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Decomposition of eucalypt litter on rehabilitated bauxite mines

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Abstract

*The initiation of nutrient cycling is important in developing a self-sustaining ecosystem, where inputs of fertilizer are not required, on rehabilitated open-cut mines. The loss of dry weight, surface area and nutrients from senescent jarrah (*Eucalyptus marginata*) leaves enclosed in litterbags for 18 months were measured on 27 rehabilitated bauxite mines and in two jarrah forests on the Darling Plateau in Western Australia. Respiration and acetylene reduction by the litter were also determined. Linear trends were found between litter decomposition on rehabilitated mines and understorey cover density, litter cover and a measure of the effect of the revegetation on soil moisture. During decomposition, N was retained relative to litter dry weight and, in most cases, amounts of N increased. Losses of Ca and S were correlated with dry weight losses. Sodium, Cl, Mg and K were lost from the litter by leaching. Rehabilitation techniques, including sowing a legume understorey and replacement of the topsoil, should favour the development of nutrient cycling on mined areas.*

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Introduction

Bauxite is mined by open-cut methods at several locations on the Darling Plateau of south-west Western Australia. Approximately 350 ha of jarrah forest (*Eucalyptus marginata* Donn ex Sm.) is mined and rehabilitated each year (Nichols *et al.* 1985).

The aim of rehabilitation is to develop a eucalypt forest which can be integrated into the management of the surrounding jarrah forest. It must also fulfil the long-term designated land use of the area. Some of these land uses include water and timber production, recreation and conservation. To do this the rehabilitated areas must develop without regular inputs of fertilizer. This requires that sufficient nutrient capital accumulate for efficient nutrient cycling to be established. Of particular importance is the development of nutrient cycling including litterfall, decomposition processes in the forest floor, incorporation of organic matter in surface soils and mineralization of organically-bound nutrients for uptake by plants.

In this study we examined the re-development of nutrient cycling on rehabilitated sites. Our aim was to investigate decomposition of litter in unmined jarrah forest and in rehabilitated mined areas, to determine which rehabilitation procedures encouraged the early development of nutrient cycling. The study involved measurement, by a variety of methods, of the decomposition of senescent jarrah leaf litter during 18 months in the field.

Methods

Plot descriptions

A total of 27 plots in rehabilitated areas (20 at Jarrahdale and seven at Del Park) and two plots in forested areas adjacent to each mine site was established in summer 1978/79. Majer *et al.* (1984) give a full description of the plots. Plots 4, 32, 33 and F2 in Majer *et al.* (1984) were not included in this study. The mined plots were rehabilitated between 1966 and 1978, using a range of methods, none of which correspond exactly with those used now. In the 1960s, mined areas were respread with stockpiled mixed topsoil and overburden and planted with a range of potential timber-producing *Eucalyptus* and *Pinus* species. Initially, only blood and bone fertilizer was applied and the trees were planted in monocultures at 625 stems ha^{-1}. During the 1970s, only *Eucalyptus* species were planted and techniques such as deep ripping, application of inorganic fertilizers, mixed plantings and landscaping, were introduced.

Plots 1–3, 5–18, 24, 25 and 28 were rehabilitated using the standard techniques for the year in which they were rehabilitated. Plot 19 was cleared but not mined, so rehabilitation took place on the original soil profile. Plot 20 was sown with 7 kg ha^{-1} of seed of native plants (predominantly *Acacia* species) at the time the eucalypts were planted. Plot 21 was sown to a sub-clover pasture. Plot 22 received a straw–bitumen mulch at planting. Plot 23 was the first rehabilitation area to receive 'double-stripped' topsoil. In this procedure, the top 5 cm of soil is stripped from an area to be mined and placed immediately on another pit under rehabilitation. The overburden, generally around 30–40 cm in depth, is stockpiled and then, after mining, is replaced on the same pit and topped off with fresh topsoil from another area. Plot 26 remained unvegetated, although it had been double-stripped. Plot 27 received fresh mixed overburden and topsoil from an adjacent area before planting.

Litter decomposition

Freshly-fallen, senescent jarrah leaves were collected from a forested area at Jarrahdale, in summer 1978/79. Only whole leaves were collected. The leaves were air-dried and ten subsamples of ten leaves were used for dry weight (70°C) determinations and chemical analysis.

Litter decomposition was assessed by measuring the loss of mass and surface area from a known mass of litter in mesh envelopes. Initially, 10 air-dried leaves were placed in white 25 cm × 25 cm nylon/polyester mesh bags which were sewn shut with polyester thread. Three mesh sizes were used — fine bags (mesh: 40 μm × 50 μm), medium bags (mesh: 1.5 mm × 1.5 mm) and coarse bags (mesh 7 mm × 7 mm). The fine bags allowed the entry of water, fungi, bacteria and other micro-organisms. Medium bags allowed the entry of these plus small invertebrates such as mites and springtails. Coarse bags also allowed larger invertebrates to enter.

At each plot, ten bags of each mesh size were placed out in April 1979 at 20 m intervals along two 100 m transects and secured to the soil with galvanized iron roofing nails. Any litter on the soil surface was removed before placing the bags.

The bags were retrieved in October 1980, placed in individual plastic bags to minimize the loss of fragments and returned to the laboratory. For each plot, medium and fine mesh bags within each transect were pooled, giving two samples per plot for acetylene reduction and respiration measurements. The leaf samples, enclosed in mesh bags, were immersed in distilled water until their moisture content was approximately 200% of leaf dry weight. Moist samples were maintained at 20°C for 24 h before being placed in 900 mL gas-tight jars with an air–acetylene mixture (9:1 v/v). After incubation for approximately 24 h at 20°C, gas samples extracted from each jar were analysed for C_2H_4 and CO_2 by gas chromatography. Samples were then oven-dried, brushed clean of any foreign matter or soil, and weighed.

The total area of the leaves in each bag was measured prior to placing in the bags and after retrieval using a Li-Cor portable area meter.

Chemical analysis

Oven-dry (70°C) samples of litter were analysed for nitrogen by a colorimetric determination using an auto-analyser following a Kjeldahl digestion. Other elements were determined by X-ray spectrometry (Norrish & Hutton 1977). Excess amounts of Si, Al and Fe in the bags left in the field, compared to fresh samples, were assumed to be present as silica, kaolin and haematite, common surface soil minerals at the experimental sites, and were used to calculate an approximate correction for weight loss for the amount of soil contamination in the field samples.

istical analysis

rson correlation coefficients (r) were comed between the litter decomposition variles and a range of physical (e.g. temperature, midity and soil moisture) and botanical (e.g. ecies numbers, equitability and stratifition) parameters measured in summer 78/79, as well as time since rehabilitation. ee Majer *et al.* (1984) for a full description of e parameters measured.) Because values of e variables under consideration often owed marked differences between forest and habilitated plots, the correlation coefficients ere computed using the data from the reabilitated plots only ($n=27$ in all analyses). Analysis of variance was used to test for the ignificance of the mesh size on the loss of weight, surface area and weight loss per unit area of leaf from the litter bags.

Results

After 18 months, loss of weight from the fine mesh litter bags on rehabilitated areas was generally 50–60% (average: 53.6%; Table 1). The greatest weight loss was 60.1% on a plot which had been rehabilitated using the double stripping technique. The least weight loss was 43.6% from plot 26, which was not planted and had no vegetation cover. The weight losses from the fine mesh bags on the forest sites were very similar to those on the rehabilitated areas (Table 1). The weight losses from the medium and coarse meshed litter bags (average: 54.4% and 52.2% respectively) were not significantly different from losses from the fine mesh bags.

Surface area losses were much less than weight losses (Table 1). Leaves enclosed in the fine mesh bags lost little surface area (average: 2.8% for rehabilitated plots). Leaves in both the medium and coarse meshed bags lost significantly more surface area than those in the fine meshed bags ($P<0.001$). There was little difference in surface area losses between the medium and coarse meshed bags indicating that, although small invertebrates were important, large invertebrates were not important in facilitating additional surface area losses. The loss of weight corrected for surface area losses (i.e. weight loss per unit area of leaf) from the fine mesh bags was significantly greater ($P<0.001$) than from the medium and coarse mesh bags (Table 1).

Carbon dioxide production (respiration) and acetylene reduction rates in litter bags provide indices of microbial activity and non-symbiotic nitrogen fixation respectively. Because the measurements were made under laboratory conditions, the rates cannot be directly extrapolated to those occurring in the field. However, they do provide a relative measure of the condition of the litter after 18 months' exposure on mine sites with various rehabilitation procedures. There was a linear trend between carbon dioxide production (log-transformed) and loss of weight from the fine litter bags ($r=0.57$). Carbon dioxide production shows the relative potential for decom-

TABLE 1. Weight loss, surface area loss and weight lost per unit area of leaf from litterbags on 27 rehabilitated minesites and two forest controls in 18 months

Variable	Rehabilitated plots			Forest plots	
	Mean	s.d.	Range	Jarrahdale	Del Park
% weight loss from bags					
Fine mesh	53.6	3.7	43.6–60.1	56.0	54.6
Medium mesh	54.4	11.5	34.0–83.1	52.6	53.4
Coarse mesh	52.5	6.5	38.5–67.1	51.6	51.2
% surface area loss from bags					
Fine mesh	2.8	2.9	0.0–11.3	1.0	1.2
Medium mesh	12.9	12.6	0.3–50.5	14.1	2.3
Coarse mesh	12.8	7.5	2.1–35.6	10.5	9.4
% weight loss from bags per unit area of leaf					
Fine mesh	52.2	3.6	41.6–58.5	55.6	54.0
Medium mesh	48.4	8.1	33.5–67.7	44.8	52.3
Coarse mesh	45.7	4.4	33.6–57.8	46.1	45.9

position of the litter after 18 months in the field, while the loss of weight from the fine litter bags shows the amount of decomposition which occurred during that 18 month period. Both carbon dioxide production and loss of weight from the fine litter bags showed linear trends with measures of the development of the vegetation on the rehabilitated plots, such as plant cover density at 0–25 cm ($r = 0.74$ and $r = 0.45$ respectively) and percentage litter cover ($r = 0.40$ and $r = 0.45$ respectively). Carbon dioxide production was also linearly related to the concentration of N in the fine litter bags after 18 months ($r = 0.76$) and the reduction in soil moisture on the plots compared with adjacent cleared areas ($r = -0.44$).

The highest rates of acetylene reduction were measured in the forest litter (22.9–38.9 nmol g^{-1} per day). The unplanted area (plot 26) and the double-stripped area (plot 23) also had high rates of acetylene reduction — 26.3 and 27.1 nmol g^{-1} per day respectively. No acetylene was reduced by litter from the sub-clover plot. Acetylene reduction rates and respiration rates were not significantly correlated.

Elements could be classified into three categories depending on their rate of loss from the fine litter bags (Table 2). Chloride, Na, Mg and K losses were greater than dry weight losses, 93%, 92%, 85% and 71% respectively (Table 2). Calcium and S losses were similar to dry weight losses. Nitrogen was retained relative to dry weight loss. The average increase in N concentration in the fine litter bags on the rehabilitated area was 128% (Table 3). Similar increases in N concentrations were seen on the forest controls. In most cases, there was also a net increase in the amount of N in the fine litter bags. There was a linear trend between this increase in N and carbon dioxide production ($r = 0.76$). Changes in N content of the bags ranged from a loss of 20.3% on the unplanted plot (plot 26) to a gain of 67.2% on the plot planted with sub-clover (plot 21; Table 2). Some of the rehabilitated plots were inadvertently fertilized with P fertilizer (double superphosphate) during the course of the experiment. Many of the litter samples from the rehabilitated plots had very high concentrations of P, indicating contamination. Because it was not possible to determine which samples had been contaminated, all the P concentration data for the rehabilitated plots was disregarded. On the forest control plots, P concentrations in jarrah litter after 18 months (0.021–0.031%) were similar to those reported previously for decomposed jarrah litter (O'Connell & Menage 1983). The amount of P in the fine litterbags on the forest control plots increased more than threefold. There were linear trends between the final concentrations of Ca, Mg, S and N (Table 3) and the weight loss from the fine litter bags ($r = 0.43$, $r = 0.57$, $r = 0.71$ and $r = 0.63$ respectively).

Rehabilitated areas had lower concentrations of N and organic C in the topsoil (0–10 cm) than the forest controls. The concentration of N in the topsoil on rehabilitated plots was 0.05% (s.d.: 0.01%) compared with 0.10% (s.d.: 0.02%) on the forest control plots. The concentration of organic C in the topsoil on rehabilitated plots was 2.2% (s.d.: 0.6%) compared with 3.9% (s.d.: 0.9%) on the forest

TABLE 2. Weight of elements remaining (percentage of original) in fine-mesh litter bags after 18 months on 27 rehabilitated minesites and two forest controls

Nutrient	Rehabilitated plots		Forest plots	
	Mean	Range	Jarrahdale	Del Park
N	105	80–167	99	96
P	*		454	310
K	29	15–59	23	18
S	49	39–60	40	42
Ca	56	43–85	50	55
Mg	15	13–19	13	16
Na	8	4–32	5	9
Cl	7	5–15	6	11

*Phosphorus losses were not calculated for rehabilitated plots as some samples were contaminated with P fertilizer.

3. Initial and final concentrations of nutrients in litter in fine-mesh litterbags on 27 rehabilitated minesites and two controls after 18 months

…nt	Initial concentration (%)	Final concentration (%)			
		Rehabilitated plots		Forest plots	
		Mean	Range	Jarrahdale	Del Park
[illegible]	0.32	0.73	0.45–1.24	0.73	0.67
[illegible]	0.003	*		0.031	0.021
[illegible]	0.19	0.12	0.06–0.22	0.10	0.08
[illegible]	0.12	0.12	0.09–0.16	0.11	0.11
[illegible]	0.87	1.05	0.75–1.71	1.01	1.05
[illegible]	0.52	0.17	0.13–0.24	0.15	0.19
[illegible]	0.19	0.03	0.02–0.05	0.02	0.04
[illegible]	0.41	0.07	0.05–0.14	0.06	0.10

*Phosphorus concentrations of the litter on rehabilitated plots were disregarded due to contamination of some samples …h P fertilizer.

…ntrol plots. The highest concentrations of …il C and N in the rehabilitated areas were on …e cleared but unmined area (plot 19), the area …anted with a dense legume understorey (plot …0) and the sub-clover area (plot 21). The latter …wo areas probably show the effect of N …xation by legumes.

…iscussion

The use of litter bags filled with a uniform sample of jarrah leaves provided an index of the rate of decomposition of litter at each site. Litter decomposition (weight loss and carbon dioxide production) on rehabilitated areas was best related to the understorey cover density (especially in the 0–25 cm stratum), litter cover and soil moisture. In general, litter decomposition rates were higher on plots where understorey and litter cover were greater, and soil moisture levels were higher (i.e. the reduction in soil moisture on the plot compared with adjacent cleared areas was lower). There was no correlation between the rate of litter decomposition and the time since rehabilitation.

The influence of moisture on litter decomposition is well known (Woods & Raison 1983). Litter decomposition may have been favoured by the changes in micro-climate brought about by increases in litter and plant cover. Hence, rehabilitation techniques that lead to an early increase in plant and litter cover should favour the initiation of decomposition processes. Techniques which could be used include the application of an artificial litter layer such as a mulch, or sowing a dense, fast-growing understorey.

The greatest loss of weight of litter in fine litter bags was on the double-stripped site (plot 23). This suggests that topsoil returned to a pit immediately after stripping provides a better substrate for decomposition than the stockpiled, mixed topsoil and overburden of other rehabilitated sites, when physical factors favour decomposition. Furthermore, freshly-collected topsoil may also be an initial source of decomposer organisms.

The weight losses from the fine litter bags in 18 months were slightly higher (approximately 54–56%) than those found in previous studies of litter decomposition in the jarrah forest (41–49%) by Hatch (1955) and by O'Connell and Menage (1983). However, weight losses per unit area of leaf from the medium and coarse litterbags (45–52%) were comparable with weight losses in these previous studies. The differences may be due to the very small mesh size of the fine bags used in this study. These retain moisture longer than the coarse litterbags used by O'Connell and Menage (1983) and the gauze-bottomed tins used by Hatch (1955). Thus, decomposition could probably proceed for longer during dry periods in the fine meshed bags. The higher surface area losses in both the medium and coarse meshed bags were probably due to feeding by small invertebrates such as millipedes.

Greatest rates of N fixation in the litterbags, as measured by acetylene reduction, were associated with the forest controls and rehabilitated areas that had received fresh, double-stripped topsoil. In general, litterbags on plots which had received mixed stockpiled overburden and topsoil showed low rates of N fixation. There was no relationship between the time since rehabilitation and N fixation rates. Acetylene reduction rates measured in litterbags from the sub-clover plot (plot 21) were below the detection limit. This, coupled with the high N concentration in the litter and the high rate of carbon dioxide production in the litterbags, suggests that nitrogen supply may be less limiting to decomposer organisms at this site than on the areas vegetated with perennial woody species.

Except for magnesium, the pattern of losses of nutrients from the litter were similar to those from eucalypt litter reported by O'Connell and Menage (1983) and Baker and Attiwill (1985). The large losses of Na, Cl and K were due to leaching. Magnesium losses were nearly as great as those of Na and Cl and considerably larger than the loss of K. O'Connell and Menage (1983) found that less Mg than K was lost from jarrah leaf litter. Magnesium is usually associated with cell structures and is usually lost at a similar rate to dry weight (Baker & Attiwill 1985). However, Baker and Attiwill (1985) found that the pattern of loss of Mg was variable and attributed significant initial losses of Mg from litter to leaching. It is likely that the large losses of Mg in this experiment were due to leaching.

Where respiration rates in the litter were high, N, Ca and S were immobilized in the microbial biomass. Nitrogen was retained relative to dry weight and in most cases there was an absolute increase in the amount of N in the litterbags. Loss of N usually occurred only when microbial activity, as measured by carbon dioxide production, was low. The absolute increases in N in decomposing litter could be a result of the translocation of N from the soil by micro-organisms; inputs via throughfall, fine litter fall and insect frass; or from N fixation by free-living micro-organisms. In eucalypt forests, N is usually retained in the litter until a critical C:N ratio is reached (Baker & Attiwill 1985). Little mineralization of N occurs until C:N ratios fall within the range 30:1 to 20:1 or less (O'Connell 1986). Assuming a carbon content of 50%, the initial C:N ratio of the jarrah litter in this study was 156:1. This was reduced during decomposition to an average of 68:1 on the rehabilitated plots. The highest final C:N ratio was 111:1 on the unplanted plot where N losses from the litter were greatest. The lowest ratio was 40:1 on the sub-clover plot where the absolute increase in nitrogen in the litter was greatest. Such absolute increases are commonly found during litter decay and usually precede net loss of N during the latter stages of decomposition (Berg & Staaf 1981).

The pattern of nutrient release from decomposing litter on rehabilitated bauxite mines has significance for the long-term development of the ecosystems on these areas. Jarrah forest soils are low in nutrients (Hingston *et al.* 1981). Following mining and rehabilitation the nutrient status of the soil is further reduced due to mixing and dilution of the top soil, with subsoils having lower nutrient content. It is important to use rehabilitation techniques which increase nutrient stores and encourage nutrient cycling.

Whether the nitrogen in litter is mineralized or immobilized depends in part on the relative proportions of C and N in the litter. In most forest ecosystems, a high C:N ratio would result in immobilization of N. However, in these rehabilitated areas, nitrogen was lost from the litterbags on some plots, despite final C:N ratios of more than 70:1. Carbon dioxide production in the litter on these plots was also low, indicating little microbial activity. On plots where maximum immobilization of N occurred, carbon dioxide production was high. Berg and Staaff (1981) have identified three separate phases in nitrogen dynamics in decomposing litter — leaching, accumulation and final release phases. On sites with little litter and plant cover, few decomposers may have been active and little immobilization and accumulation occurred. On these sites, decomposition and nutrient losses can be attributed mainly to the leaching phase and physical breakdown of the litter (c.f. Postle *et al.* (1986)). An absence of litter and plant cover is generally associated with areas not long rehabilitated or areas rehabilitated using outdated techniques. Litter fall will also be small here, so transfer of N from litter to the soil will be minimal. On sites with more litter and plant cover, decomposers rapidly colonized the litter (P. Greenslade & J. D. Majer, unpubl. data) and N was quickly incorporated into the miobial biomass. Thus, if only eucalypt litter is ded, the litter layer represents an accumulating pool of N on most sites.

All the sites in this study were rehabilitated before 1977. Since 1977, the rehabilitation process has included sowing understorey legumes and broadcasting P fertilizer (Nichols *et al.* 1985). Understorey plants, especially legumes, have an important role in the cycling of nutrients in eucalypt forests (O'Connell 1980). The legume understorey on bauxite mined areas quickly accumulates nutrients, particularly N, in its biomass and associated litter layer (Ward & Pickersgill 1985; Koch 1987). The C:N ratio of the litter on a rehabilitated mine with a thick understorey of legumes was 51:1 and the C:P ratio 2200:1 (Ward & Pickersgill 1985). This compares with 156:1 and 16700:1 respectively for the jarrah litter used in this study. This legume-dominated litter should decompose and release N and P to the soil much more quickly than jarrah or other eucalypt litter.

In addition, the legumes will increase soil N and the rapidly growing understorey should change the micro-climate at the soil surface to the benefit of decomposer organisms. This may meet the demand of the overstorey for nutrients, thus reducing the need for further fertilizer applications.

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