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While the results, therefore, cannot be regarded as conclusive, the figures obtained indicate that a lighter rate of seeding, as compared with earlier views, is conducive to better development of the individual plants without any perceptible decrease in the amount of grazing obtained. In the experiment above described it is possible that a better pasture might eventually be obtained from the plot seeded at 8 lb. per acre than from that seeded at 16 lb. per acre. Observations made on the plots gave the impression that a seeding rate of 4 lb. per acre was lighter than that required for maximum production.

It is realised that under conditions of higher general fertility, using the term "fertility" in its broadest sense, somewhat different figures might be obtained.

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# THE SALT (SODIUM CHLORIDE*) CONTENT OF RAIN-WATER.

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## SUMMARY.

Analysis of rainwater shows it invariably to contain impurities of which, in non-industrial centres, chlorides, principally salt (sodium chloride) are the most important constituents.

In coastal areas the mean salt content of rainwater may be expected to range from 15 to 50 p.p.m. and in inland areas from 4 to 20 p.p.m. The annual precipitation of salt in rainwater generally ranges from 100 to 600 pounds per acre in coastal regions and from 10 to 60 pounds per acre in inland centres.

Salt brought in by the rainfall and known as cyclic salt is deemed adequate to account for the amount of salt observed in the soils and ground waters in Western Australia. It seems unlikely that the Miocene submergence is a factor in the present condition with respect to the accumulation of soluble salts.

## CYCLIC SALT.

Visiting observers have always been interested in the obvious occurrence of salt patches in gullies in the south-western coastal regions of Western Australia, and an interpretation of the phenomenon on the basis of the salt content of rainwater has been attempted by several investigators. It is the purpose of this paper to summarise certain of the published results and to add further information obtained by the writer and associates.

It has long been recognised that rainwater is by no means pure—that it contains appreciable quantities of soluble matter such as common salt, nitrates, ammonia, dust, etc. In the vicinity of industrial centres, sulphates and sulphuric acid, soot, tar and ashes are additional and undesirable contaminants. Generally, however, common salt is the principal and most important impurity, but it is associated with small amounts of other substances of which magnesium and sulphate are the major constituents. The common source of these is sea water, the average percentage composition of which is:—

| Sodium (Na). | Chloride (Cl). | Magnesium (Mg). | Calcium (Ca). | Potassium (K). | Sulphate ($SO_4$). | Bromide (Br). |
|---|---|---|---|---|---|---|
| 1·03 | 1·90 | ·13 | ·05 | ·06 | ·28 | ·03 |

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* Sodium chloride is calculated from chloride estimated by titration with standard silver nitrate solution.

If all of the sodium is combined with chloride there would be 2.62 per cent. sodium chloride in sea salts and the remainder 0.86 per cent. would be composed of magnesium chloride, magnesium sulphate, and other compounds. Fine sea spray is lashed into the air by winds, the water evaporates and the residue, largely common salt but containing other salts as well, is carried inland to be deposited as a fine dust or dissolved in the rain. This salt is known as cyclic salt. In the vicinity of salt lakes or salinas, the salt may be derived in part from these local sources but, in principle, the action is the same. Having reached the surface of the soil, it begins to move back to the ocean (or other drainage basin) to complete the cycle —sometimes rapidly, and sometimes slowly; sometimes it may be practically immobilised in low rainfall areas in which drainage is more or less non-existent.

In studying the question of the salinity of the water in the Mundaring Reservoir, Weller (1926) calculated that an average of 28,800,000 pounds of salt is annually brought into the reservoir from its catchment of 569 square miles. This is equivalent to 80 pounds of salt per acre and agrees within very narrow limits with that found to be brought in by the rainfall. It was concluded that the salt concerned is wholly derived from the ocean and is brought to the catchment area by the wind and precipitated with the rain.

The problem was discussed from another point of view by Wood (1923) before the Royal Society of W.A. in 1923. He gave evidence over a period of 25 years which showed an increase in salinity in railway reservoirs, principally in the Great Southern and South-Western districts, following the clearing of the surrounding country. In many cases the increased salinity was traceable to newly formed saline streams entering the reservoir, sometimes on the surface and sometimes in the subsoil, often following the path of decayed roots. It was also observed that in some instances the first water entering the reservoirs with the break of the dry summer period was much more saline than the normal winter supplies, and this was attributed to salt as dust being deposited on the surface of the soil during the summer. Wood concluded that the salt was derived from evaporated sea spray driven inland by the sea breezes or "doctors" which temper the climate of coastal areas at all seasons of the year in Western Australia.

Considerable scientific and practical interest in Wood's paper led the Royal Society to appoint a committee to investigate the matter more fully and a comprehensive report was published in the Journal of the Royal Society of Western Australia for 1929. This investigation involved the analysis of rainwater and the measurement of the strength of prevailing winds during 1926 at a number of coastal and inland centres, but the bulk of the evidence was obtained for the Perth Observatory which is about 5¼ miles east of the west coast.

At the Perth Observatory rainwater was collected and analysed on 100 days of the 164 on which rain fell. On the remaining days very light rain was recorded and was not examined. The information proved that there is a strong positive correlation between the amount and strength of landward winds and the amount of salt in the rainfall. Strong, gusty weather from the western quarter caused the salinity of the rainwater to be particularly high.

Of particular significance are the figures obtained during a storm on the coast between July 18th and July 22nd, 1926, when 4.16 inches of rain were recorded and the total landward wind movement amounted to 3,185 miles for the five-day period. The average salinity of the rainwater in terms of salt was 50 p.p.m. (3.5 grains per gallon) and 45 pounds of salt per acre were deposited. The maximum concentration of salt in the rainwater and the maximum deposition in one day were recorded on July 21st, when the landward wind movement amounted to 1,032 miles, an average of 43 miles per hour. On this day 0.80 inches of rain fell and the rainwater contained 154 p.p.m. salt (10.8 grains per gallon), with the result that 28.0 pounds of salt were deposited on the city of Perth, as represented by the Observatory.

Normally, of course, the rainwater is much less saline. The average for the Observatory in 1926 was 27.2 p.p.m. salt (1.9 grains per gallon) and about 300 pounds of salt per acre were deposited during the whole year. The minimum concentration determined was on September 27th, 1926, when 6 points (0.06 inches) of rain, containing 3.26 p.p.m. salt (0.23 grains per gallon) were recorded.

A certain amount of data for a number of other stations were obtained and are summarised, with those for Perth, in Table 1. It is unfortunate that more complete data could not be obtained but it is considered that reliable deductions are possible and accordingly estimates are included in Table 1. These estimates must be accepted in the light of the data submitted.

### TABLE 1.

Summary of information published by the Royal Society of Western Australia (1926) concerning the salinity of rainfall at various centres and the estimated precipitation of salt per acre during 1926.

| Station. | Number of Days Recorded. | Total Rainfall on the Days Recorded. | Total Rainfall for Year (1936). | Salinity of Rain Water NaCl.* | Estimated Precipitation of Salt per Acre per annum.† |
|---|---|---|---|---|---|
| A.—Coastal: | | inches. | inches. | p.p.m. | lbs. |
| Perth ... ... | 100 | 41·33 | 19·22 | 27·2 | 304 |
| Geraldton ... | 15 | 5·48 | 16·23 | 47·3 | 174 |
| Esperance ... | 9 | 8·89 | 33·42 | 34·1 | 259 |
| Cordon ... ... | 6 | 5·99 | 12·52 | 13·5 | 38 |
| B.—Inland: | | | | | |
| Coolgardie ... | 5 | 3·07 | 7·94 | 19·8 | 36 |
| Cue ... ... | 15 | 4·51 | 10·34 | 15·8 | 37 |
| Mundiwindi ... | 12 | 5·19 | 7·39 | 5·8 | 9·7 |
| Wiluna ... ... | 6 | 2·33 | 6·63 | 6·6 | 9·9 |
| Rawlinna ... | 3 | 1·16 | 3·65 | 10·4 | 8·6 |

* NaCl calculated from chloride ion determined by titration with standard silver nitrate.

† For the purpose of this calculation it is assumed that the total rainfall for the year has the same average composition as that portion actually analysed. Precipitation of salt per acre equals total rainfall × salinity × 0.227 lbs.

## THE SALINITY OF RAINWATER AT MERREDIN AND SALMON GUMS.

Further information for Western Australia has been obtained by the writer and his associates in the course of soil alkali investigations in the wheat belt. The water collected in the rain gauges at the Merredin and Salmon Gums Research Stations for the four-year period 1933-1936 was sampled at monthly intervals by the courtesy of the Superintendent of Wheat Farming (Mr. I. Thomas) and analysed for chloride content by Best's method (1929). When insufficient rain was collected during one month, two, and sometimes three or four months' precipitation were bulked for analysis. In all cases the total amount of water collected in the gauges in the usual routine was sampled for analysis so that any salt falling on the gauge in the form of dust would be included in the determination. The Merredin Research Station is approximately 160 miles east of Perth and the Salmon Gums Research Station 65 miles north of Esperance.

The results of this work are summarised in Table 2.

TABLE 2.*

Salt in Rainwater at the Merredin and Salmon Gums Research Stations 1933-1936.

| Year | Merredin. | Salmon Gums. |
|---|---|---|
| 1933— | | |
| Rainfall (inches) | 9.67 | 12.13 |
| Salt—p.p.m. | 7.3 | 9.4 |
| Salt—lbs. per acre | 16.2 | 25.8 |
| 1934— | | |
| Rainfall (inches) | 13.48 | 14.95 |
| Salt—p.p.m. | 5.7 | 10.2 |
| Salt—lbs. per acre | 17.3 | 34.8 |
| 1935— | | |
| Rainfall (inches) | 10.24 | 11.46 |
| Salt—p.p.m. | 5.8 | 10.1 |
| Salt—lbs. per acre | 13.6 | 26.2 |
| 1936— | | |
| Rainfall (inches) | 8.81 | 11.53 |
| Salt—p.p.m. | 9.1 | 8.4 |
| Salt—lbs. per acre | 18.2 | 22.1 |
| Mean of four years by years— | | |
| Salt—p.p.m. | 7.0 | 9.4 |
| Salt—grains per gallon | 0.49 | 0.67 |
| Salt—lbs. per acre | 16.3 | 27.2. |

*The concentration of salt reported is the weighted average of all determinations during each year.

The average annual salt precipitation at Salmon Gums is about 27 pounds and at Merredin 16 pounds, a ratio of 1.69 to 1, and the difference is due largely to the concentration of salt in the rainfall. If all of the salt precipitated accumulated in the soil it would take over 200 years at Merredin and about 120 years at Salmon Gums to raise the soil to a depth of one foot by 0.1 per cent. salt. In the course of the Salmon Gums and Lake Brown* Soil Surveys it was discovered that the deeper subsoil layers (6-10 feet) contained about 0.6 per cent. and 0.35 per cent. salt at Salmon Gums and Lake Brown respectively. This corresponds to a ratio of 1.71 to 1, which very closely approximates that for salt precipitation and suggests that the salt content of the rainfall is adequate to explain the presence of salt in these soils and also the differential amounts found in the course of the soil surveys.

## COMPOSITION OF RAINWATER IN OTHER PARTS OF THE WORLD.

It has been considered by some that the salt precipitation in Western Australia is extraordinarily high. That this is not so is amply demonstrated by information from the literature, Miller (1906) and Crowther and Ruston (1911). For purposes of comparison data collected by these investigators are summarised in Table 3.

The composition of the rain with respect to salt at the stations from which studies are reported resembles that examined in Western Australia and the annual deposition of salt varies between similar limits. The paramount importance of the proximity to the coast and the type of wind is made clear by the data for Western Australia and is emphasised by a figure for Land's End, England, reported by Miller (1906). Rainwater collected at a height of 100 feet above the sea at Land's End analysed 360 p.p.m. salt (25 grains per gallon), a figure which probably approaches the maximum for normal rainfall.

* The Lake Brown soil survey was carried out in an area 25 to 40 miles north of Merredin township.

TABLE 3.

Composition of rainwater from various parts of the world from figures reported by Miller (1906) and Crowther and Ruston (1911).

| Investigator. | Centre. | Country. | Annual Rainfall. | *Salt (NaCl) in Rain Water. | *Salt Deposited by Rain. |
|---|---|---|---|---|---|
| | | | inches. | p.p.m. | lbs. per acre per annum. |
| Miller ... | Rothamstead | England ... | 27·25 | 3·8 | 24·5 |
| Do. ... | Circencester ... | do. ... | 30·61 | 5·2 | 36·1 |
| Crowther & Ruston | Leeds (Suburban-Garforth) | do. ... | 26·95 | 5·6 | 34·5 |
| Do. ... | Leeds (Industrial Stations) | do. ... | 26·95 | 27–54 | 160 to 330 |
| Miller ... | Perugia ... | Italy ... | 33·96 | 5·2 | 40 |
| Do. ... | Scandicci ... | do. ... | 27·67 | 9·3 | 58 |
| Do. ... | Catania ... | do. ... | 18·36 | 9·0 | 38 |
| Miller ... | La Guardia ... | Spain ... | 56·42 | 51·4 | 660 |
| Do. ... | ... ... ... | New Zealand | 29·70 | 14·5 | 98 |
| Do. ... | ... ... ... | Barbados ... | 63·95 | 13·4 | 211 |
| Miller ... | ... ... ... | British Guiana | 102·41 | 8·3 | 193 |
| Do. ... | ... ... ... | Ceylon ... | 82·13 | 16·0 | 298 |
| Do. ... | Calcutta ... | India ... | 46·01 | 5·2 | 54 |
| Do. ... | Madras ... | do. ... | 39·21 | 6·7 | 60 |

* Calculated from chloride.

These soluble salts are generally regarded as more or less innocuous and may be an advantage in the growth of special crops such as artichoke and beet. Considerable concern, however, has been occasioned by other and highly undesirable impurities in the vicinity of large industrial centres. The late Julius Stoklasa has been one of the foremost investigators of the problem in Germany, and, in England, Crowther and Ruston (1911) have thoroughly investigated the conditions near Leeds.

Crowther and Ruston found that the maximum quantity of suspended impurities deposited per acre per annum at Leeds amounted to 1,886 pounds, composed of 110 pounds of tar, 663 pounds of soot and 1,113 pounds of ash. In addition, considerable quantities of sulphuric acid were deposited, the maximum amount recorded being 90 pounds per acre per annum. Normally, there would be no sulphuric acid in rain water.

These impurities lead to the stunting of the growth of plants and prevent entirely the growth of more sensitive varieties. The suspended impurities reduce the intensity of sunlight by as much as 40 per cent., and the soot and tar block the stomatal openings of the leaves and retard the absorption of carbon dioxide and the exhalation of oxygen. Leaves badly coated were able to assimilate only 11 per cent. of the normal amount of carbon dioxide for clean leaves. The sulphuric acid in the rain water also proved deleterious to the leaves directly and caused serious damage to the soil by promoting acidity.

Fortunately, in Western Australia damage from such sources is almost non-existent, but the possible importance of the salt content of the rainwater in the accumulation of salts in soils in the agricultural areas is of considerable interest and practical moment.

## THE INCIDENCE OF CYCLIC SALT.

The data from the Merredin and Salmon Gums Research Stations afford an opportunity for some study of the incidence of the salt precipitation.

Figure 1. shows the relationship between monthly precipitation and amount of salt deposited in pounds per acre at Merredin and Salmon Gums during the four-year period under test and Table 4 gives the four-year means for each station.

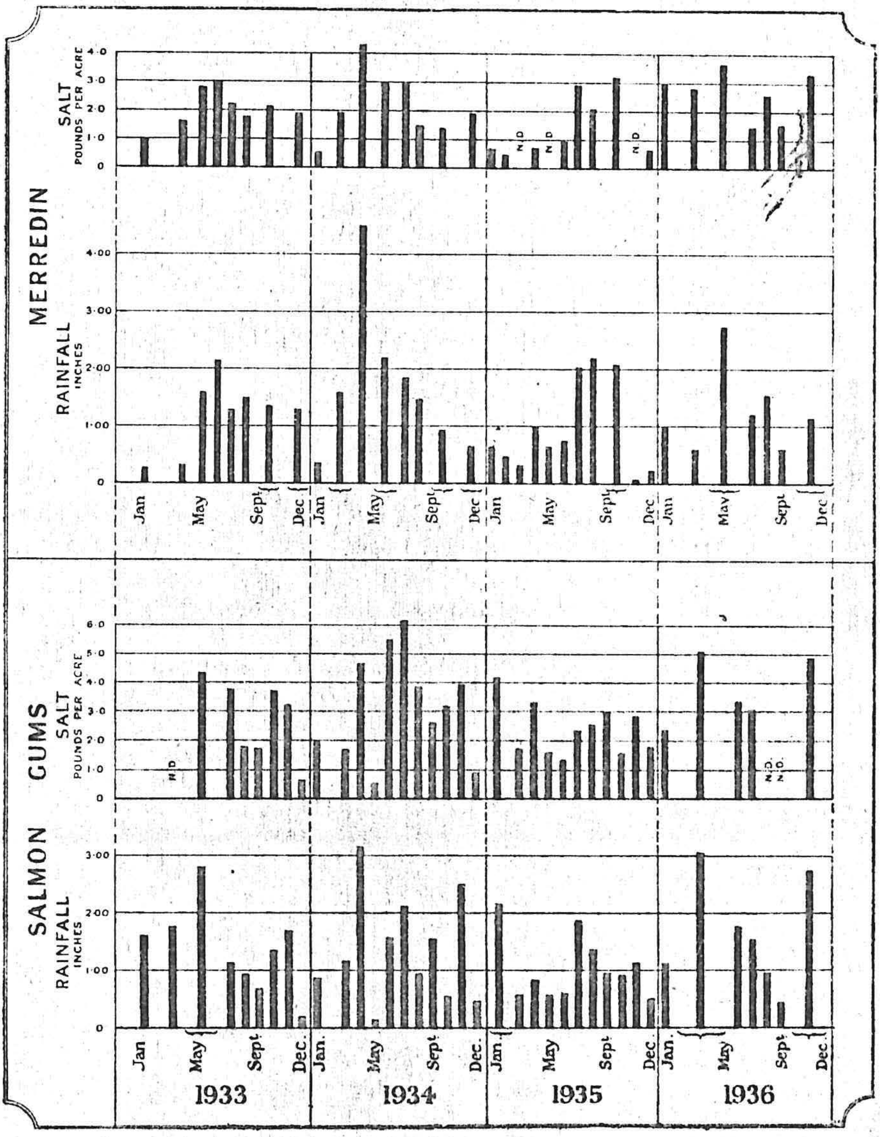


Fig. 1.—Graphic representation of the relationship between the monthly rainfall and the magnitude of the monthly deposition of salt, in pounds per acre, at the Merredin and Salmon Gums Research Stations, 1933 to 1936.

TABLE 4.

*Amount of Salt Collected in the Rain by Months at the Salmon Gums and Merredin Research Stations.*

Mean of Four Years' Results, 1933-36.

| | Merredin Research Station. | | Salmon Gums Research Station. | |
|---|---|---|---|---|
| | Rainfall. | Salt. | Rainfall. | Salt. |
| | inches. | lbs. per acre. | inches. | lbs. per acre. |
| January ... ... ... | 0·54 | 1·25 | 0·98 | 2·09 |
| February ... ... ... | 0·14 | 0·16 | 0·48 | 0·93 |
| March ... ... ... | 0·62 | 1·59 | 0·90 | 1·74 |
| April ... ... ... ... | 1·43 | 1·49 | 1·14 | 2·24 |
| May ... ... ... ... | 0·80 | 1·24 | 1·09 | 1·99 |
| June ... ... ... ... | 1·68 | 2·27 | 1·32 | 3·08 |
| July ... ... ... ... | 1·59 | 2·39 | 1·66 | 3·83 |
| August ... ... ... | 1·67 | 1·97 | 1·04 | 2·66 |
| September ... ... ... | 0·59 | 1·06 | 0·90 | 2·08 |
| October ... ... ... | 0·66 | 1·05 | 0·76 | 2·20 |
| November ... ... ... | 0·27 | 0·62 | 1·42 | 2·65 |
| December ... ... ... | 0·55 | 1·26 | 0·82 | 1·77 |
| Total ... ... | 10·54 | 16·35 | 12·51 | 27·24 |

There appears to be a maximum deposition of salt in the winter months, June, July and August, at both stations and a minimum in February, but considerable amounts of salt may be collected in the rain during any season.

At Merredin there is quite a strong correlation between the amount of rainfall and the amount of salt deposited by months but at Salmon Gums the correlation, while apparent, is far less marked. For Salmon Gums all that can be said is that months of high rainfall are months of high salt deposition but quite considerable amounts of salt may be deposited with a relatively low rainfall.

This brings up the matter of the composition of the rainfall and again it is very difficult to observe precise correlations between rainfall and salt concentration. From the data it may be concluded that in months of high rainfall the salt concentration of the rainwater tends to be lower than in months of low rainfall.

The position is represented in Table 5.

TABLE 5.

*Composition of Rainwater in Relation to the Magnitude of the Monthly Precipitation.*

| Monthly Rainfall Range. | Merredin Research Station. | | | Salmon Gums Research Station. | | |
|---|---|---|---|---|---|---|
| | Number of records during— | | Salt in Rainwater (NaCl). | Number of records during— | | Salt in Rain water (NaCl). |
| | Summer months. | Winter months. | | Summer months. | Winter months. | |
| inches. | Nov.-Apl. | May-Oct. | p.p.m. | Nov.-Apl. | May-Oct. | p.p.m. |
| 0-0·50 ... | 10 | 4 | 11·3 (5·3–23·5) | 9 | 2 | 10·6 (6·8–24·7) |
| 0·50-1·00 ... | 7 | 6 | 8·9 (3·1–20·5) | 3 | 8 | 13·4 (7·4–26·0) |
| 1·00-2·00 ... | 1 | 9 | 6·1 (4·4–7·6) | 5 | 10 | 9·2 (5·6–15·3) |
| Above 2·00 ... | 0 | 4 | 5·2 (4·2–6·3) | 2 | 3 | 8·3 (6·5–12·9) |

At Merredin, the lower concentration of salt in the rainwater in high rainfall months is much more definite than at Salmon Gums. This is probably due to the proximity of Salmon Gums to the Southern coast which is noted for strong southerly sea breezes. A number of climatic factors will influence the collection of sea-spray in the atmosphere and insufficient data renders it impossible to extend the discussion here.

## DISCUSSION.

Until recently it has generally been assumed that the salt in our soils and ground water is largely of geological origin—that is, it represents the remains of an ancient submergence when the ocean was thought to extend as far north as about latitude 29deg. S.* during Miocene times. The cyclic salt theory suggested by Wood (1923) received only scant support in Western Australia, although in South Australia, Jack (1914) has been a strong advocate and had presented much data and argument in support.

In the discussion of Wood's (1923) paper, Montgomery, then State Mining Engineer, suggested that the recognised Cainozoic (Tertiary) submergence of the southern portion of Western Australia accounted for at least a portion of the salt in the soils of the State. Simpson (1926, p. 642) associated the incursion of the Miocene sea with the occurrence of salt in the soils and ground water of the south central portion of the State as represented by Merredin and Salmon Gums.

While there is a possibility that the huge deposits of salt in some of the salt lakes or salinas of Western Australia may be related to a Miocene submergence, there is now a large body of opinion, based on more recent observations, to the effect that it is very likely that the cyclic salt theory will account for the occurrence of salt in soils and ground waters generally. The Miocene submergence began about 40,000,000 years ago and the formation of the ironstone gravels, commonly associated with sandplains of the interior, is certainly more recent than this period. As these gravels require moist conditions for their formation it is evident that since Miocene times, Western Australia has enjoyed a period of much better rainfall than pertains at present. Further evidence in support of this hypothesis is adduced by Finlayson (1936) in his discussion of the mammals of the desertic interior. The feeble specialisations of Australian desert fauna to the desertic conditions leads him to conclude (p. 57) that "if . . . . the centre is a desert, then at least it is the veriest newcomer amongst deserts, and many of its denizens retain . . . . habits which must have obviously been developed under much less rigorous conditions of climate than now obtain." Amongst the flora of the Livesey Ranges near the Western Australian border north of the Nullarbor Plains is a patch of blackboy (Xanthorrhoea sp. unknown), a genus typical of the high rainfall areas. Similar occurrences have been reported east of Wiluna and east of Leonora and it is suggested that this affords botanical support for Finlayson's conclusion.

It seems unlikely that any considerable portion of the salt at present in the soils and ground waters of Western Australia has been derived from the Miocene sea.

Considering the factor of cyclic salt alone and assuming the unconsolidated material above the rock to be 50 feet deep, in the total absence of drainage it would take 37,000 years to raise the soils at Salmon Gums to 0.6 per cent. salt and 35,000 years to raise the soils at Merredin to 0.35 per cent. In view of this there seems little reason to postulate that the salt in Western Australian soils and waters have their origin in a sea which existed 40,000,000 years ago.

In the face of this there seems little that man can do to control the forces associated with the occurrence of salt in the soils of Western Australia. It is known, however, that, under virgin conditions, an equilibrium has been established

* Mingenew and Leonora may be taken to represent the location of latitude 29° S.

in which the ratio between the percentage of salt in the soil and the percentage of salt in rainwater is about 500 to 1 under a 13-inch annual rainfall. With the clearing of the country under this rainfall, the soluble salts are rapidly leached from light textured soils and slowly, if at all, from heavy textured soils. Even in heavy textured soils, this ratio would be expected to widen in cultivated country and certain, if slow, improvement should result.

This improvement in the shape of leaching of soluble salts following the clearing of the country brings other problems as the ground water level tends to rise and is known to have risen under a 13 to 20-inch annual rainfall. With the rise of the water table low-lying areas and portions of valleys are liable to become affected with salt encroachment. As far as is known little can be done in many of these instances except to establish salt tolerant pastures and, where possible, to complete the cycle by facilitating drainage and the removal of the salt to the sea whence it came.

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## ERRATUM.

"Journal of Agriculture," March, 1937.

P. 46: "1.303 acres" in lines 19 and 23 should have read "1.803 acres."