, which suggests a link between salinization and fertilization by the application of fertilizer to promote growth. The distribution of dead trees standing along small streams indicates that a road embankment over the valley has changed the hydrology and salinity. Such changes have caused retrogressive plant succession. Land and vegetation degradation on the lunette is also significant.

1. Introduction

In the semi-arid zones of Australia, man-induced environmental changes such as soil erosion, salinization and the remobilization of sand dunes have been caused by European settlements, which have brought serious land degradation problems (Toya *et al.*, 1985).

Salinization has restricted the growth of cultivated plants, and soil erosion has destroyed farmland itself. These two phenomena have been initiated by the European

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clearance of vegetation for agricultural development. It is said that salinization is caused by evaporation of soil moisture and soil erosion by raindrop splash and the concentration of running water. However, these two phenomena associated with the progress of agricultural development are expected to have complicated interrelationships.

For an understanding of these phenomena, Western Australian Wheat Belt between Jerramungup and Newdegate (Fig. 1) was selected for the field study which was carried out in September 1983. In this study area, soil erosion, salinization and vegetation degradation were observed and their interrelationships were considered. The main objective in this study was to identify and describe the unstable surface layers and to examine these in relation to soil chemical properties and vegetation degradation.

2. Regional Setting of the Study Area

Bio-physical features

The study area is located on the Great Plateau of Western Australia, at an elevation of 200 - 300 m, about 350 km southeast of Perth (Fig. 1). The area has a basement of Precambrian granites and gneisses which are often mantled by a weathered laterite

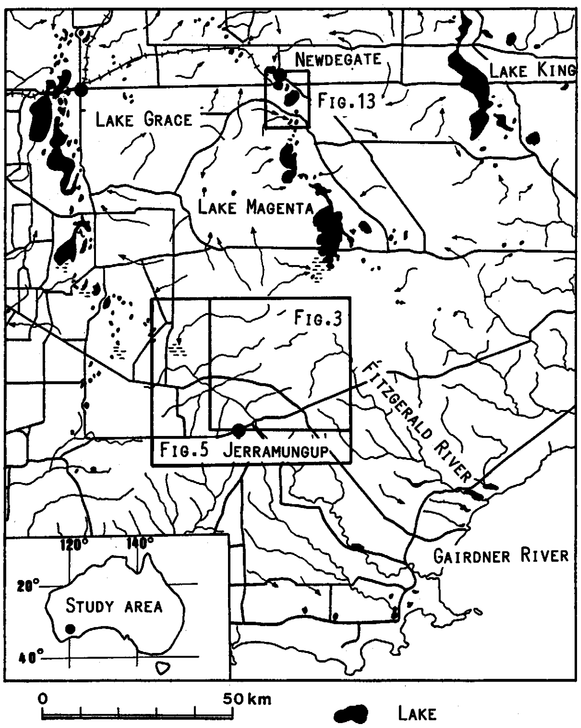


Fig. 1 Locality plan showing the study areas in the southeastern Wheat Belt of Western Australia.

profile; the granitic rocks outcrop sporadically. It is a landscape of very low relief with the drainage system comprising broad flat valleys occupied by many lakes, swamps, and clay pans; most of these have lunettes on the lee side, *i.e.*, the southeast side. These ancient valleys are not functional except during times of exceptionally heavy rainfall. The minor tributaries presently dissecting the granitic and lateritic interfluves are very shallow and have only seasonal flow.

Natural vegetation of the Jerramungup study area is shown in Fig. 2 (Beard, 1976). Scrub heath and Mallee heath are distributed on the dry and shallow soils on the gentle crest slopes of granitic hills. The middle slopes are dominated by Mallee with *Eucalyptus eremophila, E. oleosa, E. redunca, E. uncinata* being the most common species. On the lower slopes near stream channels, Yate (*E. occidentalis*) woodland with Mallee is typically distributed. These natural vegetation types are preserved in the Conservation Park though they have been affected by intense fires (Crook and Burbidge, 1982).

Land use history

Western Australia was not settled until 1829 and virtually all its farmland has been developed since the beginning of this century (around 1908). The greater part of this development occurred in the past 50 years, mostly on the infertile lands of the cereal and

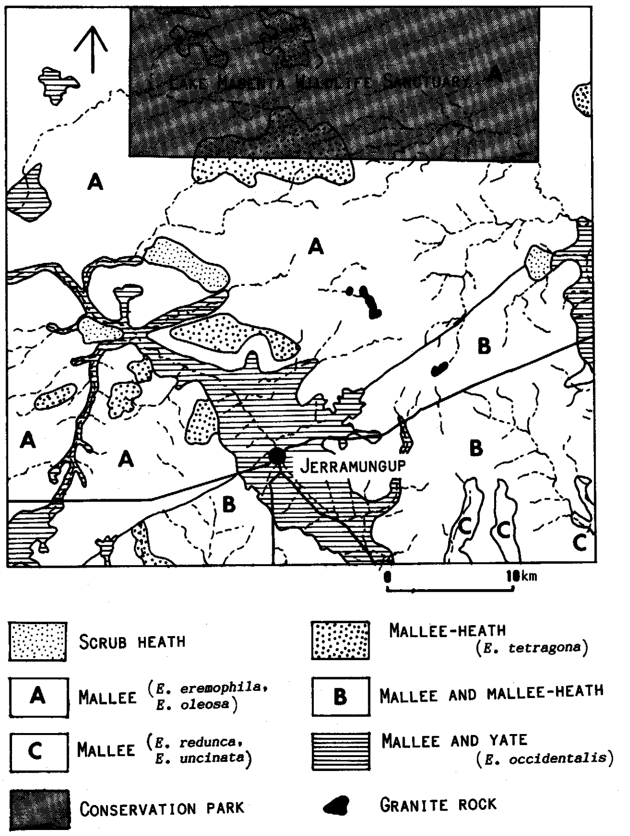


Fig. 2 Natural vegetation zone of the Jerramungup study area (after Beard, 1976, simplified).

sheep dryland farming zone during the period, 1948-1968. In this area the vegetation clearance was begun around Lake Grace and expanded eastward to Newdegate. The distribution of farmlands around 1913, when most of the land was not cleared, concentrated about Lake Grace and the farm size was rather small. By 1933 the farmlands expanded to the north-eastern and eastern parts of Lake Grace. By 1962 the distribution of farmlands spread over the area between Lake Grace and Newdegate except some conservation parks and water-supply areas.

In the area near Jerramungup, the clearing of land was developed as shown in Fig. 3. A few farm lands were distributed only along the Gairdner River and Fitzgerald River around 1913. The situation had changed little until around 1955 (Fig. 3a). During this period, most of the farm were restricted to small size, because of the shortage of annual rainfall and the inexperience of farming. In May 1955, a vast area of uncleared land northeast of Jerramungup was selected as the Conservation Park (Lake Magenta Wildlife Sanctuary). After its selection the clearance of land in this area (at the south of the Conservation Park) was intensively developed (Fig. 3b), and by 1967 the farmland spread over this area.

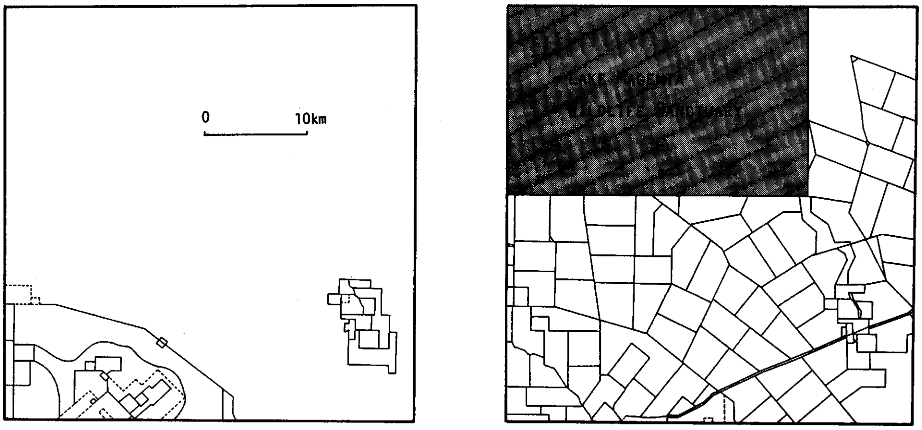


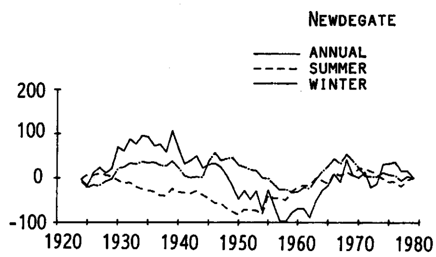
Fig. 3 Distribution of farmlands around Jerramungup in 1955 (Fig. 3a, left) and 1967 (Fig. 3b, right).

Climatic change and variability

In the south-western part of Western Australia the annual rainfall decreases progressively from about 750 mm at the western margin of the cereal zone to 270 mm in the east, with a concentration of wheat growing in the 270 mm to 450 mm rainfall belt. The study area occurs in the lower annual rainfall belt (350 mm to 400 mm) where wheat growing is the main farm activity, but with the sheep raising and some oat and barley cropping.

To clarify the climatic change and variability in this area, residual mass (RM) graphs of rainfall (Foley, 1957; Ohmori *et al.*, 1983; Iwasaki, 1984) were examined at Newdegate and Jerramungup (Toya *et al.*, 1985).

RM graphs of annual, summer and winter rainfall were examined to compare the



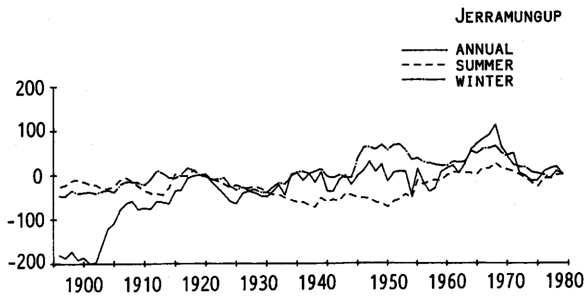


Fig. 4 Residual mass graphs of annual, summer and winter rainfall in the W.A. Wheat Belt.

rainfall variation in this region with that in the others (Iwasaki, 1984). RM graphs (Fig. 4) reveal that the rainfall variation of Newdegate belongs to the inland winter rainfall region, but the variation of Jerramungup resembles the coastal winter rainfall region. Therefore, the study area is at the southern end of the inland winter rainfall region and at the northern end of the coastal winter rainfall region.

The RM graphs also reveal that there were two wet periods: one at the beginning of this century, the other from the middle of 1958 to the middle of 1968. The RM graph of Newdegate shows the continuous dry period from 1936 to middle of 1958, especially from 1947 to 1958. In Lake Grace sand dune remobilization is said to have started around 1950, which was long after the vegetation clearance in 1928 and corresponds well to the period of significant decrease on RM graphs of Lake Grace and Newdegate (Ohmori *et al.*, 1983). However, the RM graph of Jerramungup doesn't reveal such a trend. The month to month or year to year variation of the two stations is very similar. These observations mean that local factors are included in the long-term rainfall variation of this region. The period since 1968 has been relatively dry, a trend shown in both graphs, which may have magnified the man-induced environmental changing phenomena in this area.

3. Soil Stratigraphy and Soil Chemistry on the Hill Slopes

Soil erosion and soil stratigraphy

In this area there is serious soil erosion in farmland where sandy surface materials become unstable. Field survey was carried out to identify and describe the unstable

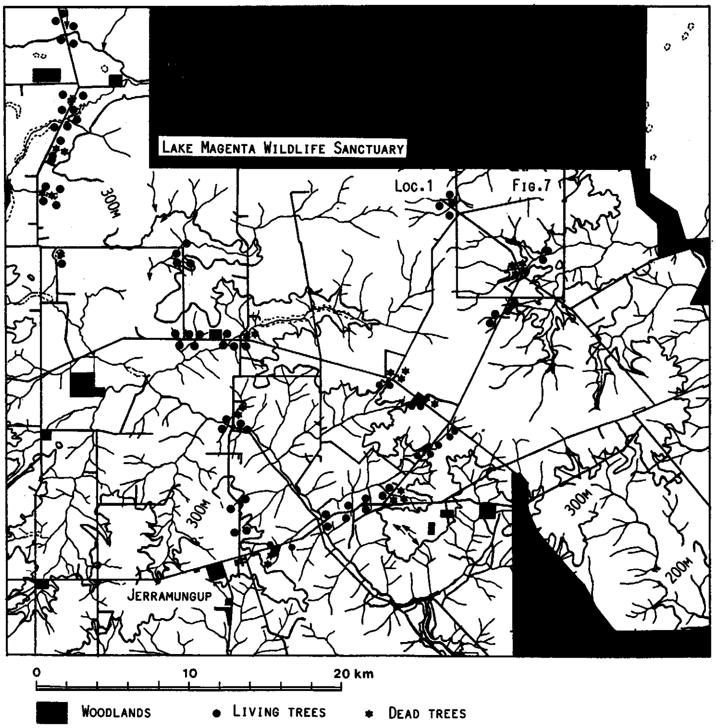


Fig. 5 The Jerramungup study area showing cleared and uncleared land and the incidence of dead and living trees on cleared land.

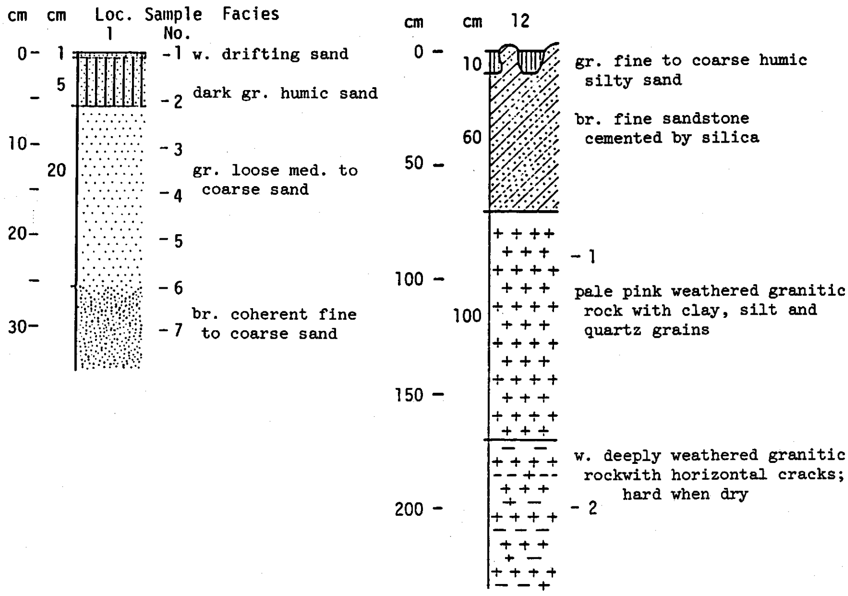


Fig. 6 Soil stratigraphy at Locations 1 and 12. Sample No. indicates the horizons for chemical analysis.

surface layers and to examine these in relation to soil chemical properties.

The soil erosion is presumed to be related to the spread of soil salinity (Conacher and Murray, 1973; Conacher, 1982). Salinization is also evident along the minor streams where trees and shrubs have recently died (Fig. 5). These effects are presumed to be caused by replacement of native vegetation with agriculture and thus allowing saline ground water to reach the soil surface.

Soil stratigraphy was studied in undisturbed land in a Nature Reserve (Loc. 1, Fig. 6) where three layers were identified. The uppermost layer of about 5 cm thick consists of dark grey humic loose sand, with a thin surface of white sand which had mobilised after a recent bushfire or had drifted in from a near-by lake area. The second layer, from 5 to 25 cm in depth, is grey loose sand which is clearly differentiated from the third layer consisting of brown coherent sand originating from aeolian or residual quartz sand of late Tertiary and early Quaternary age. The third layer is very hard when dry and tends to develop a columnar structure with columns shaped like non-sorted polygons. Weathered granitic basement occurs beneath these layers (Loc. 12, Fig. 6). These layers were also seen on agricultural land, but the cultivated horizon with the depth of 10—20 cm has been formed in the uppermost layer.

Soil chemical properties

Soil layers in the Reserve were compared with similar land under cultivation (Figs. 7, 8 and 9). The results are shown in Table 1 and Fig. 10. It is clear that, in the Reserve exchangeable cations increase towards the lower layers while in farmland the highest content is in the uppermost layer. Also the total exchange capacity and available phosphorus are higher in cultivated land. This is expected because phosphatic fertilizer has been applied causing increased growth and biological activity in the soil and so raises the level of the exchange complex. The relationship between fertility level and topographic position indicates that low gradients favour accumulation of phosphorus and cations. Thus the levels are high on crests of hills, low on slopes, and increase again in lower topographic positions (Fig. 8).

The figures of electric conductivity, exchangeable sodium percentage and soil pH in Table 1 indicate significant salt accumulation and alkaklization in the surface horizon of hill slopes in Jerramungup. Jerramungup saline soils can be classified into three groups; saline soils (Locs. 2, 3 and 11), non-saline alkaline soils (Loc. 9) and saline alkaline soils (Loc. 10) according to the classification system of Richards *et al.* (1954).

The vertical distribution of nutrients in farmland is different from that of the Reserve. Thus phosphorus decreases with depth while cations show a high-low-high pattern (Fig. 9, Locs. 8, 9 and 10). Laterite (Loc. 12) shows relatively high content of cations compared with the surficial layers. This indicates that Europeans cleared the land causing salinity and also added fertilizer which raised the nutrient level in the surface soils. The salt accumulation may be caused by the evaporation of soil moisture from the surface leaving a residue of salts. Alternatively it may be due to higher organic matter content.

Soil erosion appears to begin with the instability of the surface layer, on relatively gentle slopes such as crests and foot slopes, which then extends as finger-shaped erosion

Fig. 7 Study area showing incidence of soil erosion area on hill slopes and locations of stratigraphic sections.

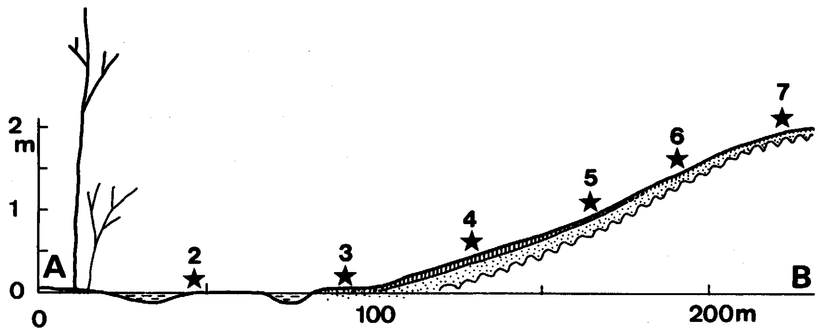


Fig. 8 Section along transect A-B (Fig. 7) showing soil statigraphy and sampling sites 2 to 7.

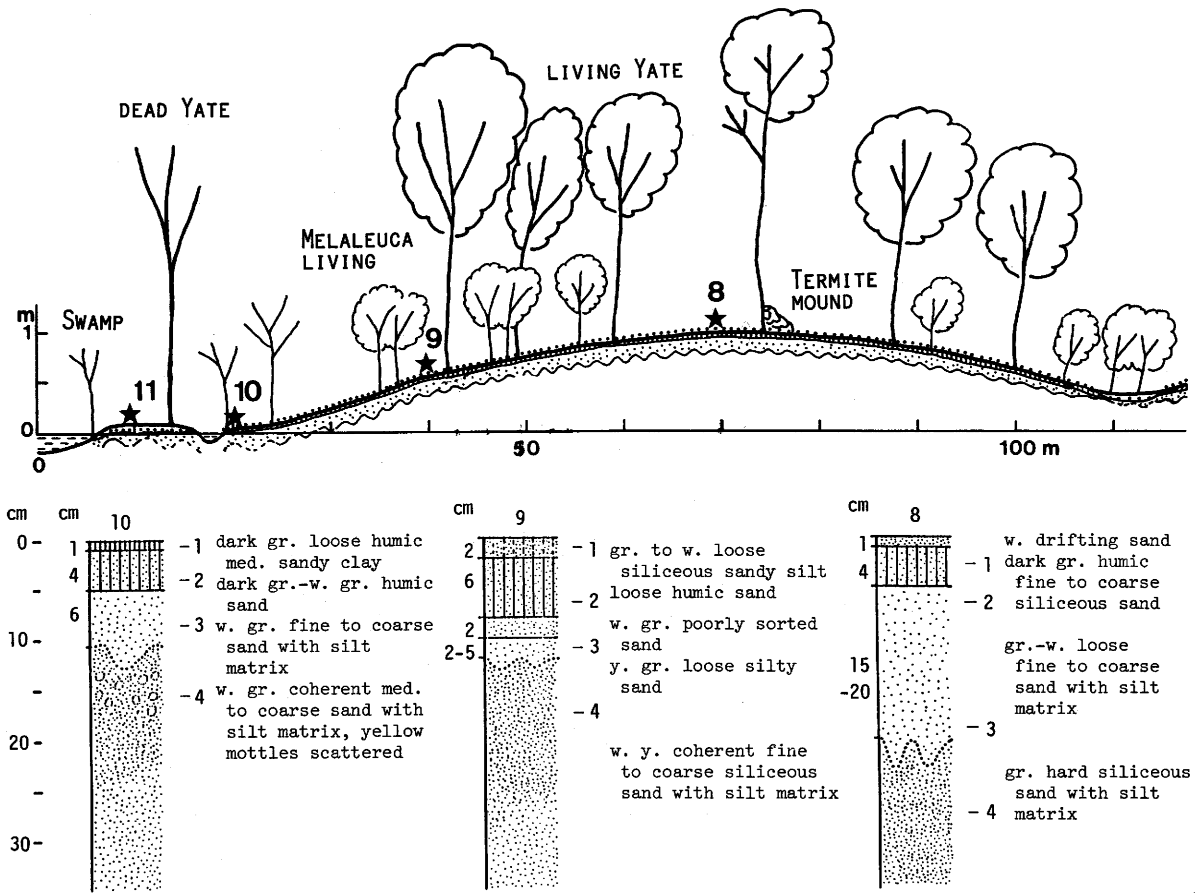


Fig. 9 Section along transect C-D (Fig. 7) showing soil stratigraphy and sampling sites 8 to 11.

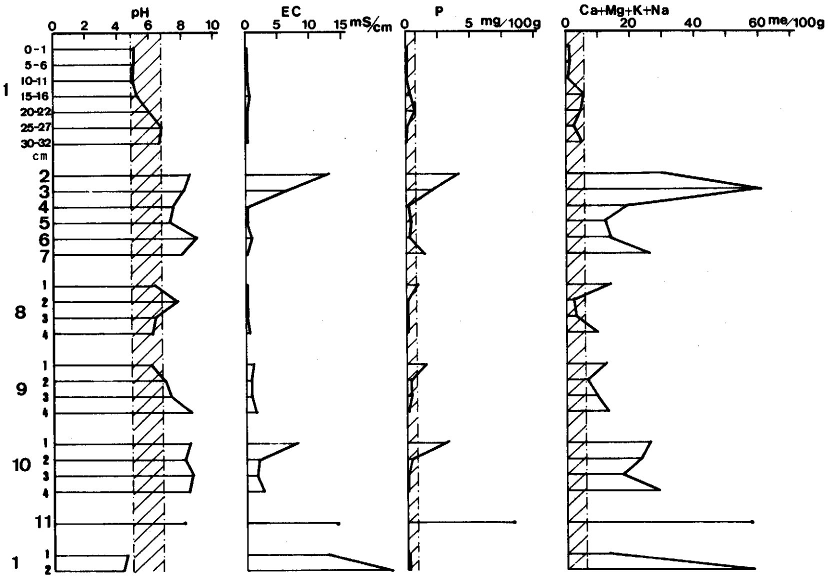


Fig. 10 Chemical properties of soils in the Jerramungup study area. Locations and sample numbers are shown in Figs. 5, 6, 7, 8 and 9.

Table 1 Chemical composition of soils in the Jerramungup study area

Loc.	No.	Texture	pH		EC	C	N	C/N	Available	Exchangeble Cations; me/100g				
			H_2O	KCl	mS/cm	%	%		P; mgP/100g	Ca	Mg	K	Na	Total
1	1	LS	5.12	4.94	0.039	0.0853	0.0061	13.8	0.08	0.50	0.06	0.21	0.12	0.89
1	2	SL	5.05	4.41	0.142	0.517	0.0208	24.8	0.08	0.42	0.18	0.34	0.48	1.42
1	3	SL	5.00	4.39	0.067	0.039	0.0145	21.2	0.14	0.25	0.10	0.29	0.23	0.87
1	4	SL	5.31	4.96	0.617	0.1578	0.0073	21.3	0.40	1.02	1.32	0.25	2.74	5.33
1	5	SL	6.12	4.95	0.052	0.1476	0.0063	23.3	0.74	2.36	1.68	0.22	0.19	4.45
1	6	L	6.83	4.70	0.073	0.2591	0.0128	20.2	0.06	0.46	1.29	0.20	0.41	2.36
1	7	SiL	6.72	4.65	0.110	0.3961	0.0294	13.5	N.D.	0.51	2.50	0.28	1.59	4.88
2		LiC	8.49	8.49	12.9	2.68	0.154	17.4	1.90	10.7	2.73	1.10	15.2	29.69
3		SCL	8.05	7.65	6.40	1.93	0.109	17.7	1.90	9.98	26.6	0.64	23.3	60.52
4		L	7.53	5.91	0.350	0.732	0.0456	16.1	0.19	1.12	14.8	0.61	3.32	19.84
5		SiL	7.22	6.40	0.228	1.32	0.0738	17.9	0.44	4.01	5.84	0.71	1.44	12.00
6		SiL	9.00	8.21	1.04	0.626	0.0229	27.3	0.26	2.59	8.57	1.07	1.82	14.05
7		SiL	8.08	7.40	0.288	2.09	0.0836	25.0	1.40	16.2	7.68	0.86	1.06	25.80
8	1	SL	6.35	5.40	0.098	1.74	0.0715	24.3	0.94	8.40	3.97	0.36	0.33	13.06
8	2	SL	7.70	6.32	0.053	0.357	0.0109	32.6	0.18	0.90	0.36	0.38	0.62	2.26
8	3	SL	6.43	6.14	0.204	0.167	0.0065	25.3	0.19	1.70	0.79	0.37	0.40	3.26
8	4	SL	6.20	4.90	0.852	0.335	0.0101	33.1	0.14	0.13	4.61	0.74	4.31	9.79
9	1	SL	6.05	5.68	1.02	2.69	0.118	22.8	1.37	5.04	3.39	0.57	3.02	12.02
9	2	SL	6.92	6.23	0.802	0.786	0.0313	25.1	0.32	2.67	2.81	0.42	0.29	6.19
9	3	SiL	7.30	6.64	0.833	0.522	0.0236	22.1	0.34	1.92	3.44	0.50	3.62	9.48
9	4	LiS	8.63	7.62	1.59	0.259	0.0089	28.9	0.17	2.75	3.56	1.15	5.11	12.57
10	1	SL	8.50	8.60	7.71	1.60	0.0548	29.1	3.00	4.84	7.84	0.69	12.2	25.57
10	2	LS	8.22	7.83	1.82	0.257	0.0061	41.9	0.35	0.46	14.4	0.27	7.91	23.01
10	3	SL	8.63	7.68	1.78	0.136	0.0084	16.1	0.04	0.12	2.91	0.65	13.6	17.30
10	4	SL	8.52	7.91	2.94	0.118	0.0050	23.3	0.19	0.40	5.04	0.94	22.0	28.34
11		LiC	8.10	8.15	14.0	3.53	0.17	20.7	8.25	8.76	7.46	0.98	40.2	57.40
12	1	SiL	4.53	4.30	12.9	0.153	0.0019	12.8	0.11	0.52	11.2	0.60	0.60	12.92
12	2	SiL	4.25	4.11	22.3	0.0944	0.0068	13.8	0.21	0.51	24.4	0.98	31.2	57.06

areas. These initial areas of soil erosion are generally co-incident with areas of high content of cations and phosphorus in the surface of gentle slopes. This suggests a link between erasion and the practice of clearing, applying fertilizer and cultivating the land (Hodgkin *et al.*, 1979).

4. Land and Vegetation Degradation

Vegetation degradation on the lowland on the hill slopes

Figure 2 shows the major distribution of "Mallee and Yate woodland"; Yate woodland also occurs along the small streams. Such small-scale stands of Yate woodland were destroyed not only by vegetation clearing but also by the change in soil condition, especially salinization.

The distribution of dead trees standing along small streams indicates that a road embankment over the valley has changed the hydrology and salinity. All dead trees are up stream from the embankment where there is evidence of a seasonal rise in surface water level to make swamps (Fig. 5). Salt content in both water and soil (Locs. 9, 10 and 11) confirm that levels are sufficiently high to cause death of trees. The rise of water level causing the decay of tree root and the high saline content causing physiological damage to vegetation are presumed to have caused a number of dead trees; there are no dead trees down stream from the road.

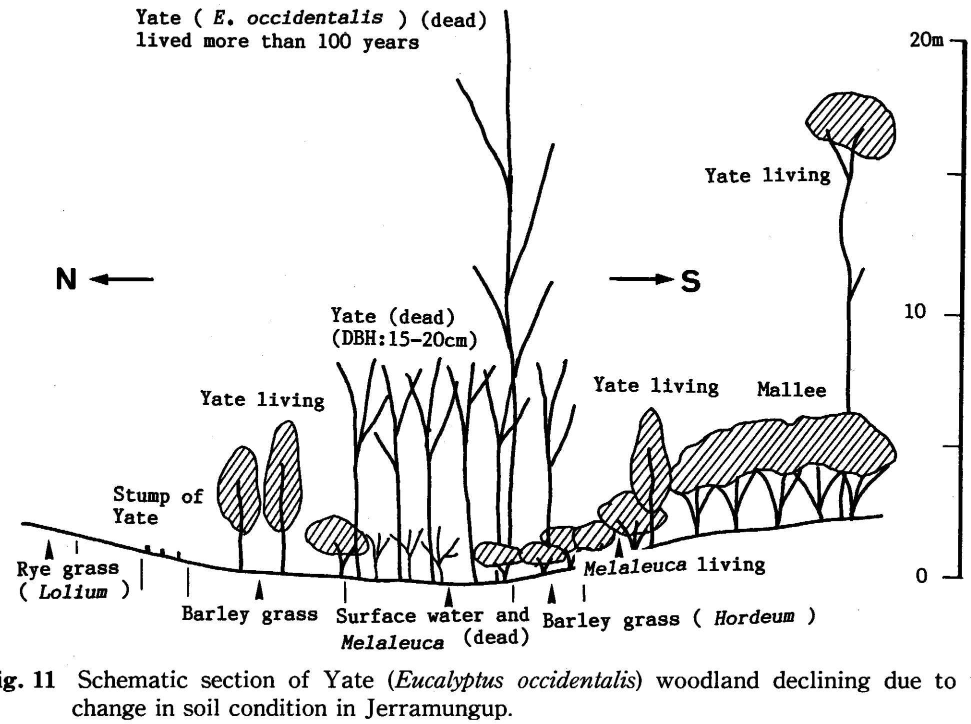


Fig. 11 Schematic section of Yate (*Eucalyptus occidentalis*) woodland declining due to the change in soil condition in Jerramungup.

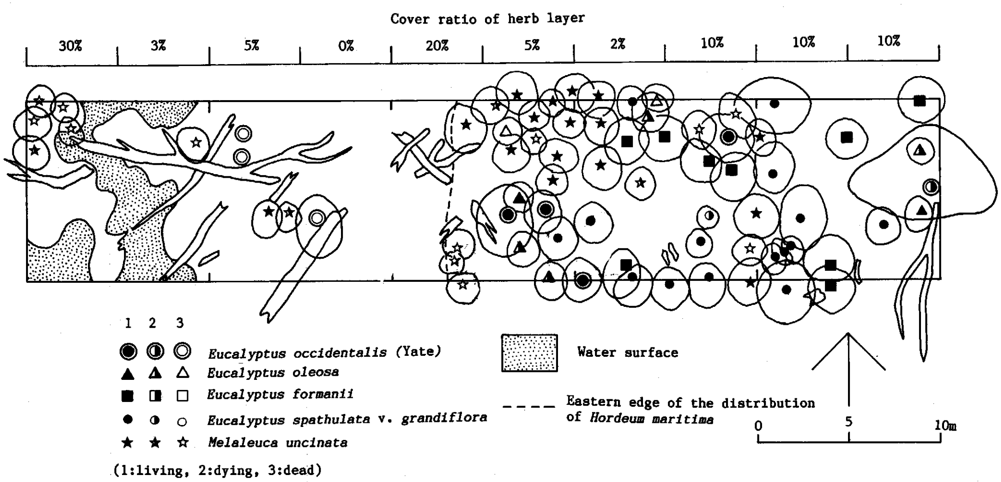


Fig. 12 Transect survey of Yate woodland declining due to the change in soil condition in Jerramungup.

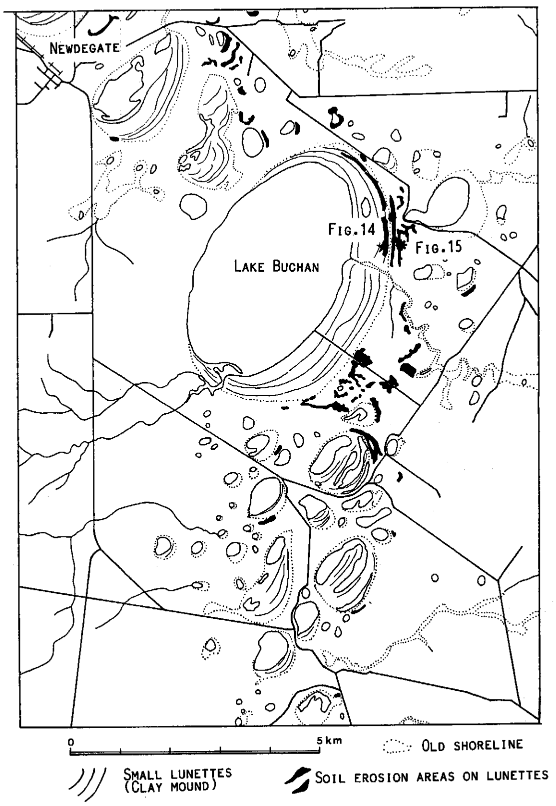


Fig. 13 Newdegate study area showing current distribution of lakes, lunettes and eroded areas in relation to formar shorelines.

Figures 11 and 12 show the schematic profile diagram and crown projection diagram of Yate woodland and these show clearly the process of vegetation degradation. The east side of Fig. 12 was dominated by Yate woodland with mallee in the pre-European days, while the west side was dominated by Yate woodland with *Melaleuca* scrub. Retrogressive plant succession from normal vegetation to salt-tolerant vegetation resulting from changes in soil condition on the lower surface is (1) tall Yate woodland —(2) low Yate woodland—(3) *Melaleuca uncinata* low scrub—(4) Salt barley (*Hordeum maritima*) grassland.

It is concluded that, in addition to the salinization, the rise of water level due to road construction seems to play an important role in vegetation degradation. However, from an interview with the land-holder, it seems that fire may have had some additional influence on vegetation degradation.

Soil erosion and vegetation degradation on lunettes

Vegetation degradation resulting from soil erosion on lunettes is also significant in this area. Figure 13 shows the current distribution of lakes, lunettes and eroded areas on lunettes around Lake Buchan near Newdegate. Soil erosion initiated by the careless vegetation clearance on this lunettes is said to have started more than 30 years ago.

Big mallee roots (lignotubers) of dead York gum (*Eucalyptus loxophleba*), with a height of 17 m and DBH of 40-50 cm, are exposed on the crest part of a lunette of Lake Buchan (Photo 1), indicating that surface lowering of lunette crest by water and wind erosion is more than 1.5 m. Other evidence shows surface lowering is at least 25 cm even on vegetated surfaces. Such surface lowering due to soil erosion associated with salinization is considered to have caused the death of York gum on the lunette.

Stratigraphic observation revealed that numerous rabbit burrows are scattered in the uppermost loose sand layer (Fig. 14). The rabbit (*Olyctolagus cuniculus*) is the most

Photo 1 Exposed mallee roots of dead York gum (*Eucalyptus loxophleba*) on an eroded lunette of Lake Buchan.

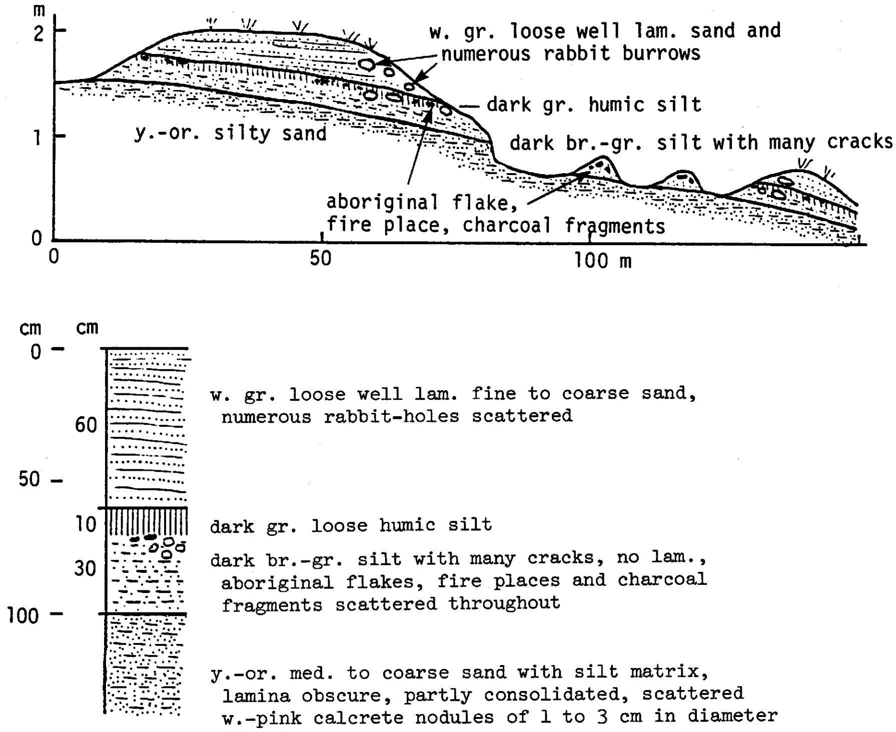


Fig. 14 Soil stratigraphy at the north-eastern part of the lunette of Lake Buchan (Fig. 13) showing numerous rabbit burrows in upper horizons consisting of loose sand and silt.

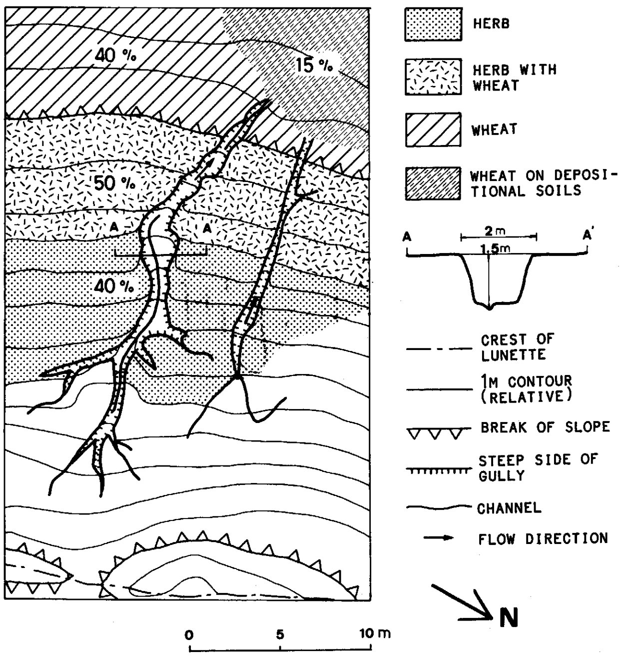


Fig. 15 Soil erosion and plant cover on the lunette of Lake Buchan (Fig. 13).

abundant feral animal introduced by European settlers in the Australian Continent and it has damaged many farmlands. Soil erosion is considered to have been exacerbated by such rabbit burrowing.

On the footslopes of lunettes, where erosion and deposition have been active, herbs and grasses have become established but, at this stage, the density is low on erosional and depositional surface (Fig. 15).

5. Concluding Remarks

As mentioned above, field study was successfully carried out to understand the land and vegetation degradation by soil erosion and salinization in the W.A. Wheat Belt between Jerramungup and Newdegate. Results obtained from this study can have been summarized as follows:

Accumulation of cations and phosphorus, which suggests a link between salinization and fertilization, is significantly recognized in the surface horizon of soils in farmland, but not in the soils in reserve covered with native scrub. Salinization is considered to be caused by the replacement of native vegetation with agriculture. Fertilization was brought by the European practice of applying fertilizer to promote growth.

Occurrence of soil erosion is significant on the low-gradient slopes such as crests and shallow valleys with high levels of cations. Soil erosion appears to begin with the instability of the uppermost layer of saline soils on such slopes. Soil erosion and salinization bring combined effect on this area.

Salinization occurs on the shallow valleys dissecting the granitic hills. Road embankment over the valley has brought the rise of water level and salinization up stream, which has caused a number of dead Yate (*Eucalyptus occidentalis*) trees; there are no dead trees down stream from the road. Salinization up stream further brings retrogressive plant succession from native shrubs to salt-tolerant weeds.

Vegetation degradation resulting from soil erosion is also significant on the lunettes. The spread of soil salinity and burrowing by the European rabbit have exacerbated the

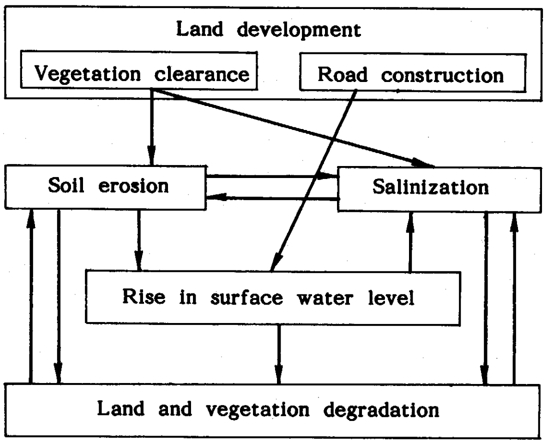


Fig. 16 Interrelationships among land development, salinization, soil erosion, and the land and vegetation degradation in the W.A. Wheat Belt.

soil erosion. Cover ratio of vegetation on erosional surface is low, which seems inadequate to prevent the continuous soil erosion.

Interrelationships among land development, soil erosion, land and vegetation degradation are schematically presented as Fig. 16. For the understanding of whole process and the establishment of the countermeasures to prevent such degradation problems, further field observation with soil-chemical analysis is required.

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