Partly cleared tableland of New South Wales is almost impossible to plow, lime, and seed conventionally. It barely carries one half sheep per acre. Right: Aerial seeding with subterrannean clover and aerial topdressing with molybdenized superphosphate and 200 pounds of limestone per acre raises capacity to two or three sheep per acre

Trace Elements

Reclaiming Acres with

CHARLES H. KLINE, ***Climax Molybdenum Co., New York, N. Y.***

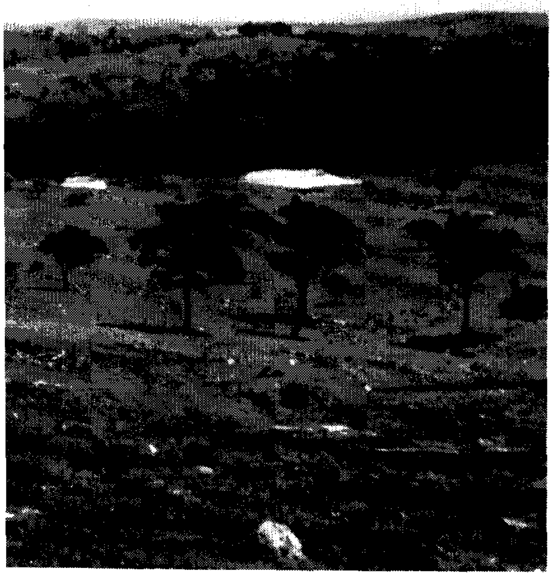
THROUGH TRIAL AND ERROR, we have developed intensively our most fertile soils, but we have also relegated large areas to native pasture and scrub timber. Some of the coastal sands and hill country where farmers were unsuccessful at the very beginning of cultivation have since been virtually untouched. On much of this less desirable land row crops fail and legumes will not grow.

The spectacular improvements in the productivity of marginal lands that farmers in Australia and New Zealand have obtained in recent years from applications of minute quantities of trace elements indicate that much of our own waste land can be profitably reclaimed. The famous Ninety-Mile Desert on the border of South Australia and Victoria, for example, had for years been regarded as virtually useless. It barely carried one sheep on 20 acres. Today after treatment with traces of copper and zinc, the carrying capacity has been raised to two sheep per acre. A large insurance company has taken over immense tracts of this former desert and is setting up a new ranch every two weeks.

Much of Waitaki County in New Zealand has undergone a similar revolution. This area had had a tragic history of poor soils made worse by depletion farming. Cash crops were poor, and legumes did not grow, so that alfalfa and improved pastures were considered impossible to maintain. Land values were depressed, and many farmers were on the verge of abandoning their properties. By aerial seeding and aerial topdressing with molybdenum and superphosphate, farmers have established improved grass-clover pastures on hill country which formerly carried only poor native grasses. Field spraying and aerial dusting and topdressing of molybdenum on the lowlands alone will bring an estimated increase in net farm income of nearly $1.5 million per year.

In the United States we have customarily regarded trace elements as remedies for specific deficiency diseases that developed on otherwise fertile soils. We use manganese for gray speck of oats, copper for dieback of citrus, zinc for white bud in corn, and molybdenum for whiptail of cauliflower and yellow spot of citrus. Borax dressings in particular have given increased yields in many areas. In general, however, we have used trace elements to make improvements, rather than radical changes, in our existing pattern of land use.

In Australia the situation is reversed. This vast continent, roughly the size of the United States, has a minimal or ade-



The importance of trace elements is recognized in the United States, but their application is mostly directed to remedying deficiency diseases. On the other side of the world, great things are being accomplished with trace element use in land reclamation

Ounces

quate rainfall in less than one third of its total area. Unfortunately, most of the soils in this region are geologically very old, highly leached, and extremely low in fertility. Deficiencies of major elements, especially phosphorus and nitrogen, are widespread. Individual trace element deficiencies occur frequently and multiple deficiencies are common.

These difficult conditions have forced Australian soil scientists to adopt a comprehensive approach to the problems of soil fertility. First, every troublesome soil is automatically suspected of deficiencies in every major and minor element. The Commonwealth Government officially recommends a strip test that the individual farmer can apply to his own land to determine deficiencies of five major and five trace elements. Second, land development is regarded as a team project requiring the concerted

The Importance of Trace Element Research

FIRMAN E. BEAR, *Rutgers University, New Brunswick, N. J.*

We started our trace element research program, as related to field crop production in New Jersey, in 1940. Our first experiments, with boron, were so rewarding that we decided to devote a considerable part of our time to the study of soil and plant relationships of all the other trace elements then known to be required by plants and animals. These included manganese, copper, zinc, cobalt, iodine, and fluorine. Areas of deficiency of all these elements were found, some to much wider extent and greater degree than others. For example, about 12% of New Jersey's farmed land was found to be seriously deficient in boron; manganese deficiency was confined largely to overlimed soils; but copper deficiency was not particularly troublesome except in peat soils.

When it was discovered that molybdenum was essential to plants, we immediately undertook a study of that element as well. Here, again, we were soon rewarded by finding that a disease of cauliflower known for 25 years was curable by one-pound-an-acre applications of sodium molybdate. Shortly after we began our studies of this element, a farmer who had planted 75 acres of cauliflower on an old potato field, the soil of which had a pH value below 5, asked us to come out and look at his crop, which was not doing well. As soon as we saw the field and the long shoestring leaves on the plants, we knew this was a very severe case of molybdenum deficiency. But it was too late to do anything for that year's crop. The plants on 45 acres failed to produce heads.

In our opinion, the point made in this article, that much of our marginal land in the humid regions of the United States might be brought into profitable production through trace-element applications, is well taken. These, of course, would have to be coupled with standard liming and fertilizing practices and with other good soil management practices. From our experience, we would not be surprised to find that the reason legumes fail to grow satisfactorily on such large acreages of land in this country is largely because of trace element deficiencies, notably of boron and molybdenum. Certainly, widespread field tests of these and all other essential trace elements are badly needed.

This report of the trace element research done in Australia and New Zealand and the application of the findings on a large-scale field basis should find a great deal of interest in the United States. There is nothing in the report that is not borne out by the evidence presented in the research reports from the countries discussed.

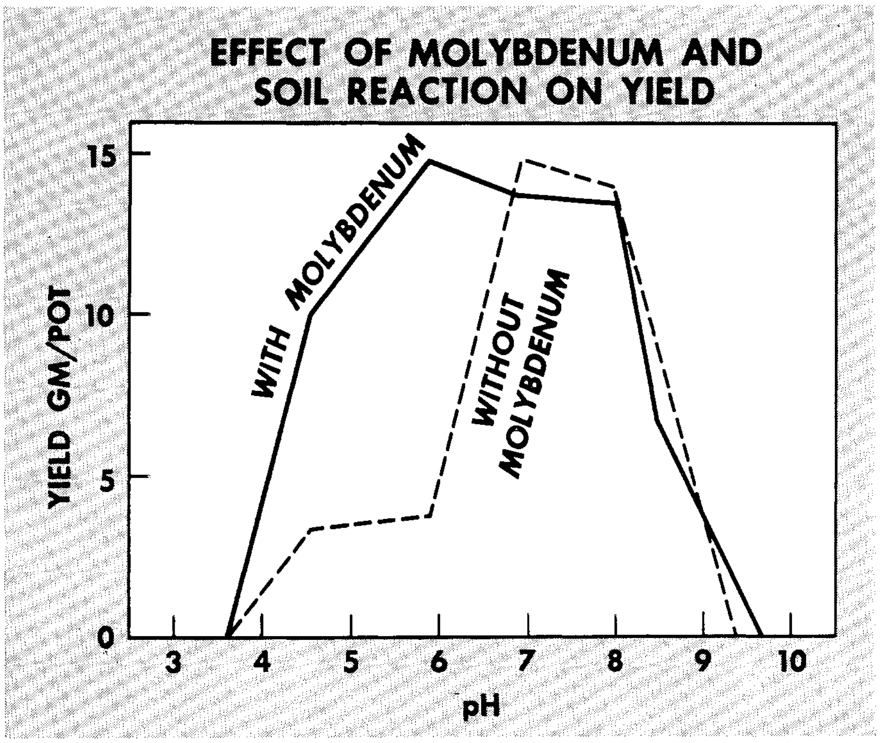


Figure 1. Molybdenum is unavailable to the plant in acid soils

efforts of specialists in soil fertility, plant selection, bacteriology, agricultural engineering, and animal husbandry. Third, no soil is considered too poor to improve if water is adequate.

Typical of the Australian approach is the ambitious project of reclaiming the coastal plain of Queensland. This tract of land stretches north from Brisbane several hundred miles and extends inland 10 to 30 miles from the sea. Its rainfall is fairly high, though strongly seasonal. However, its sandy soils are so infertile that the Forestry Department had previously considered much of it too poor even to reforest. Accordingly, most of the area bore only sparse native pasture and worthless scrub tea trees.

While other specialists select suitable grasses, legumes, and strains of *Rhizobia* and determine proper methods of pasture establishment and stock husbandry, soil fertility men are working out the mineral treatment required. Preliminary results indicate a multiple deficiency—phosphorus, potassium, calcium, copper, zinc, and molybdenum. Treatment of the newly cleared barren sand with these six elements gives a vigorous clover sward. Within a few years this huge area of several thousand square miles should become highly productive pasture land.

Replacing Tons by Ounces

Molybdenum plays a special role in land improvement because of its unique relation to soil acidity. All the other trace elements are most available to crops under acid soil conditions. Molybdenum is an exception. It is the only trace element that becomes more available as the soil becomes more alkaline. An important function of liming is to release the unavailable molybdenum that is bound in acid soils. Lima also supplies calcium, regulates the uptake of other cations, controls the availability of phosphate, and influences soil structure. However, in many areas of Australia and New Zealand, these latter functions of lime have appeared less important than its capacity to increase the availability of molybdenum.

The effect of molybdenum on subterranean clover in an acid soil adjusted to various pH values is shown in Figure 1. Without molybdenum the optimum yield was obtained at pH 6.9. With 1.25 pounds of sodium molybdate per acre the same yield was obtained at pH 5.8 and an acceptable yield at a pH as low as 4.6. The area from which this soil was taken had once been the granary of Tasmania, but overcropping had reduced its productivity to the point where pasture legumes could not be grown. Limestone, which is scarce throughout the Australian Commonwealth, was too expensive to use widely at $11 to $12 per ton. Treatment with molybdenized superphosphate at 60 cents per acre over the base price for superphosphate has converted this worn-out region to good quality improved pasture and cropland. Farmland that immediately after the war was worth only $8 to $10 per acre, today brings $100 to $120 per acre.

Much rocky land, hill country, and partly cleared woodland can never be plowed, limed, and sown economically. Replacement of lime by molybdenum makes it possible to seed and topdress this by air. In the southern tablelands of New South Wales, for example, large areas have been cleared by girdling. The rolling ground is littered with fallen branches, stumps, and dead standing timber. It is impossible to lime, yet as native pasture it carries only one third to one half sheep per acre. Aerial pasture improvement with clover and molybdenized superphosphate, at a cost of perhaps $5 per acre, has raised the carrying capacity on many properties to two and three sheep per acre and thus increased annual income by $12 to $20 per acre.

After the early work on pasture improvement in South Australia and Tasmania the need for molybdenum was actively investigated in New Zealand. Results of an early trial of lime and molybdenum on pasture in the South Island are shown in Table I. Without molybdenum, the forage yield at the first cut was around 3000 pounds per acre at liming rates up to 1.5 tons of limestone per acre. Not

Table I: Effect of Molybdenum and Lime on Yield[a] of Clover-Grass Pasture at Invermay Research Station, New Zealand

Limestone (ton per acre)	0	0.75	1.5	3
	(Yield in Lb./Acre)			
No Mo	2,813	3,129	2,715	4,356
Mo[b]	4,265	3,830	4,265	4,146

[a] First cut
[b] Molybdenum applied as sodium molybdate at rate of 2.5 oz. per acre

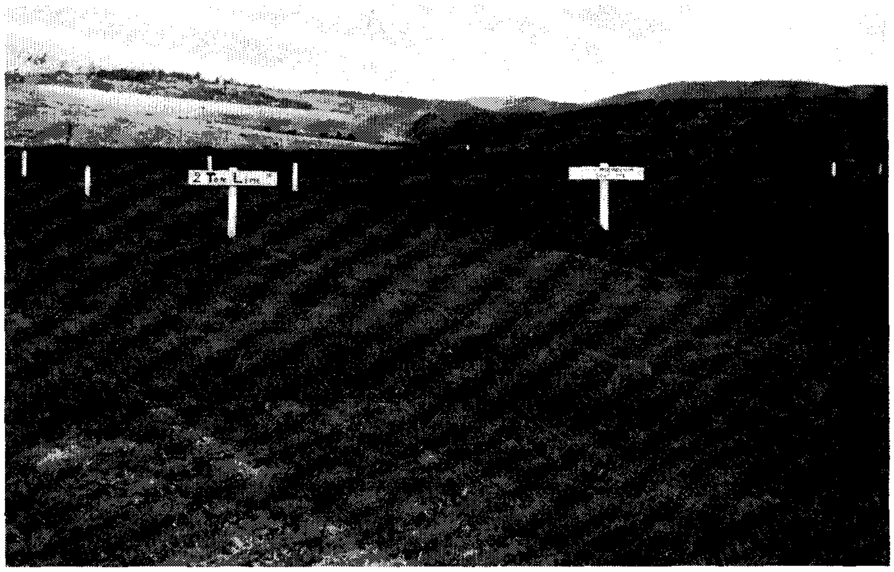
Table II: Effect of Molybdenum and Lime on Yield of Clover-Grass Pasture at Oamaru, New Zealand

Treatment per acre	Cut: Jan. 8, 1952	Cut: March 17, 1952	Cut: Jan. 17, 1953
	(Yield in Lb./Acre)		
Nil	3,300	2,000	3,600
Sodium molybdate (2.5 oz.)	5,200	9,400	17,400
Limestone (3 tons)	4,300	3,900	15,200
Sodium molybdate + limestone	7,900	5,800	15,500

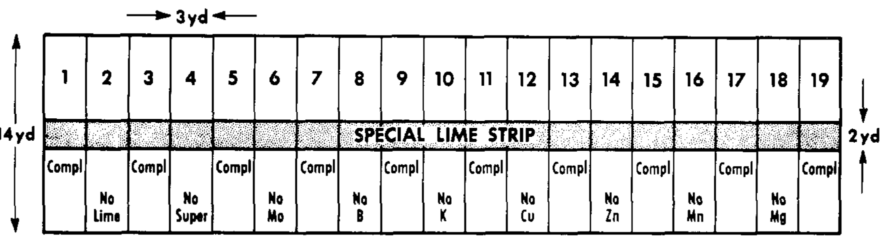
until three tons of limestone per acre were applied was there an appreciable increase to 4400 pounds. However, 2.5 ounces of sodium molybdate per acre gave a yield of 4300 pounds per acre, and liming gave no further increase. Less than an ounce of molybdate gave the same increase in yield as a ton of lime.

In other tests, summarized in Table II, 2.5 ounces of sodium molybdate per acre gave consistently better yields than 3 tons of limestone. The molybdenum-treated plots in these trials gave yields almost five times as great as the untreated plots.

The initial successes with molybdenum in New Zealand, ably exploited by one of the most efficient departments of agriculture in the world, led to the rapid treatment of a large acreage of improved pasture and forage crops. In 1950 use of molybdenum was still in the experimental stage. But in 1953, some 500,000 acres—nearly 1% of the total land area of the country—received dressings of molybdenum, and its use is growing.



In a pasture at Invermay Research Station in New Zealand, two tons of limestone were used per acre on the left. Vigorous clover growth on the right was obtained with 560 pounds limestone per acre and 2.5 ounces sodium molybdate



With this strip test for pasture legumes the Australian farmer can test for deficiencies of 10 elements. Every odd-numbered strip has a complete fertilizer mixture, but every even-numbered strip eliminates one element. (Strip four omits phosphorus and sulfur.) Rates per acre are: 224 pounds limestone, 1120 pounds superphosphate; one ounce molybdic oxide; 3.5 pounds borax; 112 pounds potassium sulfate, seven pounds copper sulfate; seven pounds zinc sulfate; 14 pounds manganese sulfate; and 56 pounds of magnesium sulfate

Redeveloping Our Marginal Pastureland

We have three classes of marginal land in the United States that offer promise of redevelopment to more productive uses: (1) unproductive pasturelands, (2) acid croplands, and (3) soils of naturally low fertility.

In wide areas of the United States pasture improvement is limited by the amount of lime considered necessary for the establishment of legumes. In the Northeast especially, much of this potentially improvable pasture is thought to require two or three tons of ground limestone per acre. At $6 per ton spread on the land, this treatment will cost $12 to $18 per acre under favorable conditions. Replacement of all or most of this lime with a few ounces of sodium molybdate or molybdic oxide, as practiced in Australia and New Zealand, would cost 15 to 25 cents per acre for material and a few cents to perhaps $1.00 per acre for application.

Charles H. Kline started out his career with the Texas Co. as a research chemist after taking his Ph.D. at Princeton in 1942. A year later he joined the Navy, serving as a minesweeping officer and later as an intelligence officer at various locations in the U. S. and China. After the war, he returned to his home town (Pittsfield, Mass.) and became supervisor of General Electric's chemical and metallurgical training program. Subsequent positions with General Electric were as manager of product planning and sales manager of GE's phenolic products. In 1952, he switched to Climax Molybdenum as assistant to the director of industrial development. Last year, he assumed his present job as manager of chemical sales and development.

Acid soils on which deficiencies of available molybdenum are especially apt to occur include well-leached upland areas, soils high in manganese, and high-iron soils such as red loams and laterites. Some coastal sands and some leached alkaline or neutral soils of limestone or serpentine origin have lost nearly all their total molybdenum. Such soil conditions occur in many regions of the eastern United States and along the Pacific Coast, and molybdenum may well prove highly effective in economic pasture improvement in much of this area.

The productivity of some pastureland is poor because the forage provides a deficient mineral diet to the grazing animal. The need of animals for iodine and cobalt is well known; these elements must be provided in the forage or as feed supplements. In coastal soils forage is sometimes very low in copper, and ruminants suffer from chronic copper deficiencies—characterized in sheep by steely wool, uncoordinated gait, brittle bones, and general debilitation; and in cattle by anemia, deterioration and bleaching of the coat, scouring, and general unthriftiness. This is a simple copper deficiency and it can be readily cured by adding copper salts to the feed or by topdressing the land with copper sulfate or copperized superphosphate.

On forage of normal copper content, ruminants sometimes show very similar symptoms if the molybdenum content is high. Excess molybdenum apparently induces copper deficiency in the animal. This disease is variously known as molybdenosis, peat scours, or "teart" sickness. It occurs on peat soils in Florida, New Zealand, and Ireland and alkaline soils in southern England and parts of the San Joaquin Valley in California. As with the simple copper deficiency, this condition can also be easily corrected by supplying additional copper as a feed supplement or as a topdressing on the pasture.

Occasionally overliming has raised the molybdenum and depressed the copper contents of forage enough to induce this disease artificially. No cases are known where topdressing pasture with molybdenum has caused the disease. To avoid possible ill effects, however, treatment on pasture should generally be limited to 2.5 ounces of sodium molybdate per acre or its equivalent and should be repeated no more often than once every four to six years. Treatment on peat soils should usually be avoided.

In some areas of Australia and England sheep suffer from chronic copper toxicity. This disease is characterized by the slow accumulation of copper in the liver, a sudden breakdown of the kidneys, passing of red water, jaundice, and almost immediate death. Surprisingly enough, it often occurs on land where the forage has only a normal copper content, but where molybdenum and sulfate contents are low. In preliminary experiments in Australia this disease was remedied by supplying inorganic sulfate in salt licks and by topdressing the pasture with molybdenized superphosphate.

Treating Acid Croplands

Many of the crops that are believed to require a rather high pH frequently respond to molybdenum alone in the field. Among these are alfalfa, the clovers, cauliflower, broccoli, Brussels sprouts, cabbage, turnips, lettuce, spinach, and melons.

Molybdenum is required for nitrogen fixation by the bacteria in the nodules on the roots of legumes. Symptoms of molybdenum deficiency in legumes are thus primarily those of nitrogen starvation—stunted growth and pale yellow foliage. Nodules form in good number, but the bacteria in them do not function. Plants are difficult to establish and stands do not persist.

In all plants molybdenum is necessary for nitrate reduction in the leaves. Accordingly in nonlegumes, or in legumes such as peas and beans that are fed fertilizer nitrogen, the symptoms of molybdenum deficiency are those of excess nitrate. A mottled yellowish color appears in the young plant between the veins and around the margin of the leaf. Sometimes the interveinal spots develop a water-soaked appearance. Eventually the tissue in the affected areas dies, leaving dead spots between the veins and a scorched rim around the leaf margin. Affected leaves generally curl upward to give a cupped appearance. Older leaves are most affected, and in flax and corn they may die while the upper leaves are still green and turgid. In cauliflower, broccoli, Brussels sprouts, and related crops a condition described as whiptail develops. The younger leaves develop in an irregular pattern from the midrib. The leaf is long, narrow, and irregular in outline. In places the leaf tissue barely develops beyond an eighth-inch feather edge along the midrib.

These symptoms occur in crops grown on acid soils. As in pasture improvement, the use of lime in such cases can be at least partially replaced by application of molybdenum as spray or dust to the seedbed or field. Adequate calcium must, of course, be supplied, either through the use of superphosphate or by liming. But the overseas evidence suggests strongly that by applying molybdenum, the operating field pH can be dropped at least one unit. The potency of small amounts of molybdenum is demonstrated by the observation that large seeds, such as beans or peas, grown in balanced soil, can contain enough molybdenum to carry the plant through the animal life cycle.

Upgrading Soils of Low Fertility

In general, the worst soils will show the best response to trace elements. In the United States we have appreciable areas where the soils are of naturally low fertility but have a favorable climate or geographical location. Florida sands and Hawaiian laterites, for example, are valued more for their climate and structure than for their inherent fertility. In the Hawaiian pineapple plantations a number of the essential mineral elements are applied directly to the plant by highly mechanized and relatively inexpensive means. In the Florida citrus groves today all 12 major and trace fertilizer elements are applied in one area or another. Treatment with manganese, copper, zinc, boron, and molybdenum is relatively cheap because soluble salts of these elements can be incorporated into the regular spray program. Iron is applied to the soil as a chelate; in this form the amount required is less than one ounce per tree.

Workers from other regions are likely to regard these extreme cases of improving soil fertility as uneconomic solution-culture techniques. But these examples illustrate the points that virtually any soil fertility problem can be solved and that no element, major or minor, can be neglected. There are many possible reasons why crops will not grow on a given soil: poor soil structure, poor drainage, inadequate rainfall, and infestation by parasites. But some of the reasons ordinarily given may be secondary. With trace element deficiencies now being investigated thoroughly, there is increasing evidence that often the basic problem in crop failure is the lack of one or more of the nutrient elements.

Applying Modern Technology

Modern methods of improving soil fertility should make it possible to upgrade substantial areas of marginal land throughout the world. There are many Ninety-Mile Deserts in underdeveloped regions and probably some even in the more highly developed agricultural countries. Here in the United States we have millions of acres of poor pasture, unproductive coastal sands, worthless hill country, and cropped-out farm land.

Simple trace element tests may be helpful preliminary indicators of possible mineral deficiencies in these waste lands. For example, much of New Zealand was quickly and successfully surveyed for molybdenum deficiency by trials of this type. Some consisted of only a single plot rated visually against the surrounding untreated area. Others included four plots: control, molybdenum, lime, and molybdenum plus lime. On poor soils responses of the order of several hundred percent in yield often result from trace element treatments. Complex, highly replicated experiments are not necessary to show up such striking differences.

Inexpensive means of applying trace elements are essential where deficiencies exist. Mixed fertilizers incorporating specific trace elements will generally be most economical to apply, either by conventional field spreaders or by airplane. One producer in New Zealand has considerably expanded his total business by selling borated, cobaltized, copperized, and molybdenized superphosphate, each in several grades. On some croplands field spraying will be cheapest, especially where the mineral supplements can be combined with other spray programs. Treatment of the seed and aerial dusting will also be practical in some areas.

The farmer today has powerful tools for soil improvement. Backed by modern concepts of soil fertility, he can often treat his acres of wasteland with minute quantities of trace elements to bring about a revolution by the ounce.

Acknowledgment

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