NATIONAL ACADEMY OF SCIENCES

WALTER PEARSON KELLEY

1878—1965

A Biographical Memoir by

HOMER D. CHAPMAN

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THE DEATH OF Walter Pearson Kelley terminated more than sixty years of productive research and scholarship in the field of soil science. During this period (1904 to 1965), an extensive body of knowledge concerning the genesis, nature, properties, variability, and management of soils came into being. Kelley was among the distinguished contributors to this science, and his name will be forever linked to alkali soils, ion exchange, and clay mineralogy. Two widely known books and nearly one hundred research papers were published by him and his colleagues.

He was born on a tobacco farm near Franklin, Kentucky, on February 19, 1878, and died in Berkeley, California, on May 19, 1965. He was the son of John William Kelley and Mary Eliza (Mayes) Kelley. His father was of Scotch-Irish ancestry, a descendant of immigrants to North Carolina in early colonial times, and his mother was of English ancestry, a descendant from immigrants to New England in early colonial times.

Kelley was educated in the elementary public schools of Simpson County, Kentucky, and a private high school. He graduated from the University of Kentucky in 1904 with a B.S. degree in chemistry. His intention was to go into medicine, but the necessity of finding work led him to take a job as Assistant Chemist at the Purdue Agricultural Experiment Station. He spent three years there, engaged both in study and in the routine analysis of agricultural materials. He got his M.S. degree at Purdue in 1907. In 1908 he was appointed by W. H. Evans, then Chief of Insular Affairs, Office of Experiment Stations, U.S. Department of Agriculture, to direct research in agricultural chemistry and soils at the Hawaii Agricultural Experiment Station. This station subsequently became a part of the University of Hawaii. It was here that the interesting problems and challenges of agriculture influenced him to devote his life to serious research in this field.

In 1911 Kelley enrolled as a graduate student in soils at the University of California, Berkeley, where he got his Ph.D. degree in 1912. His major professor was E. W. Hilgard. Kelley returned to Hawaii to continue his research, but soon thereafter he was invited by Dr. H. J. Webber, Director of the newly established Citrus Experiment Station and Graduate School of Tropical Agriculture at Riverside, California, to become Professor of Agricultural Chemistry and head of that department. He remained in this position until 1939, and much of the research for which he became famous was carried out during his twenty-four years in Riverside.

With the administrative reorganization of the Department of Soil Technology at Berkeley, Kelley became chairman of the Division of Soils on that campus in 1940 and continued his research until retirement in 1948 as Emeritus Professor of Soil Chemistry. Though his active involvement in research slackened somewhat following retirement, his keen and relentless interest in soils (and particularly clay mineralogy, cation-exchange phenomena, and alkali soils) continued unabated. It was following retirement that he wrote two books—one entitled *Cation Exchange in Soils,* and the other, *Alkali Soils:*

Their Formation, Properties, and Reclamation—both American Chemical Society monographs.

My personal association with Kelley began in 1927 when I joined his staff at Riverside, and for the following twelve years it was my pleasure to work in close association with him, though my assignment was in soil fertility and citrus nutrition. But even after he transferred to Berkeley we kept in close touch by letter and frequent visits right up to the time of his death. Thus it was my privilege to have known him well for a period of nearly forty years. Though the years gradually slowed him down physically, his mind remained razor-sharp to the very end. A close friend in Berkeley, Mr. J. E. Tippett, talked with him just a few hours before he passed away; he said that Kelley was mentally alert, though in some physical pain and discomfort.

Kelley had planned to attend the June 1965 meetings in Riverside of the Western Society of Soil Science, of which he was a charter member, and I had several letters from him just a few weeks prior to his death about his forthcoming visit. Plans were made to take special note of his attendance and to call on him for a few remarks. Perhaps anticipating some of the comments he might make, he wrote to me on April 14, 1965, and I quote in part from this letter.

"Thinking back over the period of my activity, this period was certainly one of notable advancement in the field of soils. In fact, it is somewhat difficult to realize what these advances have been. In my opinion, nothing equal to this period has ever taken place in the whole history of soil research. These advances pertain both to the soil itself and to plant nutrition. Regarding the latter, practically the whole of our knowledge concerning the role of minor elements has come to light. In regard to the soil, the most comprehensive understanding of the actual constituents of the soil has been developed.

"It was only near the close of the second decade of the 20th century that a realization began to dawn as to the important role of cation exchange. Out of this has grown definite knowledge as to the most active and important constituents of the soil. Until this study had developed for about ten years, it was almost universally held that the so-called clay of soils is amorphous. So long as this view prevailed, the vast majority of the work was necessarily empirical, for the reactions were taking place with unknown substances. Now we know what these substances really are and are in a position to really understand what reactions take place; why different soils react differently; why one and the same treatment produces variable results on different soils; and the agricultural significance of the results is susceptible of rational understanding. Perhaps the most important of all these advances applies directly to irrigated soils; cation exchange has different effects, agriculturally speaking, with different soils, owing to the fact that the reacting substances are different.

"In a certain sense, it might be thought that the soil, in consequence of these researches, has become increasingly complex, for the interpretation of experimental data was formerly not encumbered with too much knowledge; sweeping conclusions could be and were, as a matter of fact, drawn on a purely empirical basis. It is always easier to explain if too many facts are not in the way. Much more could be said about this period. Suffice it to say, I am happy to have been rather closely involved in many of these advances. I wonder if corresponding advances will accrue in the next half century. Please excuse me for this digression.

"As I wrote previously, there is a possibility of my being able to attend the meetings in Riverside next June. It has occurred to me that at the meeting of the Western Society of Soil Science would be a suitable occasion to inform the younger members about the origin and early held views of the founders of the Society. It seems probable that I am the only surviving one of the first meeting in Salt Lake City, called, incidentally, at my request for another purpose."

While Kelley is best known for his research on alkali soils, base exchange, and clay minerals, his inquisitive mind, capacity for organized research, deductive reasoning, and keen powers of observation are readily apparent in his very first investigation in Hawaii. This research had to do with a chemical study of soils in which pineapples became chlorotic, made poor growth, and were largely unfruitful. He found that these soils (black) were extraordinarily high in total manganese, with values ranging from 3.91 to 9.74 per cent Mn_3O_4, as compared with 0.15 to 0.91 per cent in red soils, where pineapples grew well. Although previous studies had shown some Hawaiian soils to be high in manganese, Kelley was the first to establish a relation between the aforementioned pineapple disorder and a high manganese content of soils. He also suggested the possibility that the yellowing effect of the manganese might in some manner be related to an effect on iron metabolism. Subsequent findings by others proved this to be the case.

Kelley's was really the first thorough description of the effects of excess manganese on the growth, appearance, and fruit characteristics of the pineapple. He likewise noted the appearance of corn, rice, oats, wheat, beans, peanuts, cotton, sugar cane, and other plants in these high manganese soils. Stunted growth, chlorosis of foliage, burn on older leaves (followed by abscission), and purplish or reddish coloration of leaf sheaths and stems were some of the effects described. He noted that the condition on pineapples and other plants was worse in winter, tending to improve or clear up in summer. He observed great differences in plant sensitivity to excess manganese, sugar cane being much less affected than pineapples. Other sensitive plants were rice, cowpeas, peanuts, kidney beans, pigeon peas, corn broom, corn, and sorghum.

He made ash analyses of many of these plants and found in some a marked tendency to accumulate manganese in the leaves and stems and, in others, very little accumulation. He discovered that the composition of other elements was commonly greatly altered when the plants were grown in manganiferous soils, calcium tending to increase while magnesium and phosphorus decreased.

Kelley's passionate interest in soils and soil-forming processes and his inquisitive nature were revealed by his studies to determine the mode of origin of the manganiferous black soil areas of irregular shape and size occurring on the alluvial plateau of Oahu. After a thorough study of the location and depth of these deposits, the chemical composition of the original lava and of the soil resulting therefrom, plus the geology of the islands, he concluded that the manganese enrichment resulted from the dissolving action of water, the transport of manganese in solution to lower levels, and the subsequent oxidation and deposition around various nuclei of soil or rock particles. The manganese concretions found in these soils strongly suggested that in the geological past the lower alluvial plateaus had had a history of submergence; he noted in this connection the findings of manganese concretions scattered promiscuously near the floor of the ocean at various places between Hawaii and Japan and to the south of Hawaii. These deposits were discovered and reported in connection with the voyage of the H.M.S. *Challenger* in 1873-1876.

In rereading Kelley's early publications on manganese, one notes several traits which marked all his writing and research activity. First, his ability to write and express himself clearly and logically; second, his capacity for thoroughness. This latter trait is revealed in his extensive and knowledgeable review of existing literature (both old and current), plus the prodigious amount of analytical work carried out (he was aided in this, of course, by assistants) in connection with his inquiries. Third, his ability to single out and spend time on the significant, as against the pursuit of the less important or insignificant.

In his six years in Hawaii, some twenty major pieces of research were completed. In addition to his manganese studies, extensive chemical analyses of Hawaiian soils and of rice and pineapple plants were made; field fertilizer experiments with rice were conducted; and, growing out of the latter, extensive studies were carried out on the humus of Hawaiian soils and on various nitrogen and humus problems.

Some of his first nitrogen work was with rice, in which he showed that ammonium sulfate gave better growth and yields than equivalent amounts of sodium nitrate. The poor results with nitrate fertilizer, especially with young rice, were due in part to leaching losses from the soil, denitrification, and formation of nitrite, which if it reached levels of 5 ppm or over made the rice yellow. He also hypothesized that in young rice there may be a lack of nitrate-reducing enzymes.

Extensive investigations of nitrification and ammonification in Hawaiian soils were made, and he noted the importance of aeration and lime in the development of nitrate in soils. Studies were made of the rates of ammonification of various organic nitrogen compounds. He discovered that casein underwent much more rapid ammonification than dried blood, soybean cake meal, cottonseed meal, and linseed meal, and he concluded that basic diamino acid nitrogen compounds were converted into ammonia more rapidly than the nitrogen of other compounds.

In further studies of nitrification, Kelley found that, while calcium carbonate additions increased ammonification and nitrification of dried blood added to soils, magnesium carbonate decreased ammonification, inhibited nitrification, and brought about actual ammonia losses from soils. Calcium carbonate did not prevent or decrease the action of magnesium carbonate. Additional research with various Hawaiian soils revealed that magnesium carbonate stimulated ammonification in some and was toxic in others. Natural dolomite had effects similar to calcareous limestone. In later California work on nitrification, he noted that under alkaline conditions large amounts of nitrite sometimes formed.

Kelley's interest in nitrogen transformations, gains, and losses in soils persisted, and he was responsible for the installation of twenty-four large lysimeters at Riverside, in which he planned to conduct further nitrogen research. However, he became so involved in cation exchange and alkali problems that it remained for the author of this memoir to plan and execute the lysimeter nitrogen research which Kelley had hoped to get started.

In recognition of his interest and research on nitrogen, Kelley made a trip to Europe in 1930 under the joint auspices of the American Society of Agronomy and the Chilean Nitrate Educational Bureau to study nitrogen fertilization problems. His report on these observations was published in 1933.

In much of his Hawaiian work, Kelley was materially aided by W. T. McGeorge and Alice Thompson. McGeorge has written a very interesting account of his early experiences with Kelley in *Soil Science,* 97:76-79.

Shortly after his arrival in California in 1914, Kelley's energy and interests became channeled into various citrus problems. He was appointed chairman of a staff committee on field experiments and helped plan a 40-acre, long-term field fertilizer experiment with oranges. While the management of this experiment was turned over to others, his interest in it remained active during its entire course. The author was brought to

California by Kelley to grow up with this fertilizer experiment and to carry on collateral citrus nutrition studies.

The probable origin of Kelley's great and lasting interest in alkali soils, cation exchange, and clay mineralogy, in which one thing led in more or less logical sequence to another, was the increasing incidence of alkali injury to lemons and oranges and the prevalence of "mottle leaf," which appeared to be in some way related to the alkali problem. Hilgard and Loughridge in California had earlier noted the ill effects of saline irrigation waters on citrus, but their investigations were, in general, of a qualitative nature. Kelley and his colleagues, E. E. Thomas, S. M. Brown, and A. B. Cummins, proceeded systematically to investigate the problem. The first irrigation water survey was carried out by Kelley and Brown, and some thousand samples from widely scattered citrus areas were analyzed. He noted that wells and surface waters close to major watersheds were, in general, low in salt, but wells located at some distance from these watersheds often (but not always) showed notable amounts of salt. The soils of many citrus orchards irrigated with waters of varying quality were analyzed for their salt content, and tree condition was related to both the soil and irrigation water analyses. As a result of this work, it became possible roughly to classify waters as to suitability for citrus irrigation, and in the years that followed an enormous number of well waters were analyzed for farmers in many parts of the state and an extremely valuable service was rendered to agriculture generally. Kelley and his colleagues noted a high nitrate content of well waters in some regions—a finding which has both interested and puzzled investigators ever since. No final explanation of the source of nitrate in many of these waters remote from agricultural areas has as yet been uncovered, though a number of theories have been propounded.

Kelley added considerably to the descriptions of salt injury to citrus, noting the yellowing, burning, and premature abscission of leaves from affected trees, and their greater susceptibility to frosts, heat, and winds. The salt content of composite soil samples taken from irrigated middles in orchards showing severe injury was around 1,000 ppm. He noted, as have many later investigators, the buildup of salts in furrow crests and in the unirrigated spaces under the trees. Salts move laterally into such zones by capillarity.

It was in connection with this work that Kelley observed that sodium was absorbed by the soil from some of the waters and calcium was released; further, that in these instances the physical condition of the soil was altered. He found, as had Hilgard and others much earlier, that gypsum applications would somewhat ameliorate this condition and help improve orchards. Kelley repeatedly stressed in his early studies the need to apply sufficient irrigation water to flush the salt residues out of the root zone, cautioning, however, that this might raise water tables in some areas and make a bad situation worse.

The aforementioned work with citrus led Kelley into a greatly expanded program of alkali research. He was encouraged and supported in this by the then Dean of the College of Agriculture and Director of the Experiment Station, Thomas F. Hunt. While recognizing that irrigation waters contributed significant amounts of salt, he emphasized and stated repeatedly that the thousands of acres of land which in California and throughout the world had become salt-impregnated were largely the result of the capillary rise of salt from high water tables, the latter a consequence of seepage from unlined canals and laterals plus overirrigation. He was quick to recognize the importance of installing an adequate system of drainage to carry away excess water and salt, both as a preventative of alkali formation and as the only means of reclaiming land made unproductive by salt impregnation. In all of this he was fully aware of the previous distinguished investigations of Hilgard and others on the subject.

The impermeable soil conditions which existed when black alkali was present and the difficulties of getting water to pass through such soil even where gypsum had been applied led Kelley and his associates to make special studies of this problem.

During the same period, Kelley's attention had been drawn to a fertilizer plot at the old Rubidoux Station at Riverside, which had been receiving sodium nitrate at rates of about one thousand pounds per acre. The citrus trees in this plot had developed severe "mottle leaf," and the soil had become hard and took water poorly. The condition of the soil and trees in this plot, together with the aforementioned black alkali conditions, led Kelley and his associates to make extensive laboratory studies of the chemical effects of salts on soils.

His first research paper on this subject was published in the February 1921 issue of *Soil Science*. He and his assistant, A. B. Cummins, treated two different soils with equivalent concentrations (0.01 normal) of the chlorides (also sulfates) of sodium, potassium, calcium, magnesium, and ammonium, and noted that an essentially equivalent exchange of bases took place, with the result that a portion of the base of the added salt passed out of solution and a chemically equivalent amount of other bases was set free from the soil. In this process, there was no essential change in the concentration of the added anion. He noted that these reactions were reversible, that concentration played a part, and stated that apparently the reactions obeyed the principle of mass action. Further, the subsequent distilled water leachate from the sodium-chloride-treated soils was turbid and dark-colored, and the soil became progressively impermeable to water as the free salt was leached out. From this and collateral studies, he quickly deduced that the essential difference between black and white alkali soils was that the former had absorbed considerable amounts of sodium, and it was this fact which accounted for their impermeability and black color.

These studies led Kelley into a search of the literature, and he discovered that Thomas Way of England was apparently the first (1850) to note and write about the exchange reaction in soils. Way's work was followed by that of several German workers—notably Eichhorn (1858), Henneberg and Stohmann (1859), Lemberg (1870-1877), Peters (1860), and Van Bemmelen (1888). A review of much of this early work was covered by Sullivan in 1907.

Very shortly after this first paper on cation exchange by Kelley and Cummins, the extensive work by Gedroiz in Russia and Hissink in Holland came to Kelley's attention. English translations of the Gedroiz papers were made by S. A. Waksman and became available to Kelley and his co-workers through C. S. Scofield, of the U.S. Department of Agriculture. All of these investigations added fuel to Kelley's intense research activities in this field, and there followed during the next twenty years a succession of papers dealing with one or another aspect of cation exchange, the nature of the clay fractions in soils, and the varying physical and chemical properties of soils containing different kinds and proportions of exchangeable bases.

A great deal of this early work was motivated and closely tied in with his alkali reclamation research, particularly on soils containing sodium carbonate. Though he found it possible under laboratory conditions to quickly leach out chlorides, nitrates, and (to a lesser extent) sulfates, the problem of ridding soils of carbonate and bicarbonate led him and his colleagues into studies of the generation of sodium carbonate in soils. This problem and conflicting theories about it held his interest for many years.

Early work by Kelley and Cummins demonstrated that the hydrolysis of sodium clays in soil systems where soluble electrolytes had been removed was responsible for the formation of sodium hydroxide, which (reacting with CO_2 of the air) resulted in the formation of sodium carbonate. He was, of course, well aware of the sodium sulfate–calcium carbonate reaction.

In connection with studies of cation exchange, considerable effort went into investigations of methods for determining the exchangeable bases and the cation-exchange capacity of soils. Throughout his papers there is more or less discussion of the exchange phenomena, whether the replaceable bases were held by some sort of physical adsorption or in true chemical combination. Kelley from the first (and long before the existence of more knowledge of the crystalline nature of these compounds and the residual electrical charges on the edges and surfaces of these crystals which account for the adsorption of positively charged ions) held to the view that the bases were tied by true chemical binding forces and that, in the main, behavior was in accord with that obeyed by all chemicals. In his studies of methods, he was quick to appreciate the complications posed by the solubility of other materials in soils, silicates, lime, dolomite, and oxides, and concluded that highly precise determinations of total exchangeable bases and exchange capacity were difficult, if not impossible.

Kelley recognized the special suitability of ammonium chloride as a replacing agent, and for many years normal solutions of this chemical were used by workers all over the world, to replace both the bases of soils and (by determining the amount of ammonium ion retained by the soils) their so-called exchange capacity. Later, others proposed the use of ammonium acetate, and this latter method is still widely used.

In acid soils, Kelley noted that neutral normal ammonium chloride brought aluminum, iron, and manganese into solution and these he then regarded as exchangeable bases. He was, of course, fully aware at this time of the concept that the hydrogen ion could also replace the various bases and in acid soils was responsible, at least in part, for soil acidity. The question of whether the trivalent bases brought into solution by neutral salt extraction had preexisted as replaceable bases or were dissolved from the soil by the replacement of hydrogen and the formation of strong acids was discussed by Kelley. His experiments with a few soils at the time led him to believe that, in some soils at least, the trivalent bases preexisted in replaceable form. It is interesting that much recent work has confirmed this view, especially in regard to aluminum.

There was much speculation during the early 1920s, and earlier, too, about the actual nature of the finely divided alumino-silicates responsible for base exchange in soils. Speculating on the reasons why a part of the replaceable calcium, and possibly other bases as well, are more easily removed than others, Kelley foreshadowed later findings by hypothesizing that differences in replacement rate might be due to "the occurrence of molecular aggregates of the replaceable compounds, submicroscopic crystals in fact, some of whose chemically combined bases occur on the interior of the particle and can be replaced only as a result of diffusion." This statement was published in a 1924 paper. In ensuing years, Kelley became interested in bentonites and their high base-exchange capacity. The findings of Ross and Shannon, that some bentonites contain a finely divided micaceous crystalline mineral (montmorillonite), led Kelley to grind bentonites finely in a ball mill, with the result that the base-exchange capacity was greatly increased; in some bentonites, much of the originally nonreplaceable magnesium became replaceable. Also in some bentonites, considerable replaceable potassium appeared as a result of grinding. These results led Kelley to the separation and grinding of soil colloids. Results remarkably similar to those with bentonites were obtained. Not only was there a great increase in exchange capacity, but both replaceable magnesium and potassium (and in some cases hydrogen ion) appeared subsequent to the grinding. These results led Kelley to the conclusion that the base-exchange constituents of both soils and colloidal bentonites are crystalline and that the replaceable bases are contained within the interior of the crystals, as well as on the exterior. To secure further evidence, both soil colloids and bentonites were subjected to X-ray diffraction examination, and the case for the crystallinity and similarity of both was confirmed. Chemical analyses of a wide range of soil colloids had led Holmes, of the U.S. Department of Agriculture, to suspect that the basic materials of these colloids might be crystalline, and in a paper submitted to *Soil Science* on November 29, 1929 (just four and one-half months before the paper by Kelley, Dore, and Brown was submitted to the same journal), Hendricks and Fry presented extensive X-ray diffraction data on colloids from many soils indicating that they contained crystalline substances of a nature similar to those of the montmorillonite and beidellite clays.

The results of these investigations laid to rest many previously held ideas, such as, for example, that the inorganic base-exchange material of soils was amorphous; that all soils contained just one principal component; that the replaceable bases were held by some vaguely defined adsorption force; that the material was a zeolite or zeolite-like substance. In place of these concepts, it became clear that the inorganic colloidal components of soils having base-exchange properties were crystalline in nature, were definite chemical compounds, and were identical with a number of the well-known clay minerals such as montmorillonite, kaolinite, and others. Also, that the cations, principally magnesium, potassium, or a combination of these, occurring primarily in the interior of these crystals would become replaceable if the crystals were broken up by grinding.

This work led to an expanding series of investigations, not only with X-ray equipment, but with the electron microscope, with the result that the nature and identity of the inorganic base-exchange components of soils are now much better understood.

Kelley and his associates continued their work on various questions, such as the kinds of bonds with which exchangeable bases are held, the reasons why some minerals (even when finely ground) possess little or no base-binding capacity as compared with those that have a high capacity. All of this led him into a thorough study of crystal structure and the role of aluminum, magnesium, and hydroxyl ions in relation to the existence of negative electrical forces on the platy surfaces and edges of crystals which attract and bind cations with varying degrees of force or tenacity. Also, he was much interested in the mode of origin and the properties of the clay minerals in soils, and his active research in this matter continued until his retirement in 1948. Moreover, his special interest in this subject continued actively even after retirement, when for a period of years he was retained as a special consultant by the Gulf Research and Development Company of Pittsburgh, Pennsylvania. For a period of some six years, he spent part of each year at the research headquarters of this company in an advisory and consulting capacity.

In his work at Riverside from 1925 on, Kelley was ably assisted in the physical chemistry of the exchange phenomena by Dr. A. P. Vanselow and in mineralogical aspects by A. O. Woodford and W. H. Dore. Kelley's initial interest in salinity and alkali problems, as already indicated, was related to citrus, but in 1919 he was given the responsibility of seeing what could be done about reclaiming lands which had become salt-impregnated on the Kearney vineyard property in Fresno County, California. Previous attempts in 1914-1915 to reclaim the land through installations of tile drains and by flooding were only partially successful. It was this and his previous work on citrus which led Kelley and his associates, S. M. Brown, E. E. Thomas, and A. B. Cummins, to initiate his basic work on soils and, at about the same time, to set up a carefully laid out alkali reclamation experiment in the Kearney vineyard. The affected soil in this area was black alkali, and it was Kelley's extensive studies of the effects of salts on soils which led to the discovery that the difficulties of reclaiming this type of soil were due to the fact that the sodium salts had reacted with the clay components to form sodium clays. As already discussed, the generation of sodium carbonate and the tendency of such soils to become impermeable upon leaching away the accompanying soluble salts, together with a great amount of other information (now all common knowledge, but previously unknown), were revealed by his research on this subject. Kelley and his co-workers arrived at this information independently, though (as already stated) he subsequently learned of Gedroiz's series of papers on the subject, as well as the work of a de Dominicis in Italy in 1918.

While the value of gypsum as a means of ameliorating black alkali soils had been known for a long time, it was not appreciated until Kelley's research indicating that, in addition to its direct action in converting Na_2CO_3 to Na_2SO_4 and $CaCO_3$, a part of its beneficial influence was in changing sodium into calcium clays. The successful outcome of the reclamation work on the Kearney vineyard soil was due basically to the aforementioned discovery, as well as to the recognition that the existing tile drainage system was inadequate and the subsequent installation of a 70-foot well in the area. This well lowered the water table sufficiently to permit the salts to be leached below the root zone of the crops being grown.

As with gypsum, the research of others had indicated that sulfur, sulfuric acid, iron, and aluminum sulfates might be useful in counteracting the sodium carbonate of black alkali soils, but a complete understanding of the effects of these materials in soils and their relative usefulness in alkali reclamation did not emerge until the work on the Kearney plots was carried through to completion, accompanied as it was by many detailed laboratory investigations. Kelley's research on alkali soils continued for some twenty years following his initial work, and his interest in various facets of the subject, especially the mechanisms by which sodium carbonate is generated in soils and the whole broad subject of the permanence of irrigated agriculture, continued.

While this brief account of Kelley's interests and contributions covers his most important work, mention should be made of some other research activities. He always had an active interest in the disorder known as citrus "mottle leaf," and suspecting it to be nutritional in origin, he and his associate, A. B. Cummins, made extensive analyses of normal and mottled citrus leaves. While the work revealed important compositional differences between mottled and green leaves, he and Cummins did not analyze for zinc (the lack of which eventually proved to be the cause of mottle leaf) and thus narrowly missed uncovering the reason for this disorder, which for so many years had puzzled investigators.

Of special interest were his findings on boron in relation to some citrus and walnut disorders. Both the essentiality and toxicity of boron had been well known to plant physiologists for a long time, but there had been no connection of these to citrus troubles until the latter part of 1925, when Kelley's attention was drawn to a mottling, necrosis, and excessive leaf shedding of orange trees in the vicinity of some citrus packing houses. It was quickly found by soil and leaf analyses that the trouble was due to excess boron. Boron compounds are commonly used as fungicides in the packing house wash waters, and in some cases the discarded wash waters found their way into irrigation supplies. This finding led to the discovery that certain California irrigation waters naturally contain enough boron to produce toxicity symptoms on citrus identical to those seen near the packing houses. On the basis of these findings, Congress made a special appropriation to study the natural occurrence of boron in irrigation waters and soils of the western regions, and also the tolerance of a wide range of plants for this element. This work was initiated in Kelley's laboratory by F. M. Eaton, under the general direction of C. S. Scofield, both of the U.S. Department of Agriculture. Kelley and his colleague, S. M. Brown, were the first to establish the leaf levels of boron in normal and injured walnut leaves, the boron content of soil likely to produce injury in citrus and walnuts, and the levels of boron in irrigation waters which will produce injury. This research provided the basic data for the identification of excess boron troubles in many parts of the world.

This brief review of Kelley's research activities reveals that in all of his work motivation arose almost always from practical agricultural problems. However, he was never content with a superficial or partial solution. He always wanted to probe into the basic reason for things, and his attention was directed primarily to the soil and its chemistry. He did not attempt to pursue all aspects of soil and plant relationships, leaving the physiological side of plants, in general, to others.

A great deal of his success can be attributed to selection of and emphasis on aspects likely to yield results and avoidance of blind alleys. Thus, a great deal of insight, intuition, and sound judgment went into all of his research.

Though he pursued his special interests with remarkable tenacity and singleness of purpose, he kept thoroughly abreast of research in all other aspects of soils and read widely in the field. This is shown by his broad knowledge of soils, their complexity, and their variability.

Kelley was never content to publish a piece of research or embark on any new line of work without thoroughly reviewing the literature. In later years, he remarked to me repeatedly about the tendency of many younger researchers to do a superficial job of literature searching. His writing and research revealed true scholarship in the finest sense. He read not only widely but meticulously. He would puzzle over certain findings of others for days and was quick to single out the flaws or omissions in the research of others, as well as his own. Another outstanding trait, as already mentioned, was his clear and logical thinking. This is apparent in all his writings and was evident to the many with whom he conversed in his long life.

One of his close and long-time friends, J. E. Tippett, of Berkeley, commenting on some of Kelley's traits, wrote to me as follows:

"Over the years I had hundreds of conversations with Kelley concerning many different subjects. By and large, I found him to be just about the most objective man I ever knew. I never knew him to express a judgment based on his personal advantage or disadvantage, or based on a personal bias. He was always concerned with ideas, with concepts, and with things, rather than with the personalities of people. Even though he was a strong advocate of basic or so-called fundamental research, he felt that such research should not be limited to a scientific laboratory but should be related to the actual conditions of life and living. He genuinely believed that basic research could, in part, be conducted in the field where the particular problem existed, and therefore related very directly to the problem. He was a well-read man in many fields other than soil science. His apartment home was literally full to overflowing with good books. Not only were the bookshelves filled, but books were stacked on tables, on chairs, and on the floor. Not only was he a good citizen, but he kept himself quite well informed in many fields, and he never expressed himself without a background of reliable knowledge."

Kelley loved conversation as well as reading and always searched for just the right word to express his meaning clearly. As indicated, his reading and conversation were by no means confined to his research. He was interested in everything around him, especially the main currents of political and social thought, the direction of national and international life, and the implication of social legislation. He was well informed on the affairs of the day and was never content with a superficial understanding of things, but strove constantly to seek for the undercurrents or motives behind the events of the day.

He was also frank and outspoken, not only as regards his research and that of others, but on practically any and every subject to which he turned his attention. Kelley was a lively and stimulating conversationalist, and while he loved to discourse at length himself, he was always willing to listen to anyone who had something significant to say or contribute. Likewise, he was always full of questions—the fount of good conversation.

Increasingly in his later years, Kelley loved to settle down in a chair in a laboratory or office, put his feet up on a desk or chair, light a cigar, and launch into some discussion about a phase of his or the other fellow's research. This would commonly lead to other items of interest, both related and unrelated. Over the nearly forty years of our acquaintance, I never saw him smoke either a pipe or a cigarette; cigars were his love.

Though Kelley played golf and badminton and engaged in lawn bowling at various periods in his life, not one of these activities ever became dominant or occupied much of his time. He was never an avid sports fan, though he followed sports (especially college football) with considerable interest. He played a good game of bridge, but again this was secondary; he always preferred reading when alone or conversation when with associates or a group.

He had a lively sense of humor and loved (and could tell) a good story. When especially entertained, he would laugh heartily, long, and with gusto—a likable and infectious trait. He was a genial and interesting companion on trips; the writer spent many pleasurable days in his company on visits to the Imperial Valley and other places of interest in California.

Kelley married Sue Katherine Eubank, of Oakland, California, on August 6, 1913. They had no children. Mrs. Kelley was a charming and gracious person and a sparkling, vivacious hostess. She took up oil painting shortly after coming to Riverside, and, accompanied by her husband, made many trips into the high Sierras, where she sketched and painted while Kelley relaxed, hiked, and read. They developed the habit of reading aloud to one another in later years, and when Mrs. Kelley's eyesight began to fail, he continued to read aloud to her. He was devoted and most solicitous of her and missed her greatly when she predeceased him by several years.

Kelley's achievements and research career won him widespread recognition and many honors. He was a member of the American Chemical Society, the American Association for the Advancement of Science, the American Society of Agronomy, the Soil Science Society of America, the Western Society of Soil Science, the International Society of Soil Science, the Western Society of Naturalists, the Geophysical Union, the American Mineralogical Society, and the National Academy of

Sciences. In 1950 he was elected an honorary life member of the Florida Soil Science Society.

Kelley was a Mason and a Congregationalist. He was a political liberal in the best sense. He participated to some degree in civic activities, especially those related to his special interests, but more or less steered clear of too much involvement in either outside civic organizations or committee work within the University.

In recognition of his achievements, he was elected a Fellow of three societies—the American Association for the Advancement of Science, the American Society of Agronomy, and the American Mineralogical Society.

In 1930 he was elected President of the American Society of Agronomy; earlier he had served as President of the Western Society of Soil Science, of which he was a founder and charter member.

He was elected to the National Academy of Sciences in 1943. In 1950 he was made Honorary President of the International Society of Soil Science, in recognition of his interest and assistance in helping to found this organization. Earlier (in 1935) he had been President of the American section of this organization and also President of its alkali section. His researches on alkali soils gained him wide recognition throughout the world, and he was frequently asked to serve as chairman of sections and to present invitational papers at meetings of international symposia. Such meetings were much less common then, in comparison to the current great increase in international travel and exchange.

Kelley also served as an associate editor and later honorary editor of *Soil Science.* He was an associate editor of *Agrochimica* (Italy) from 1950. After retirement in 1948, as mentioned earlier, Kelley was employed as a consultant with the Gulf Research and Development Company until 1955. He also acted as a consultant to the U.S. Bureau of Reclamation for ten years (1948 to 1958).

In recognition of his contributions to the agriculture of California and his long and distinguished career as a scientist, Kelley was awarded an LL.D degree from the University of California in 1950. In 1958 the University of Kentucky awarded him a D.Sc. degree for the distinction and honor he had brought to his alma mater. This institution had elected him to Phi Beta Kappa during his student days. He was also elected to membership in the honorary societies of Sigma Xi and Phi Lambda Upsilon.

In his various positions, teaching students was not a part of his responsibilities. This is unfortunate, for with his energy, forceful personality, ability to think and speak clearly, fierce independence, and lively mind and spirit he would have generated enthusiasm and motivation, on the one hand, and insisted on high performance on the other. He believed strongly in basic research, though he fully recognized the importance of practical problems in producing motivation and direction.

His life was one of enthusiastic devotion to his science; his contributions to soil science and agriculture were many and distinguished; and his impact on colleagues, friends, and relatives was powerful and enduring.

BIBLIOGRAPHY

KEY TO ABBREVIATIONS

Am. Chem. Soc. Monograph = American Chemical Society Monograph
Am. Soil Survey Assoc. Bull. = American Soil Survey Association Bulletin
Calif. Citrogr. = California Citrograph
Centr. Bakteriol., Parasitenk. u. Infektionskr. = Centralblatt für Bakteriologie, Parasitenkunde und Infektionskrankheiten
Hawaii Agr. Exp. Sta. Bull. = Hawaii Agricultural Experiment Station Bulletin
Hawaii Agr. Exp. Sta., Honolulu, Press Bull. = Hawaii Agricultural Experiment Station, Honolulu, Press Bulletin
J. Agr. Res. = Journal of Agricultural Research
J. Am. Chem. Soc. = Journal of the American Chemical Society
J. Am. Soc. Agron. = Journal of the American Society of Agronomy
J. Geol. = Journal of Geology
J. Ind. Eng. Chem. = Journal of Industrial and Engineering Chemistry
Proc. & Pap. 1st Internat. Congr. Soil Sci. = Proceedings and Papers of the First International Congress of Soil Science
Proc. Soil Sci. Soc. Am. = Proceedings of the Soil Science Society of America
Rept. Com. Sedimen. 1940-41, NRC, Washington, D.C. = Report of the Committee on Sedimentation 1940-41, National Research Council, Division of Geology and Geography, Washington, D.C.
Soil Sci. = Soil Science
Trans. 3d Internat. Congr. Soil Sci. = Transactions of the Third International Congress of Soil Science
Univ. Calif. Agr. Exp. Sta. Bull. = University of California Agricultural Experiment Station, Bulletin
Univ. Calif. Agr. Exp. Sta. Circ. = University of California Agricultural Experiment Station, Circular
Univ. Calif. Agr. Exp. Sta. Hilg. = University of California Agricultural Experiment Station, Hilgardia
Univ. Calif. Agr. Exp. Sta. Tech. Pap. = University of California Agricultural Experiment Station, Technical Paper

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