A PINCH OF SALT: TRACE-ELEMENT AGRICULTURE IN AUSTRALIA*[1]

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One hundred seventy-three years after the first English settlers landed at Botany Bay, Australia, the only habitable continent entirely within the southern hemisphere, attained a population of ten million. This was in April, 1959. Why it took Australia, with an area almost equal to that of the coterminous United States, so long to reach this ten-million mark is a many-faceted study and one in which geographers are greatly interested, for here is a welter of physical and cultural threads beautifully entangled. This paper is concerned with the untangling of one of these: why some of Australia's soils were for so long agriculturally[2] useless.

The first decades of white settlement in Australia brought no notice of these shortcomings. There was land in abundance and if one spot proved poor there were many others, since the early settler was a mobile individual. However, by the middle of the 19th century clues were accumulating indicating that some areas were definitely poor agricultural risks. At first these hints related largely to a peculiar malady afflicting sheep grazing on certain areas of calcareous soils in southern Australia; because of its association with coastal areas the disease came to be called "coast disease." While the southeastern portions of the continent were filling up, "coast disease" was little noted and not at all understood, but it became a matter of increasing importance following World War I, when returned servicemen were settled on marginal lands in South Australia and Victoria. These settlers soon began to find their work seriously endangered, first by the "coast disease" in coastal areas, and more alarmingly by crop failures which seemed to be due to soil infertility.

In Australia as a whole there are thousands of square miles of country covered with "light" soils—sandy and gravelly soils of diverse nature and origin running the entire range from skeletal soils forming on sand and rock through podzols and laterites. In southern Australia these "light" soils are associated with a native vegetative cover of scrub forest which may range from heath-like associations to forest. In its typical form, however, this scrub is dominated by eucalyptus of several species, most of which exhibit the "mallee habit," i.e., a number of trunks sprouting from a single, large underground lignotuber. Such a scrub attains a height of 12 to 40 feet and will often be extremely dense; it is somewhat analogous to the larger types of California chaparral. Associated species are acacias, melaleucas, banksias, hakeas, and numerous other shrubby plants. Because these soils and their attendant vegetative associations occurred in those portions of

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[2] In this paper the term "agriculture" will be used broadly to include both farming and pastoral pursuits.

southern Australia where rainfall is sufficient for agriculture and reasonably reliable, it was of the utmost importance to the development of the Commonwealth that the scrub and forest be replaced by crops and pastures. These precipitation characteristics, combined with improving accessibility to urban and overseas markets fostered by an expanding system of railways, induced many settlers to attempt the development. Their experiences were all too often unhappy.

The scrub lands were not easy to clear. As late as 1930 much hand labor was involved, for in heavy scrub or forest the larger trees could only be ring-barked (girdled) and left standing. Lighter scrub could be rolled flat by huge horse-drawn rollers made of sections of discarded steam boilers and burned when dry. Plowing would have been almost impossible because of the roots remaining in the ground had it not been for an ingenious Australian invention, the *"stump jump plow."* This was a multiple (two to four furrow) plow in which each plowshare and mouldboard were hinged from the frames so that when the share struck an obstacle the entire "bottom" swung up and back until the obstruction was passed, whereupon its own weight dropped it back into the soil. In the sandier soils disc plows were often used. A major problem was the regrowth of shoots from the remaining lignotubers, which easily withstand burning. Shoots had to be slashed by hand and some reappeared for several years in spite of the best efforts. Even in 1890 when labor was cheap it cost at least thirty dollars to prepare an acre of scrub land for crops. Broadcasting of seed was a common method, and harvesting was accomplished by another Australian invention, the *"stripper,"* a horse-drawn combine in which the power was obtained from a set of gears on a large drive wheel.

Such labor and costs might have been borne if good crop yields could have been obtained, but a whole series of baffling and disastrous phenomena occurred: cereal grains often produced poor straw and failed to fill their seed heads; legumes, such as clovers, would not seed properly, while perennial grasses grew poorly, if at all. Even the use of commercial fertilizers, introduced after 1890, did little to alleviate the situation in these "light" soils, although they were shockingly low in phosphates and nitrogen. These areas, particularly the mallee scrub lands, soon acquired a bad reputation. Occasionally a run of particularly good seasons or higher grain prices would encourage a small foray into these lands, but with few exceptions the discouraged settlers soon withdrew. There the matter rested until the 1930's.

By 1930 the "coast disease" problem was causing major curtailment of pastoral activities in many areas of southern Australia, and the Council for Scientific and Industrial Research[3] was asked to undertake research which might lead to a possible solution. Accordingly, an officer of the Division of Animal Nutrition began field experiments on Kangaroo Island

[3] Later the Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.). This organization, operated by the Federal government, but enjoying a very high degree of professional autonomy, is specially charged with research into all fields of primary production, althought it engages in much other research as well. The premier research body of the Commonwealth, it commands the highest respect in all segments of the population, and a major portion of Australia's recent advancement has been directly attributable to C.S.I.R.O. research.

(South Australia) where the disease was well-known. Eventually the disease was diagnosed as acute anemia, so profound that unless arrested most body functions became involved, even to the extent of deterioration of bone structure. It was discovered that the afflicted animals seemed to recover if removed from the calcareous country where the disease developed and put on laterite country which was equally poor from the standpoint of plant and animal nutrition. Finally, in 1933, the solution was found: the pastures of the calcareous areas were deficient in copper and cobalt, and sheep nearly dead from "coast disease" recovered miraculously when given as little as one milligram of copper and cobalt (soluble) per day, although neither of these elements effected the cure when administered singly.

The next chapter of the story also comes, curiously enough, from Kangaroo Island. Nearly sixty percent of this island carries a suite of laterite and lateritic soils which for a century had defied the best efforts to bring them successfully under crop or pasture. These soils were notoriously low in phosphates and nitrogen, and, although numerous attempts had been made to grow cereal grains on them with the aid of generous applications of superphosphates, all such efforts had failed. The complaints were standard for the mallee country: unhealthy plants and poor yields. In 1936 the C.S.I.R.O. turned its attention to this problem, for similar soils are widespread in southern Australia. The initial aim was to establish permanent pastures in which legumes figured strongly, on the sound principle that if the nitrogen level could be raised, other crops would then thrive. The legume chosen was subterranean clover *(Trifolium subterraneum)*, an introduced plant which has proved to be of inestimable value.[4] However, it proved to be impossible to establish a good cover of this legume on the lateritic soils of the island; the seeds did not set properly and no combinations of fertilizers, mulches, and bacterial inoculations alleviated the situation.

By this time a significant body of data had been accumulated in Australia and overseas on the role of various metallic elements in the metabolism of plants and animals.[5] The officer in charge of the Kangaroo Island soil experiments, recalling the recent work on "coast disease" on the island, planted a new series of test plots, some of which received, in conjunction with superphosphates, a very small amount of copper sulphate. The results were most gratifying. Eventually it was determined that much of this formerly useless land could be made into excellent pasture of perennial grasses and legumes if, along with superphosphates, as little as five pounds of copper sulphate per acre were applied.

[4] The origins of this clover are obscure. It appears to have been noted in pastures in the Mt. Lofty Ranges of South Australia as early as 1890 and was deliberately spread by graziers because of its excellent grazing and propagation characteristics. Although an annual plant, its seeding habit makes it virtually perennial in areas where it becomes established. When its seeds are ripe the seed capsules bend toward the ground and bury themselves in the uppermost layers of soil. A number of varieties have been developed and it has been the most important single pasture plant in the development of the areas of "light" and lateritic soils.

[5] It should be noted that the C.S.I.R.O. was not the only Australian organization engaged in research along these lines. Some of the State Departments of Agriculture, notably that of Western Australia, contributed greatly to the general knowledge of the role of trace elments in agriculture.

This was just prior to the outbreak of World War II, and for the next several years facilities to put the new methods into extensive practice were not available. However, further experiments were carried out on Kangaroo Island and elsewhere. With the end of the war the climate for land development changed abruptly. Thousands of servicemen returned and governments devised plans for bringing men and land together. Now governments and private enterprise were quick to take up the new techniques on a large scale.

Further research in field, test plot, and laboratory disclosed that zinc, molybdenum, manganese, boron, iron, magnesium, and sulphur deficiencies exist in many Australian soils. Once recognized, the correction is usually simple: a small quantity, varying from a few ounces to a few pounds, of a generally cheap salt of the metal are mixed in with the superphosphate which all of these soils require. Soils so treated grow subterranean clover and perennial grasses without trouble, and, when their nitrogen content has been brought up to respectable levels, cereals and other crops may be grown successfully.

Several peculiarities associated with the lack of these minor elements have come to light. First, there is as yet no laboratory method which will indicate whether a soil is deficient in an element or a group of them. The only way this can be definitely determined is by controlled plot experiments on the land itself. Second, while detailed mapping of the distribution of particular deficiencies had not yet been done, enough evidence has accumulated to indicate that they are not consistent in their occurrence over any considerable area. As yet there has been no adequate geological or pedological explanation of why some soils are so grossly deficient in one or more of these minor elements and adjacent soils are not. Third, the role of these elements in plant metabolism is as yet poorly understood; the evidence obtained to date suggests a catalytic role.

After World War II, particularly since 1950, a virtual agricultural revolution has swept southern Australia, based very largely on what has come to be called the "trace element-superphosphate technique" for developing poor soils, especially those of coastal areas or with sandy or gravelly "A" horizon. Although slow to get under way due to restrictions and shortages of manpower and material during the immediate post-war period, the changes which this technique has wrought in the landscape and economy of the Commonwealth have been remarkable.

Because each state has varied somewhat in its methods of reporting these gains, it is not possible to present a composite picture for the entire Commonwealth; however, a state-by-state summary is possible.

South Australia. The state in which the new techniques may be fairly said to have begun has profited largely from the discovery. Less than five per cent of the state's area has an annual rainfall of eighteen inches or more, and it has been very important that considerable areas of formerly useless scrub land within the assured rainfall zone could be brought under pasture or crop.

In this state it has been the pastoralist, rather than the farmer, who has been the principal beneficiary of the new techniques, for of the 412,000 tons of trace-element superphosphate sold between 1940 and 1959, only

14,900 tons were used on crops. The bulk of this material, in excess of 212,000 tons, has been used directly in the establishment of new sown pastures,[6] and the amount of land so brought into production during the twenty-year period has been approximately 2,000,000 acres. On Kangaroo Island alone slightly more than 400,000 acres were so seeded. A fuller realization of what this means to the state's economy is conveyed by the fact that government officials estimate that in the districts concerned the number of sheep has increased by about 3,000,000. A conservative estimate of the value of the *annual* production from the additional 3,000,000 sheep would be $11,150,000 for meat and $15,610,000 for wool. The benefits are even more remarkable when it is realized that this was entirely unuseable land in 1940 and that eventually a portion of it will be useable for the production of crops as well as sheep.

In South Australia the principal elements which have brought a response in pastures have been copper, zinc, manganese, cobalt, and molybdenum. At least copper is almost always applied as a "standard treatment" for newly cleared land. All of the elements are usually applied as sulphates except molybdenum, which is applied as sodium molybdate. A small amount of cobalt and copper is also applied to pastures in known deficient districts to ensure the provision of these elements for stock. The principal element which has shown a response in cereal crops is manganese.

Western Australia. Western Australia is certainly the state in which fullest use has been made of these techniques, largely because a major share of its soils which lie within the zone of reliable rainfall are of the "light" sandy varieties which are notoriously deficient in the minor elements. It is estimated that most of the land in southwestern Western Australia is deficient in one or more of the trace elements. Following World War II new land was brought into production at a rate of more than 750,000 acres per year, and nearly 11,000,000 acres were cleared between 1945 and 1959. Of this total slightly more than half is estimated to have been cleared on established farms, while ninety per cent of the clearing was done in so-called "light" soils. During the same period improved pasture acreages increased by more than 5,400,000 acres. A conservative estimate places the area receiving the minor elements at approximately 9,000,000 acres.

Most of the same elements noted for South Australia have been used in the western state. Cobalt, however, seems to have been little used there, and there are other differences in the use and form of the element applied. In Western Australia, which has its own supplies of copper ore, it has been found that oxided copper ore is both cheaper and more stable than copper sulphate. Zinc and molybdenum are both applied in oxide form, but manganese sulphate is used as in other states. One other difference is worth noting: Western Australia's major cereal growing areas are based on the "light" soils, and wheat, barley, and oats have all shown a response to applications of copper and zinc. Indeed officers of the State Department of Agriculture assert that it is advisable to apply both copper and zinc to the first crop grown on any land with a sandy or gravelly topsoil. Hence considerable quantities of superphosphate containing trace elements have been ap-

[6] The remainder, approximately 184,500 tons, have been used to supplement the amounts initially applied during the establishment of pastures on new lands.

plied to land growing cereals, a practice which is less common in other states. Western Australia's farmers enjoy one advantage over those of other states: locally manufactured superphosphate contains some zinc and copper as an impurity.

New South Wales. It is in New South Wales that the broadest spectrum of trace-element deficiencies has been found to date. Copper zinc, manganese, molybdenum, magnesium, boron, and sulphur have all been found to be deficient in various districts in the eastern half of the state. It is possible that deficiencies may be present in the western sheep grazing areas, but the broad scale of grazing operations there has not made them apparent. It is also considered impossible to improve pastures on so extensive a scale. Because the eastern portion of New South Wales lies well within the twenty-inch isohyet, where cultivation is possible, considerable attention has been paid to the response of cultivated crops to trace elements. The results indicate there may well be deficiencies which are as yet unrecognized in other parts of the Commonwealth.

One of the most striking responses was obtained by the application of as little as one to two ounces of molybdenum per acre to such legumes as subterranean clover. Yields were, in some cases, increased several times. It appears that in New South Wales this is the most generally deficient element. Another deficiency rarely noted elsewhere in the Commonwealth is sulphur; this lack may be supplied in part by the simple use of superphosphate, but, once an adequate phosphate level is attained, there are cheaper ways of supplying plants with sulphur (*e.g.* by the use of calcium sulphate). Boron deficiencies have been reported from a number of districts, particularly those in which vegetables are extensively grown and where heavy liming has been carried out to assist in the growth of leguminous pastures. Curiously, a deficiency of copper is less frequently noted in this state than in the southern states generally, and iron deficiency is even rarer, although a response has been obtained with both in certain districts.

Since 1946, when large-scale pasture development and improvement began following World War II, the area of sown (improved) pastures has been increased by approximately 7,500,000 acres. No estimate is available of the portion which received minor element treatment, but from data received from other states and publications of the State Department of Agriculture, it appears that thirty per cent, or approximately 2,250,000 acres, is a very conservative estimate. No estimate is available of the applications to crops, but such applications have been made. It seems to assume that at least 3,000,000 acres in New South Wales have been brought under cultivation or have had their productive abilities materially increased by the use of trace elements.

Victoria. The situation in eastern and northeastern Victoria is very similar to that in New South Wales, while the western and southern coastal areas display deficiency patterns more like those of South Australia. The use of trace elements in this, the most intensively developed state in the Commonwealth, has been largely restricted to pastures, although zinc has been widely used in some of the wheat-growing districts. As in South Australia, sandy soils both on the coast and in the western interior respond to the application of copper and cobalt. Molybdenum has proved to be lacking in many areas of the eastern and northeastern portions of the state. Apparently sulphur, iron, magnesium, and boron are generally present in sufficient quantities, although further research may demonstrate their lack in some localities.

Between 1940 and 1959 the acreage of sown (improved) pastures in Victoria has increased by approximately 6,450,000 acres. No accurate data are available to indicate what percentage of this increase has been assisted by the application of minor elements, but because copper and cobalt deficiencies are widespread it is probable that it exceeds the thirty per cent figure adopted for New South Wales. An estimate of forty per cent, or approximately 2,580,000 acres, seems conservative.

Tasmania. This, the smallest state in the Commonwealth, has long been aware of trace-element deficiencies, especially in certain islands in Bass Strait, where conditions very similar to those on Kangaroo Island prevail. Copper, cobalt, zinc, and molybdenum appear to be the major and most widespread deficiencies, although responses to boron, iron, and manganese have been reported locally. Thus far systematic research has been largely confined to pasture plants, but, because the state raises important fruit and vegetable crops, investigations are being pressed in these directions as well.

In Tasmania, including its off-shore and straits islands, the total areas under crops and pasture has been increased by approximately 730,000 acres since 1945, when the minor element techniques came into general use. The State Department of Agriculture estimates that at least fifty per cent, or 365,000 acres, has been developed by methods including their use. This does not include the application of trace elements to many thousands of acres of established crops and pastures for which no accurate estimate is available.

Queensland. Queensland is the only state which has not used the trace-element techniques extensively. This is not to say that deficiencies do not exist in that state, or that agricultural authorities are unaware of their possible presence. At least 1,650,000 acres of new land have been brought under crop and pasture since 1940, but none of it has been by means of the trace-element techniques so widely used in the south. The reason for this lies in the fact that the lands known to be deficient in some elements are so poor in all respects that it has not been considered economical to bring them under management at all. For the most part these lands lie in the coastal regions of the southeastern part of the state. Other areas, apparently not deficient in these elements, show more promise for development. Nevertheless, agricultural authorities are aware that deficiencies may exist in areas under development.

The Northern Territory. This portion of Australia is as yet virtually undeveloped except for extensive cattle grazing based on natural, unimproved pastures. However, it appears likely that at least certain areas of the far north are capable of growing permanent improved pasture and certain crops, such as peanuts, rice, and possibly cotton. Officers of the Division of Land Research and Regional Survey of the C. S. I. R. O., who have been actively engaged in the experimental work done to date, believe that certain light, sandy, and heavily leached soils may hold some potential for agriculture, and that some of these may prove to be deficient in one or more of the minor elements described above. As yet no data are available and no development using these elements has been attempted.

Summary. It is clear that there is widespread deficiency of several of these minor elements in the soils in southern, southeastern, and southwestern Australia. On a statistical basis a conservative estimate indicates that between 1940 and 1959 the following new areas have been brought under crop or pasture by the use of the trace-element-superphosphate technique:

South Australia	2,000,000 acres
Western Australia	9,000,000 acres
New South Wales	3,000,000 acres
Victoria	2,580,000 acres
Tasmania	365,000 acres
Total	16,945,000 acres

It has been estimated that this amount of new development accounts for at least one third of all the new land in the Commonwealth brought under crop and pasture during the twenty-year period. This new land has considerably bolstered the national economy, has provided homes and property for hundreds of Australian families, and has made possible the Commonwealth's recent increase in population. Certainly this is no mean accomplishment for a few pounds of metallic salts.