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Conservator of Forests

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## SUMMARY

The ash beds formed after heaps of forest slash are burnt, have a pronounced stimulating effect on the early development and growth of of many Western Australian eucalypts.

These slash burns, which have temperatures of the order of 850 degrees centigrade, cause immediate and marked changes in the chemical properties of the soil.

Ash bed properties have been investigated on two forest types, *viz.*, karri and wandoo forests, covering a wide range of climatic and soil conditions.

The chemical changes in ashbeds are most pronounced in the first inch of soil and decrease rapidly with depth. The most important of these are increases in pH, total soluble salts, nutrients extracted by 2·5 per cent. acetic acid, and the formation of calcium carbonate. By contrast, however, soil organic matter is reduced by the high temperature burns.

The stimulating effect of an ash bed is known to fall off rapidly with increasing age, and changes in chemical properties of ash bed soils with time, have been investigated.

It is shown that a period of at least twenty years is required before the ash bed soils return to their previous condition.

## INTRODUCTION

The effect of fire on forest soils has received considerable attention from overseas workers during the last thirty years, but despite numerous papers on the subject, confusion still exists on many aspects of this problem.

However, it is generally accepted that a very hot fire, such as a slash burn (where accumulated heaps of heavy forest litter, *e.g.*, tree crowns and logs, are burnt), has a significant effect on soil properties.

These concentrated heaps of debris cause very hot fires, and the soil is exposed to high temperatures for a prolonged period while the heavy litter burns. By contrast, with regular controlled burning, the litter is much thinner, burns more rapidly and the soil is not exposed to high temperatures for more than a few minutes.

The resulting burnt areas, with their associated heaps of ash and charcoal are commonly called " ash beds." These areas differ markedly in their properties from the adjacent unburnt or lightly burnt soil.

Ash beds in Western Australian forests are generally formed as a result of a top disposal burn following trade cutting for sawmilling operations. In this operation the unmerchantable tops of felled trees are partially broken up by hand cutting, allowed to dry and then burnt. The top disposal burn is normally carried out during mild weather or at night. Ash beds are also formed by uncontrolled fires burning heaps of debris, and in the final clearing burn in plantation establishment.

One feature of these ash beds, is that they have a pronounced stimulating effect on the germination and early development of many eucalypts. Typical examples of this are as follows :—

1. At Treen Brook, near Pemberton, twenty-eight-year-old karri (*Eucalyptus diversicolor,* F.v.M.) regrowth on an ash bed, attained a height of 115 feet and a girth breast height (G.B.H.) of 53 inches, whereas similar aged trees which had developed off the ash bed, were only 50 feet high and 14 inches G.B.H.

2. In the mallet (*E. astringens,* Maiden) plantations at Dryandra, spot-sown mallet on ash beds has shown an average height increment of 1·5 feet per annum, while adjacent mallet trees have a height increment of only 0·5 feet per annum. In addition the ash bed areas are always fully stocked with trees. By contrast, the non-burnt areas are usually sparsely stocked and in several cases large blanks are present due to failure of the spot-sown seed to become established.

The aim of this study was to quantitatively examine some of the chemical properties of these ash bed soils, and to compare them with adjacent unburnt soil.

## LOCATION

Two sets of samples were collected for the experimental work. These were from prime karri forest at Pemberton and from mallet plantations at Dryandra established on natural wandoo sites.

## CLIMATE

The two areas offer a complete contrast of climatic conditions. The karri forest area forms the temperate eucalyptus rain-forest of Western Australia (Stoate and Gardner, 1952), with an average annual rainfall of between 50 and 60 inches. The mallet plantations are associated with the wandoo (*E. redunca* var. *elata,* Schau.) and powderbark (*E. accedens,* W. V. Fitz) savannah forests, with a mean annual rainfall of approximately 20 inches.

## SOILS

Soil samples were collected from prime karri forest areas, and these were typically red-brown loamy sands overlying red-brown clays. Ferruginous gravel was frequent throughout all the profiles sampled.

The samples from the mallet plantations were collected from the upper wandoo slopes. These soils are primarily lateritic in origin, being derived from colluvial materials eroded down the valley slopes and from the heavy clay subsoils of the old laterite profile. They were generally grey-brown sandy loams overlying heavy massive yellow-brown clays.

## EXPERIMENTAL

### (a) *Temperature of the Slash Burns*

In some preliminary experimental work carried out at Dwellingup and Dryandra, a series of metal alloys with a range of melting points were placed across and above the heaps of slash prior to the burn. By inspection of the alloys after the burn, it was possible to determine the temperature of the fire at a particular point.

The typical temperature distribution of the slash burn is set out hereunder and is schematically represented in Fig. I.

| Position of Alloys | Reference to Figure 1 | Temperature °C. |
|---|---|---|
| Ground level—centre of ash bed | 1 | 850 |
| ,, ,, —edge of ash bed .. | 2 and 3 | 600-650 |
| ,, ,, —surface litter adjacent to ash bed | 4 | 320-450 |
| One foot above top of slash .. | 5 | 700 |
| Four feet above top of slash .. | 6 | 600 |

As mentioned previously, the soils under the slash heap (1) are exposed to these high temperatures for several hours, whereas the soils adjacent to the ash bed (4) are only subject to heat for a few minutes.

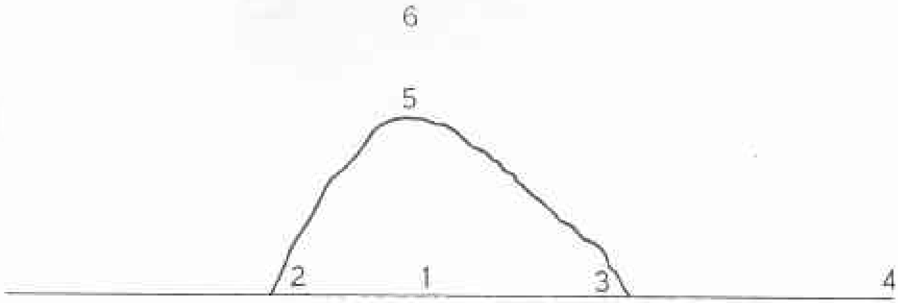


Fig. 1. Diagrammatic representation of slash heap showing location of sets of alloys.

(b) *Soil Sampling*

Soil samples were collected from ash beds of known ages in the two areas. Three profiles were sampled for each age group, and the samples combined to give a composite sample. The depths of sampling were 0–1, 1–3, 3–6 and 6–12 inches. The samples were air dried, passed through a 2 mm. sieve, and the fine earth bottled for analysis.

In the analysis of the samples most of the methods used are those described by Piper (1944), except that calcium and magnesium were determined by titration with E.D.T.A. (Bond and Tucker, 1954, and Hutton, 1954). Potassium and sodium were estimated by the Eel flame photometer (Hutton and Bond, 1955).

The acetic extracts were prepared by the method of Williams and Stewart (1941) and analysed for calcium, magnesium, potassium, sodium and phosphorus.

Readily soluble manganese was extracted with 0·2 per cent. quinol in neutral normal ammonium acetate (Leeper, priv. comm.). The manganese was determined colorimetrically by oxidation with potassium periodate, after organic matter in the extract had been destroyed by digestion with nitric, sulphuric and perchloric acids.

## ANALYTICAL DATA

(a) *Comparison of Ash Bed and Unburnt Soils*

The analytical data for the two series of ash beds are set out in Figs. 2 and 3. For purposes of comparison similar soils from adjacent unburnt areas have been included in the graphs. In the karri forest region the control area had been free from fire for a period of thirty years, and the mallet control samples had been protected from fire for twenty years.

It is evident from the data that very pronounced changes have occurred in the ash bed soils as a result of the slash burn. These changes are more marked in the karri ash beds than in the mallet area. This is believed to be due to the greater accumulation of slash in the karri forest, consequently the high temperatures will be maintained for longer periods and also a greater amount of ash will be returned to the soil.

The most important of these changes are the increase in soil pH, total soluble salts and the formation of calcium carbonate. Loss on ignition, which represents both organic matter and bound water, is sharply decreased by the burn, and this decreased loss on ignition is accompanied by a lower organic carbon and nitrogen content.

The chemical changes are much more evident in the immediate surface horizon (0–1 inch), which has been exposed to the full heat of the fire, and the differences decrease rapidly down the profile. The actual magnitudes of the differences between the burnt and unburnt soils is shown in Table I.

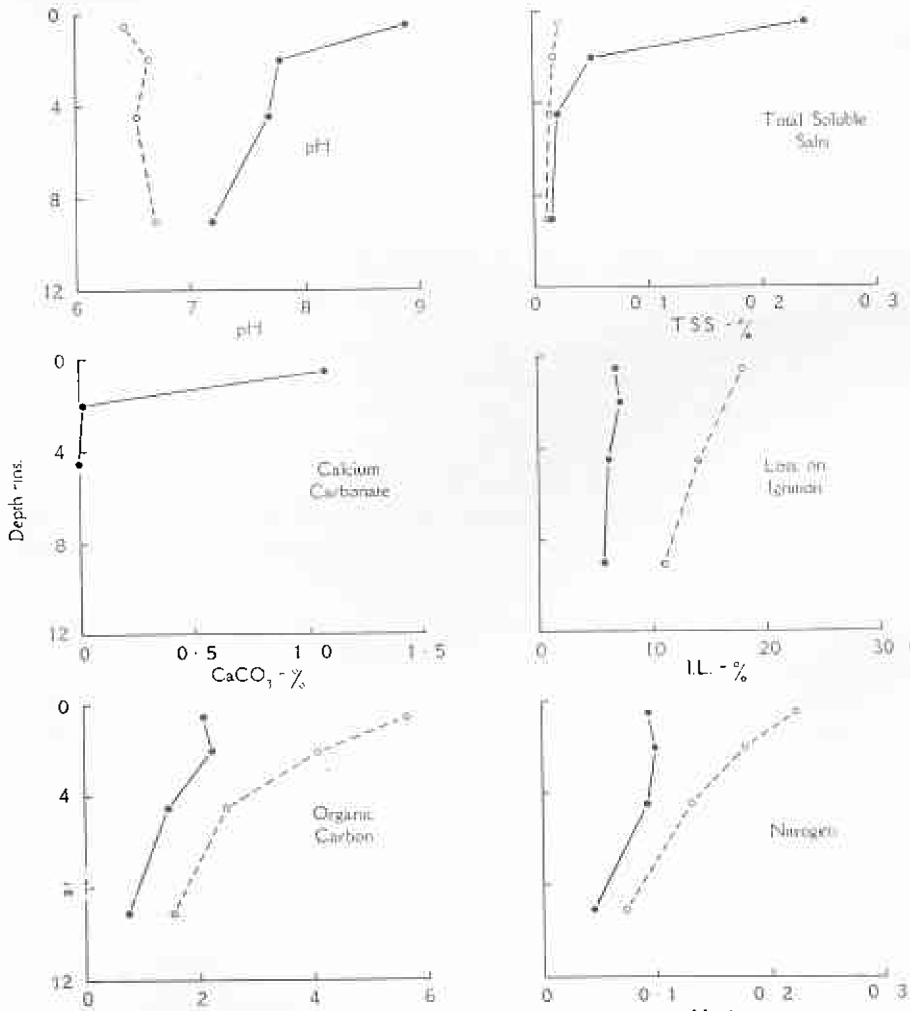


Fig. 2. Karri Ash Beds. Chemical properties of ash bed and unburnt soils. Ash Bed Soil ————; Unburnt Soil – – – – –.

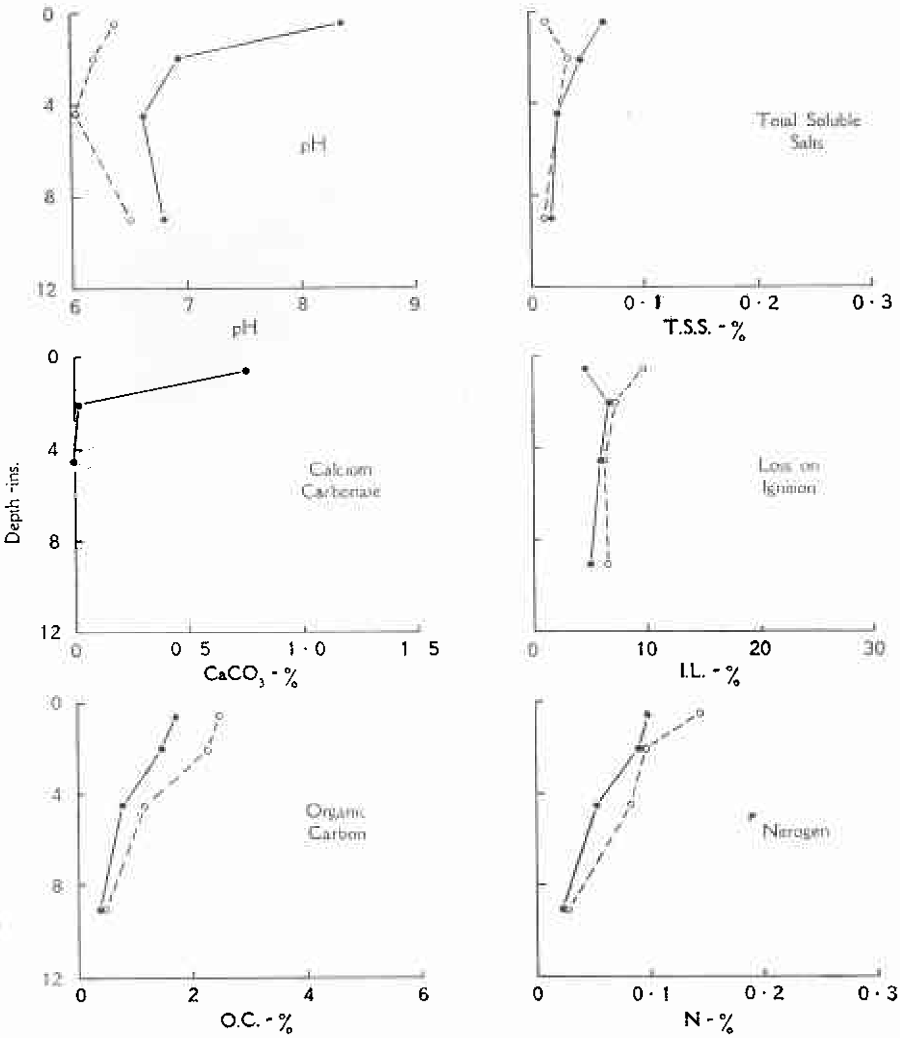


**Fig. 3. Wandoo Ash Beds. Chemical properties of ash bed and unburnt soils.**
**Ash Bed Soil ————; Unburnt Soil — — — — —.**

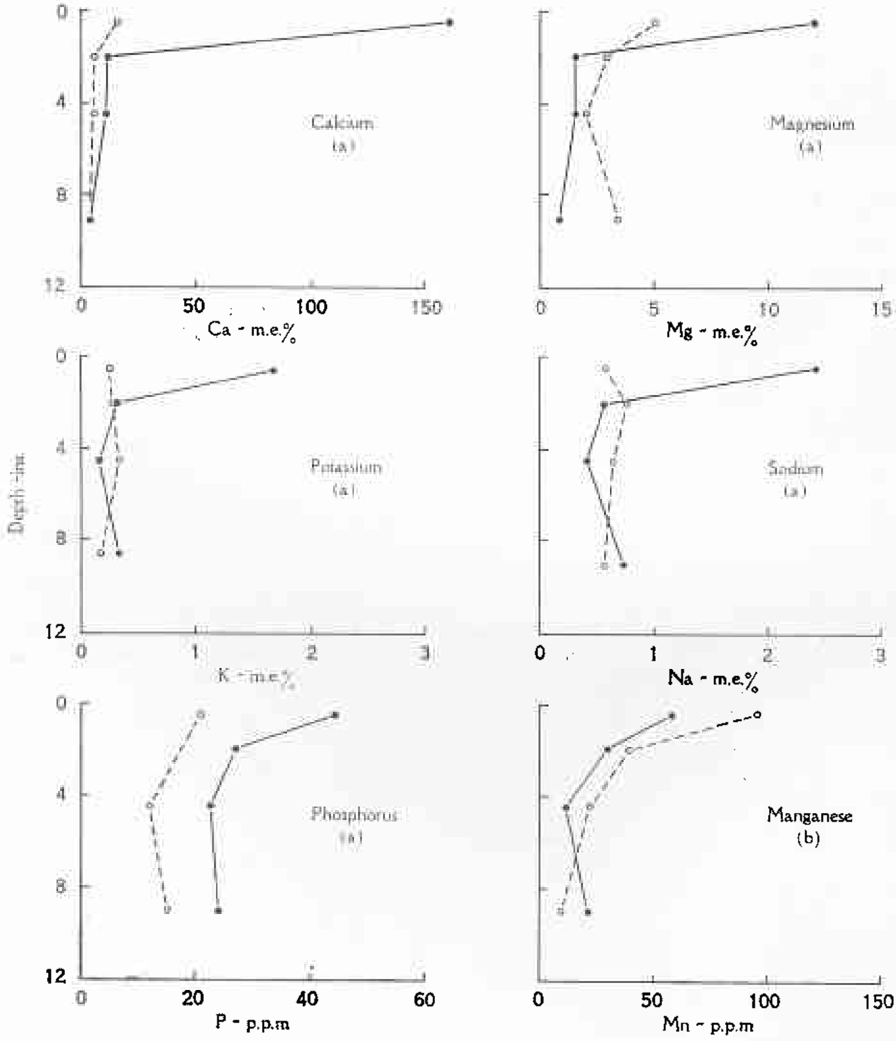


Fig. 4. **Karri Ash Beds. Readily soluble nutrients in ash bed and unburnt soils. Extractants :—(a) 2·5 per cent. acetic acid ; (b) 0·2 per cent. quinol in neutral N/1 ammonium acetate.**

**Ash Bed Soil ————— ; Unburnt Soil – – – – –.**

TABLE 1

KARRI AND WANDOO ASH BEDS

Differences between Ash Bed and Unburnt Soils

*Age of Ash Bed—3 months*

| | Karri | | | | Wandoo | | | |
|---|---|---|---|---|---|---|---|---|
| Depth (in.) .... | 0–1 | 1–3 | 3–6 | 6–12 | 0–1 | 1–3 | 3–6 | 6–12 |
| pH .... .... | 2·4 | 1·1 | 1·1 | 0·5 | 2·0 | 0·7 | 0·6 | 0·3 |
| Total Soluble Salts —% .... .... | 0·215 | 0·033 | 0·007 | 0·004 | 0·051 | 0·011 | 0·001 | 0·007 |
| Calcium Carbonate —% .... .... | 1·073 | 0·027 | 0 | 0 | 0·750 | 0·025 | 0 | 0 |
| Loss on Ignition —% .... .... | —11·2 | —9·4 | —7·8 | —5·3 | —4·97 | —0·51 | —0·34 | —1·56 |
| Organic Carbon— % .... .... | —3·55 | —1·85 | —0·99 | —0·79 | —0·77 | —0·84 | —0·38 | —0·07 |
| Nitrogen—% .... | —0·128 | —0·079 | —0·038 | —0·029 | —0·047 | —0·007 | —0·030 | —0·006 |

In a second series of experiments, soils from karri ash beds were extracted with 2·5 per cent. acetic acid, and the extracts analysed for the more common inorganic constituents. In addition, readily soluble manganese was determined by extraction with 0·2 per cent. quinol in neutral normal ammonium acetate. The data are shown in Fig. 4.

Again, it is evident that only the immediate soil surface has been markedly affected by the burn, and this has caused a large increase in all the nutrients examined, except manganese, which is reduced in solubility by the burn. This reduction in soluble manganese is probably related to the high pH of the ash bed soils, as it has been demonstrated by various workers that increased soil pH causes a marked decrease in the availability of manganese.

Below the first inch of soil, the nutrients extracted by these methods decrease very rapidly and are similar in amount to those present in unburnt soils. The differences between the burnt and unburnt soils are tabulated in Table 2.

TABLE 2

KARRI ASH BEDS

Differences between Ash Bed and Unburnt Soils

Readily Soluble Nutrients

*Age of Ash Bed—3 months*

| Depth (in.) | 0–1 | 1–3 | 3–6 | 6–12 |
|---|---|---|---|---|
| Calcium m.e. % (*a*) .. .. .. | 143·6 | 5·9 | 3·5 | —0·4 |
| Magnesium m.e. % (*a*) .. .. | 7·2 | —1·2 | —0·4 | —2·5 |
| Potassium m.e. % (*a*) .. .. | 1·44 | 0·04 | —0·16 | 0·16 |
| Sodium m.e. % (*a*) .. .. .. | 1·84 | —0·16 | —0·24 | 0·16 |
| Phosphorus p.p.m. (*a*) .. .. | 23·6 | 10·0 | 10·4 | 8·3 |
| Manganese p.p.m. (*b*) .. .. | —34·2 | —8·6 | —10·6 | 11–6 |

Extractant.—(*a*) 2·5 per cent. acetic acid.
(*b*) 0·2 per cent. quinol in neutral N/1 ammonium acetate.

## (b) *The Effect of Time on Ash Bed Properties.*

The ash bed samples in the karri and mallet areas range from 0 to 30 and 0 to 20 years respectively. The changes in the different soil properties with time are shown in Figs. 5, 5A, 6, 7 and 7A.

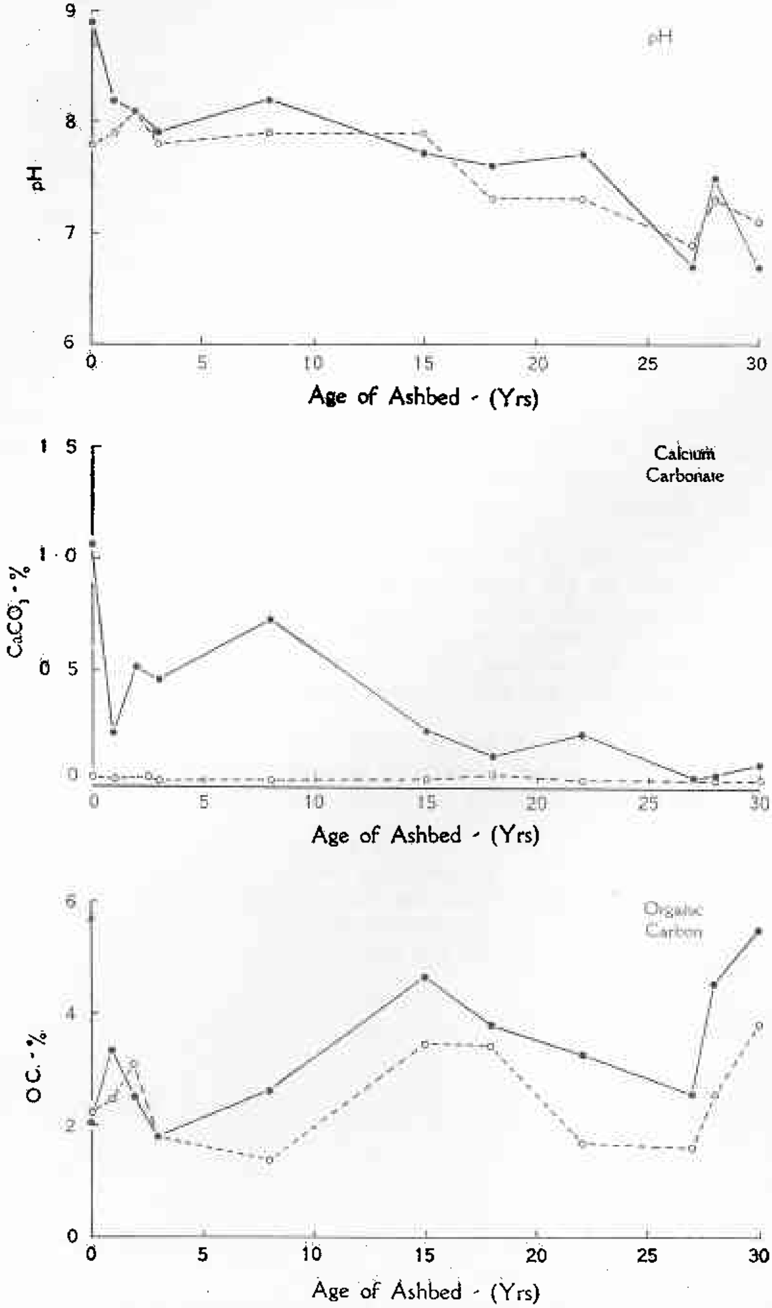


Fig. 5. Karri Ash Beds. Variation of chemical properties of Ash Beds with time. 0–1 inch ————— ; 1–3 inches — — — — —.

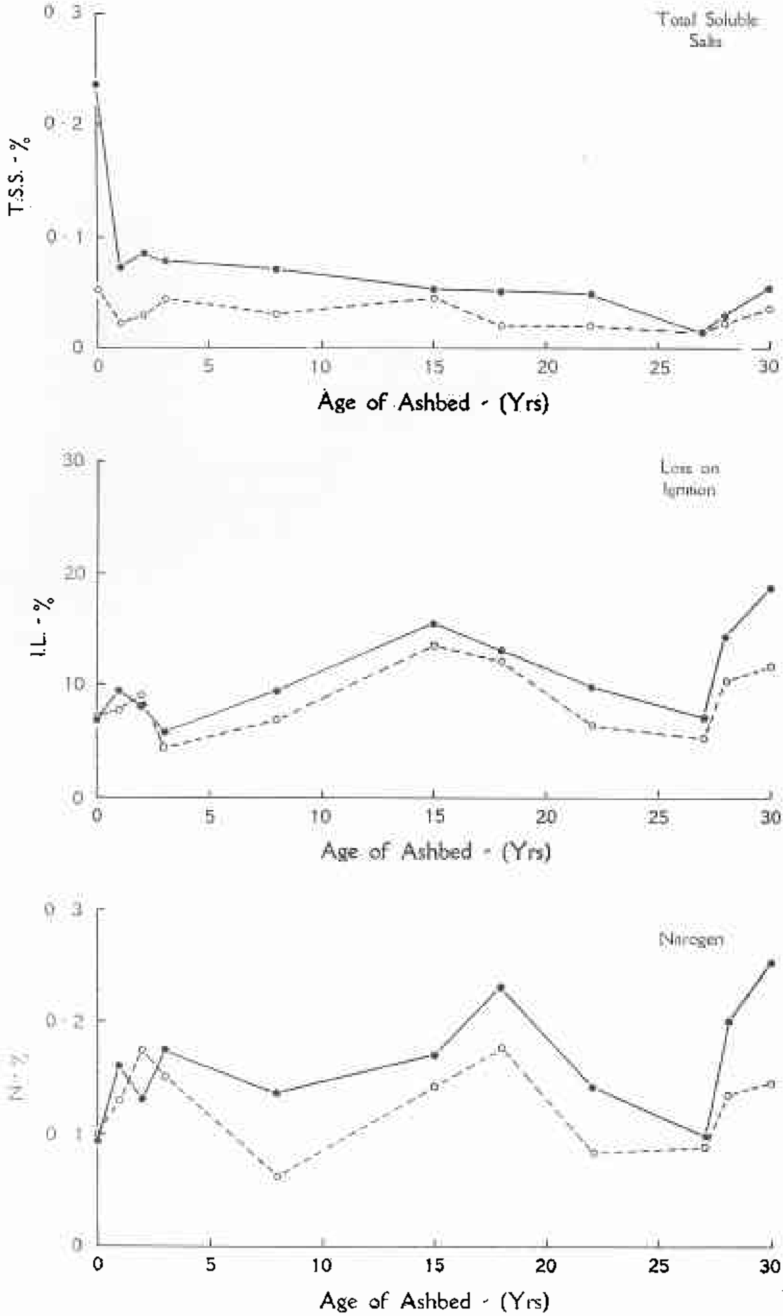


**Fig. 5a.** Karri Ash Beds. Variation of chemical properties of Ash Beds with time. 0–1 inch ————; 1–3 inches — — — —.

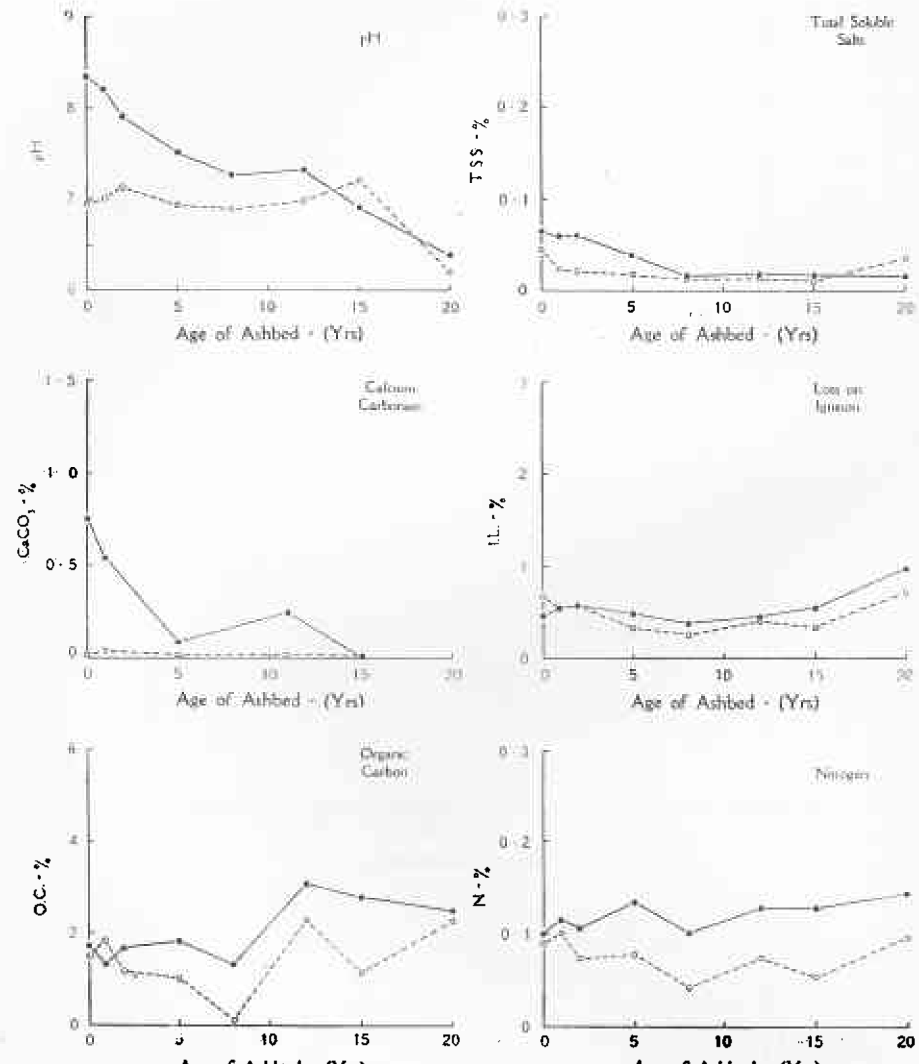


**Fig. 6.** Wandoo Ash Beds. Variation of chemical properties of Ash Beds with time. 0–1 inch ———— ; 1–3 inches – – – – –.

Although considerable variation exists in certain of the results, there is sufficient data to indicate some definite trends in the properties of the ash beds according to age.

The most pronounced changes in the soils are the decrease in soil pH and the loss of soluble salts. In the karri ash beds there is at first a rapid decline in both these factors, and this is followed by a slow decrease in pH and total soluble salts. The wandoo ash beds show a similar pattern, but the initial change is not as great. This is probably due to the more intense leaching experienced in the karri forest area.

The calcium carbonate figures are very variable, but there does appear to be an initial rapid loss of this substance followed by a gradual decrease over a period of twenty-nine years. The eight-year-old karri ash bed is an exception, and this is probably due to a much higher original carbonate content in the ash bed. It is of interest to note that the thirty-year-old ash bed still contained 0·04 per cent. of calcium carbonate. The wandoo ash beds contain less carbonate than those of the karri forest, and the variation in the samples is not as great. The trends in carbonate content are rather similar, but after fifteen years the wandoo ash beds have lost the calcium carbonate formed at the time of the burn.

Loss on ignition in the karri ash beds is again very variable, but the older ash beds have definitely increased in loss on ignition. In the wandoo samples, this factor remained relatively constant for about twelve years and then showed a rapid increase with time.

Organic carbon and nitrogen values show marked fluctuations in the karri samples, but in the old ash beds these values are well above the original levels. In the wandoo areas the organic carbon values do not show any marked changes until eight years after the burn, when a rapid increase in organic carbon occurs. Nitrogen values are variable in the younger ash beds, but after eight years, these show a steady increase to the twenty-year-old samples.

The nutrients extracted by 2·5 per cent. acetic acid, show an initial sharp decline in the first year after the burn. With regard to the individual elements, calcium and magnesium show considerable variation for at least eighteen years after the burn. This is related to the amount of carbonate present in the surface soil. After eighteen years the amounts of these two elements extracted are relatively constant.

The amounts of potassium and sodium extracted, show little change after the second year, and this is attributed to the fact that these cations are very soluble and excessive amounts are rapidly leached out of the surface soil.

The phosphorus extracted does not show any definite trends for 14 years after the burn and in these samples varied from 15 to 173 ppm. After this time, however, the amount of phosphorus extracted is relatively constant, being of the order of 20 ppm.

The readily soluble manganese decreases during the first three years after the burn, and then gradually increases for fifteen years. From fifteen to thirty years the manganese values decrease and increase rapidly and apparently bear no relationship to the age of the ash bed. At present, no explanation can be given to this data, as so little is known of the forms of manganese present in these soils.

The second horizons do not show such marked changes as the surface soils. Generally, they have lower values than the surface soils, and their variation with the age of the ash bed tends to follow rather closely those of the surface soils.

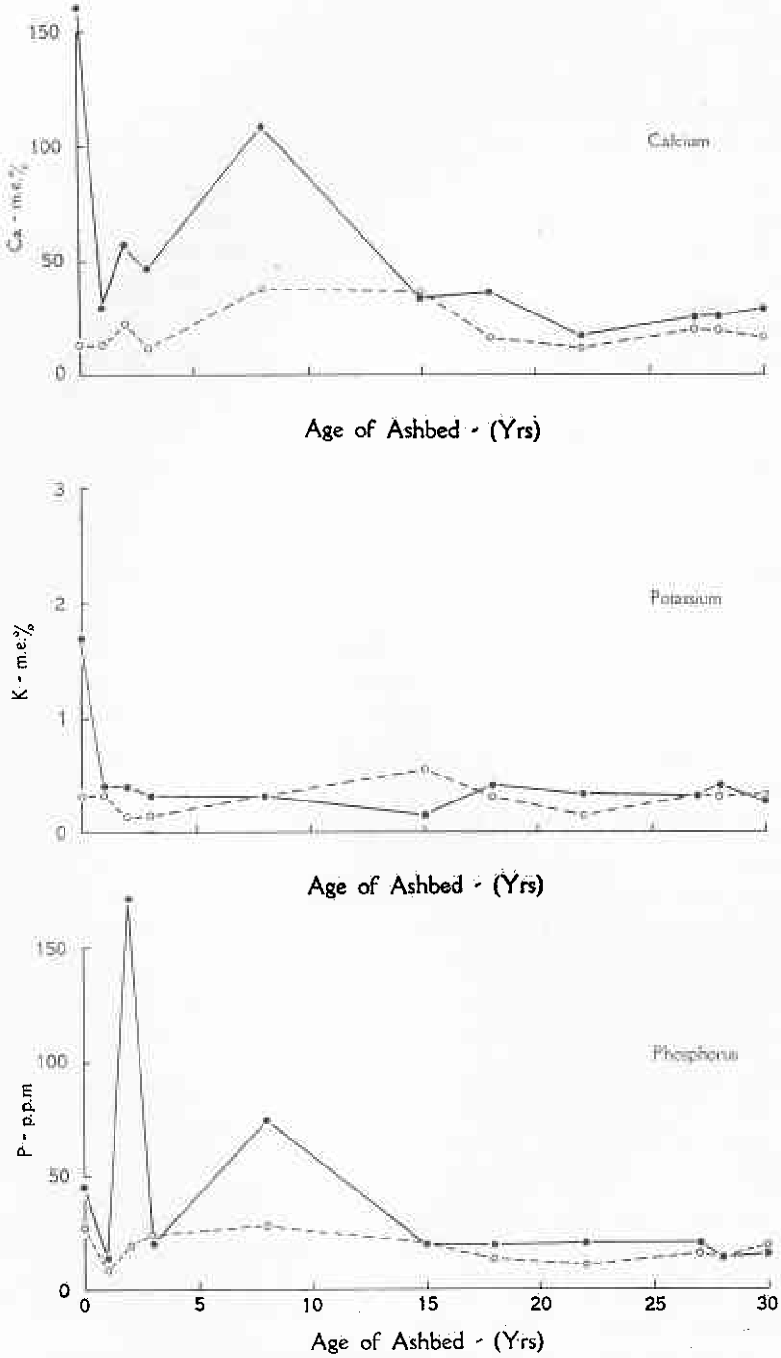


**Fig. 7.** Karri Ash Beds. Variation of readily soluble nutrients with time.
Extractants :—(a) 2·5 per cent. acetic acid ; (b) 0·2 per cent. quinol in neutral N/1 ammonium acetate.
0–1 inch ———— ; 1–3 inches — — — — —.

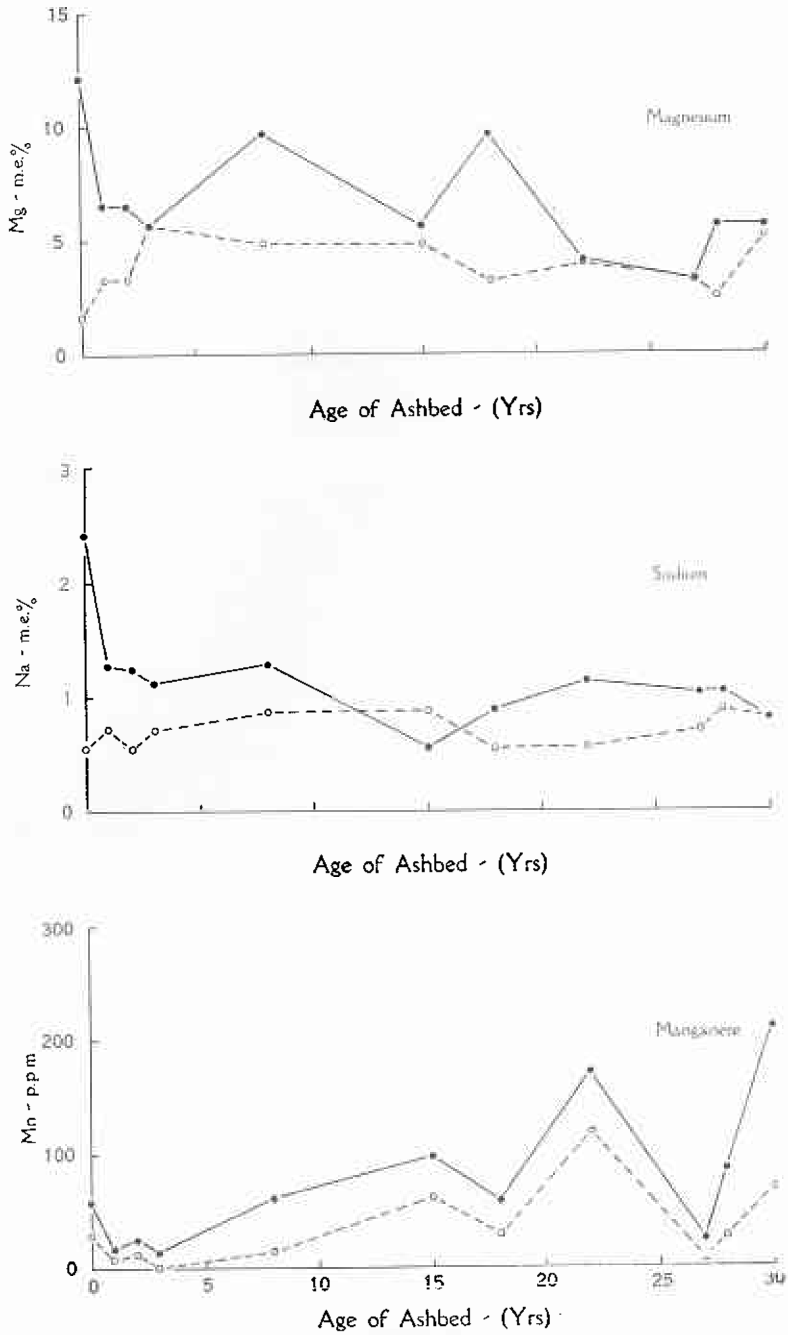


Fig. 7a. Karri Ash Beds. Variation of readily soluble nutrients with time.
Extractants :—(a) 2·5 per cent. acetic acid ; (b) 0·2 per cent. quinol in neutral N/1 ammonium acetate.
0–1 inch ————— ; 1–3 inches – – – – –.

TABLE 3

KARRI ASH BEDS

Differences between Ash Beds and Unburnt Soils

| | Age of Ash Bed (years) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15 | | | | 22 | | | | 30 | | | |
| Depth (in.) .. .. | 0–1 | 1–3 | 3–6 | 6–12 | 0–1 | 1–3 | 3–6 | 6–12 | 0–1 | 1–3 | 3–6 | 6–12 |
| Ph .. .. .. .. | 0·5 | 0·8 | 0·5 | 0·1 | 1·0 | 0·6 | 0·3 | 0·6 | 0·2 | 0·4 | 0·3 | 0 |
| Total Soluble Salts—% .. | 0·030 | 0·023 | 0·009 | 0·001 | 0·024 | 0·005 | 0 | 0 | 0·030 | 0·018 | 0·001 | 0·001 |
| Calcium Carbonate—% .. | 0·221 | 0·013 | 0 | 0 | 1·860 | 0·011 | 0 | 0 | 0·040 | 0·009 | 0 | 0 |
| Loss on Ignition—% .. | 2·2 | 4·0 | 1·2 | 0 | —2·7 | —1·5 | —1·3 | 0·2 | 0·7 | —4·8 | —4·4 | —3·5 |
| Organic Carbon—% .. | 1·19 | 1·47 | —0·07 | —0·32 | —2·02 | —0·91 | —0·70 | 0·25 | —0·15 | —0·29 | 0·02 | —0·27 |
| Nitrogen .. .. .. | 0·027 | 0·002 | ND* | ND | —0·085 | —0·034 | ND | ND | 0·025 | —0·031 | ND | ND |
| Readily Soluble Nutrients— | | | | | | | | | | | | |
| Calcium m.e.—% .. | 19·2 | 21·6 | 0·8 | —4·0 | 3·0 | 1·6 | 1·6 | 1·6 | 12·0 | 9·9 | 1·2 | 2·5 |
| Magnesium m.e.—% .. | 0·8 | 3·2 | 0·8 | —2·4 | 2·6 | 1·6 | 4·0 | —2·4 | 5·6 | 5·2 | 2·8 | 2·1 |
| Potassium m.e.—% .. | —0·16 | 0·24 | 0·40 | —0·08 | 0 | —0·16 | 0·16 | —0·16 | 0·04 | 0·04 | —0·16 | 0·08 |
| Sodium m.e.—% .. | 0 | 0·32 | 0·32 | —0·56 | 0·24 | —0·16 | 0 | 0·16 | 0·24 | 0·08 | 0 | 0·16 |
| Phosphorus p.p.m. .. | 6·4 | 14·4 | —4·8 | 4·0 | —0·8 | —1·6 | 0 | 3·2 | —4·0 | 0·8 | 2·8 | 6·0 |
| Manganese p.p.m. .. | 62·6 | 49·6 | —2·4 | 2·4 | 51·8 | 37·1 | 21·0 | 33·5 | 117·6 | 29·4 | 12·2 | 24·5 |

* Not determined.

An examination of the data from the four horizons indicates that very little of the materials leached from the surface is held in the first foot of soil. It appears that the material is either partly taken up by young plants growing on the ash bed or else leached away into the lower horizons of the soil.

With regard to the time required for the karri ash bed soils to return to a condition similar to the unburnt soil, it has been shown that marked differences, particularly in calcium carbonate, loss on ignition, organic carbon and nitrogen are still present in ash beds aged fifteen and twenty-two years, but the majority of these differences have almost disappeared in the surface soil after thirty years. Manganese, again, is an exception to this and big differences still occur between the thirty-year-old ash beds and the adjacent unburnt soil. The differences between these three groups of ash beds are tabulated in Table 3.

The wandoo ash beds, generally show only slight changes after fifteen years, but at twenty years they are almost identical with the unburnt soils.

## DISCUSSION

It is evident from the analytical data that the slash burn in both areas has converted the normal forest soil to an alkaline soil with a marked accumulation of soluble salts in the surface horizon. In conjunction with these changes there has been a reduction in soil organic matter due to the burn. Associated with these chemical changes in the soil, are pronounced changes in physical properties, and frequently the surface horizon is altered to a structureless soil with a powder-like consistance

These results are similar to those reported by overseas workers. Stent (1934), showed that the ash from the burning added large quantities of mineral plant food to the soil, and that there was a lack of response to fertilisers, other than nitrogenous ones, on the burnt areas. Fowells and Stephenson (1934) claimed that burning stimulated nitrification, increased the soluble mineral nutrients in the soil, and destroyed some of the organic matter in the immediate soil surface. Blaisdell (1953), working on the upper Snake River plains (U.S.A.) showed that heavy burning temporarily decreased organic matter and total nitrogen in the top half inch of soil, and the same trend was evident in a degree to two and a half inches depth. Requier (1953) demonstrated that land clearing carried out by felling and then burning the slash appeared to destroy organic matter and humus without necessarily reducing available nitrogen. This procedure also greatly increased soil pH and the quantity of assimilable nutrients. The question of slash burning and soil organic matter maintenance was investigated by Youngberg (1953) and this worker showed that the practice of burning slash in logged stands at the end of a long dry season led to the destruction of up to seventy per cent. of the organic matter in the surface three inches of soil However, these losses could be avoided by delaying the burning until there had been four or five inches of rain in autumn.

An interesting feature of the literature on this subject is that several workers, notably Fowells and Stephenson (1934), Griffith (1946), and Vlamis, Schultz and Biswell (1955), have shown that the nitrogen supplying power of the ash bed soils has markedly increased after the burn, despite the fact that the total soil nitrogen has decreased.

All workers stress the dangers of accelerated erosion following slash burns. However, this position does not arise in the areas mentioned, as the ash beds only occupy a small percentage of the total forest, and generally are not associated with steep terrain. In addition the ash bed areas are rapidly covered with young seedlings.

The source of the increased soluble salts of the burnt areas is the ash formed from the tree after the burn. Woody material forms the bulk of the slash, and the composition of this ash is shown in Table 4. (Stoate, Forests Dept. reports and 1950.)

TABLE 4

CHEMICAL ANALYSIS OF KARRI AND WANDOO WOODS

| Analysis of Sand-free Ash | Percentage of Composition | |
|---|---|---|
| | *Karri | *Wandoo |
| SiO .. .. .. .. .. .. .. | ·51 | ·20 |
| $Al_2O_3$ .. .. .. .. .. .. .. | *Nil* | ·05 |
| $Fe_2O_3$ .. .. .. .. .. .. .. | ·20 | ·18 |
| $Mn_3O_4$ .. .. .. .. .. .. .. | ·13 | 2·00 |
| CaO .. .. .. .. .. .. .. | 32·51 | 51·95 |
| MgO .. .. .. .. .. .. .. | 34·45 | 15·37 |
| $Na_2O$ .. .. .. .. .. .. .. | 1·73 | ·83 |
| $K_2O$ .. .. .. .. .. .. .. | 1·63 | ·29 |
| $H_2O$ .. .. .. .. .. .. .. | 2·50 | 1·50 |
| $TiO_2$ .. .. .. .. .. .. .. | Trace | ·01 |
| $CO_2$ .. .. .. .. .. .. .. | 22·42 | 24·12 |
| $P_2O_5$ .. .. .. .. .. .. .. | 2·84 | ·26 |
| $SO_3$ .. .. .. .. .. .. .. | 1·48 | 3·61 |
| BaO .. .. .. .. .. .. .. | .. | *Nil* |
| CuO .. .. .. .. .. .. .. | ·02 | ·01 |
| ZnO .. .. .. .. .. .. .. | Present | Present |
| Cl .. .. .. .. .. .. .. .. | ·34 | ·13 |
| | 100·76 | 100·57 |
| Less $O_2$ = Cl .. .. .. .. .. .. | ·07 | ·03 |
| | 100·69 | 100·54 |
| Undetermined (chiefly $CO_2$, Cl, $H_2O$, etc.) .. .. | .. | .. |

* Percentage Ash on Dry Weight at 100°C. : 0·213 and 0·397, respectively

The dominant cations of the ash are calcium, magnesium, sodium and potassium, while carbonate and phosphate are the dominant anions. The relative abundance of these cations and anions is reflected in the composition of the surface soil of the ash beds.

When considering the stimulating effect of ash beds on the development and growth of eucalpyt seedlings there are several factors which could influence plant growth.

Firstly, there is a rich source of nutrients readily available to the young seedling, and secondly it appears probable from overseas work that the supply of readily available nitrogen is greater on these soils.

In addition to these chemical changes, the burn also causes other important site changes. One of the most important of these is that the surface soil is broken up to produce a seed bed suitable for young eucalypts. In addition to this, the ash bed area is free from all associated undergrowth species, and the young plants do not suffer from excessive competition in the early stages of development.

## CONCLUSION

It is evident from the data that slash burning causes very marked changes in the immediate surface soil, and that these changes decrease rapidly down the profile. The results of this work confirm the results found by various overseas workers.

The soil changes that occur on the ash beds provide a good seed bed for the development of young eucalypts, and these changes do not appear to cause any permanent damage to the soil.

## ACKNOWLEDGMENTS

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