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THE INTERRELATION OF SOILS AND PLANT, ANIMAL AND HUMAN NUTRITION[1]

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OUR knowledge of many aspects of the interrelations between soils, plants, animals and human beings is limited, but some of the work that has been done in recent years gives us fascinating glimpses of the possibility and importance of further discovery. I would go so far as to say that we can now see the outlines of a whole new field of biological, or shall I say, agricultural, research. From what is already known, this phase of agricultural research should lead to a new orientation of agricultural thinking. Certainly it suggests profound implications for human welfare.

The interrelation of the soil, the atmosphere, the plant and the animal is a cycle in which the same materials are used over and over again. Minerals, moisture and certain constituents of the atmosphere under proper conditions of light and temperature enter the plants, and by them compounds of potential energy are made and the excess over their own utilization stored. When such products are eaten by human beings and animals, these compounds are broken down and reworked, energy becomes available for growth and movement, and parts of the compounds are again released into the air in the form of carbon dioxide and moisture or returned to the soil. Such compounds may then be taken up again by plants and rebuilt into new plant bodies. Thus there is an obvious interrelationship, the animals being dependent upon plants, the plants upon soil, and the soil upon parent rock and the materials that are returned to it through the decay of plants and animal products. Thus a great cycle or *wheel of life*

[1] Address of retiring vice-president and chairman of Section O (Agriculture) of the American Association for the Advancement of Science, Richmond, December, 1938.

is established, constructive processes balancing the destructive; the whole, a cycle of energy exchange, which in modifying animal and human development also modifies the whole complex of thought, emotion, happiness, sorrow and the other factors affecting life.

In our scientific procedure so far, we have more or less neglected the interrelationship between soil, plants, animals and man, although in nature this is a fact, a reality. We have been prone to consider the problems of each separately rather than to study them as a whole.

Fairly early in the development of modern science, specialization became necessary, and to-day we have reached the point where the whole of science is rather minutely departmentalized. Each department has its own language and traditions and pursues its own objectives. By this method, we have accumulated a vast amount of information—for example, regarding the classification, chemical and physical properties and management of soils; and regarding the growth and reproduction of plants and animals. Chemistry, physiology, anatomy, pathology, physics, genetics, bacteriology and other sciences have all contributed to the knowledge concerning these subjects but each in its separate department.

That method was necessitated by the vastness and complexity of the facts with which science deals, and it is still necessary. But the unity of nature no less than its complexity is important, and the time has come when we shall have to pay more attention to this unity without neglecting the advantages of specialization.

This is not a new or original idea. It is part of the mental atmosphere of our time, and this association has given a good deal of thought to the possibility of closer coordination between the sciences. But what suggests it strongly to me, with my particular interest in agricultural research, is the direction taken by recent developments in the science of nutrition, both plant and animal, and the parallels or closeness of association of the two.

These developments emphasize the importance to the health of man and animals of certain mineral elements, vitamins, hormones and other factors. At the same time, we are discovering that deficiencies of certain elements essential to the health of the animal organism exist in some soils, while other soils have accumulations of harmful substances. Hitherto the principal objective of many of our plant investigations has been to adjust soil-management practices, change environmental conditions, and in many cases modify the above-ground portions of the plant in order to obtain as large crop yields as possible. But these developments in the science of nutrition suggest that we ought to give more attention to producing crops of the highest *nutritional* quality for man and animals. That would be worth doing even if it should involve a sacrifice in yield, which should not happen, but which, if it did, would run counter to the main trend of our work in the past.

That is what I meant when I said that these interrelationships might affect the orientation of agricultural thinking and practice. Obviously here is a case where an interrelationship must be studied—the interrelationship between the physical well-being of man and the factors in the soil that affect the composition and development of plants. The investigations should include thorough studies of proteins, amino acids, carbohydrates, fats, vitamins, enzymes, hormones, other growth accessory substances, the ordinary minerals and the so-called "trace" or "rare" elements and their effects upon man. Knowledge of the nutritional significance of some of these factors has increased rapidly as a result of research during the past twenty-five years. What we need especially to do now is to put together the various parts we do know so that in acquiring new knowledge we can move forward on a unified front.

Mineral Requirements of Plants and Animals

Plants are dependent on the soil, particularly the nutrients in it, among other things, for their best development and growth. In turn, man and animals are dependent upon plants for their existence. Thus the soil is the mother of all living things. In addition to carbon, hydrogen and oxygen, plants apparently need at least the following chemical elements for normal development: Calcium, phosphorus, potassium, magnesium, sulfur, nitrogen, iron, manganese, boron, copper and zinc. Certain elements, such as boron, are required in relatively small quantities but may be definitely toxic if present in too large amounts.

Animals require all these, with the possible exception of boron, and in addition sodium, chlorine, iodine and cobalt. The possible value of such elements as nickel, bromine, arsenic, lead and fluorine, together with some of the rarer elements, such as molybdenum, strontium, vanadium, uranium, caesium and others sometimes found in the ash of plants, still remains in question. They may be needed to perform certain functions or they may simply be absorbed by plants or eaten by animals with their food, exciting little or no physiological effects. We do know that certain elements such as selenium, thallium, fluorine, arsenic and lead, if present in too large quantities, are definitely toxic to both plants and animals. Our present information indicates that they are undesirable soil constituents even at low concentrations. Undoubtedly, in the future additional elements may be found to be essential for the best development of plants, man and animals.

Elements essential for the normal development of plants apparently occur in sufficient quantities in many soils, yet the normal requirements of the plants for each of the elements may differ considerably. Thus boron, zinc, copper, iron, manganese, iodine and cobalt are apparently needed only in relatively small amounts. These and others have come to be known as rare, trace or micro elements. Recent investigations in this and other countries have shown deficiencies of these elements in certain soil areas. Certain elements may have been present in only very small amounts during the formation of some soils, amounts insufficient for crop plants; or they may have become exhausted through continuous cropping or partially removed by drainage and erosion through the years. Frequently nutritive elements are present in soils in forms unavailable to plants and special treatment of the soil may be necessary to bring them into the soil solution. The unavailability of iron in calcareous soils, the greater availability of zinc in acid soils, and the "fixation" of phosphorus in many soils serve as examples.

SOME SOIL DEFICIENCIES RESULTING IN NUTRITIONAL DISORDERS OF PLANTS AND ANIMALS

Results of only a few of the more recent experiments have shown that the following physiological troubles of plants, among others, have been corrected by furnishing the necessary limiting elements: Sand drown of tobacco in the soils of the sandy Coastal Plain by magnesium; chlorosis of tomatoes on some of the calcareous soils in Florida by manganese; internal browning of cauliflower and dry rot of sugar beets in Michigan, crown rot of sugar beets in Ireland, and die-back of citrus in Africa by boron; pecan rosette in the South by zinc; internal cork and drought spot of apples in British Columbia, West Virginia and elsewhere by boron; citrus leaf mottle in California, South Africa and Florida by zinc; little leaf of apples and other deciduous fruits in the West and Northwest by zinc; cracked stem of celery in Florida by boron. Improved yields of potatoes, snapbeans, cabbage, lettuce, peppers, carrots, beets, citrus and corn result when manganese is applied to the calcareous soils of Florida, and white bud of corn on the Norfolk and Hernando fine sands in Florida is prevented with zinc. Improved growth of several crop plants occurs in the organic soils of Florida and the muck soils of Holland and parts of western New York when copper is added. Yellows of tea in Nyasaland, Africa, is corrected and growth of field crops in Oregon and other areas is improved by the addition of sulfur.

Many of the elements just mentioned are likewise important for the best development of man and animals. The necessity of sufficient amounts of calcium and phosphorus and a suitable ratio between them, together with Vitamin D, is recognized. According to Maynard[2] over 70 per cent. of the ash of the animal body consists of calcium and phosphorus, and approximately 99 per cent. of the calcium and 30 per cent. of the phosphorus of the body are present in the bones and teeth. The importance of calcium and phosphorus in bone building and the prevention of osteomalacia and rickets are thus easily understood.

It is not my purpose here to attempt a discussion of the roles of magnesium, sodium, potassium, chlorine, sulfur and zinc in animal nutrition. It is important to point out, however, that some of the rare or trace elements, now considered as essential to plants, likewise play an important part in human and animal nutrition and in the prevention of diseases. Thus iron, as a constituent of the respiratory pigment of haemoglobin, is essential for the functioning of every organ and tissue in the body and plays a fundamental role as a catalyst for cellular oxidation. Its importance, together with copper, in the treatment of nutritional anemia, is well known. Sometime ago in Australia, and more recently in New Zealand, the lack of cobalt in certain soils, and thus in the plants, has been determined as the cause of the so-called "bush sickness" of sheep; and the addition of cobalt is now preventing the trouble. Manganese is concerned in the physiology of reproduction and among other things prevents perosis in chickens. Magnesium is closely associated with calcium and phosphorus, both in its distribution and metabolism, and, among other things, appears to assist in the normal functioning of nerves.

The lack or unavailability of iodine in soils and crops results in human and animal goiter. Iodine-deficient areas exist in the Northwest, the Great Lakes region, and parts of Europe and Asia, such as the Alps, Tyrol, Pyrenees and Himalaya Mountains. Before iodine feeding was practiced in Montana it is estimated that goiter caused an annual loss of many thousands of pigs. According to Maynard, the principal demand for iodine in farm animals occurs during pregnancy.

THE PRODUCTION AND USE OF ENERGY

The importance of continuing investigations to determine which elements are essential not only for the best development of plants but for the production of the highest quality plants, which, when consumed, will meet the nutritional requirements of man and animals, is evident. Many factors affect the growth of plants and their value as food.

Nutrient materials must be either in solution or capable of becoming dissolved at the margin of the root hair before they enter the plant body. After their entrance, they become a part of the vast complex of compounds that make up the plant body, and when the plants are consumed by man or animals the nutrients included become part of their bodies. It is the capacity of green plants for manufacturing food—

[2] Leonard A. Maynard, "Animal Nutrition." McGraw-Hill Book Company. 1937.

for accumulating energy as food—that makes them prominent in any system of economy dealing with living things. Green plants, in the presence of sunlight, accomplish this by combining the carbon dioxide of the air and water to form carbohydrates. The minerals and other substances absorbed by the plant from the soil, water or atmosphere are combined with the carbohydrates or other materials formed from them and help to make up such compounds as proteins, fats, vitamins and other growth and regulatory factors.

These combinations of foods, both simple and complex, found in plants, are the chief source of energy and are essential for the health of man and animals. The importance, therefore, of producing plants of the highest nutritional quality can easily be appreciated. In addition, the nutritive value of animal products, as regards mineral content and in a large part vitamins, is dependent on the plant foods they consume. This emphasizes the importance of knowing whether the necessary and desirable nutrients are available in the different soil types of the various regions in the country, to insure not only crop productivity but also that such crops may contain these elements. As previously mentioned, evidence indicates that this is not so in many instances. In other words, certain of the minerals are not present or available in sufficient amounts in some soils for the most satisfactory growth and development of many crop plants. It can be assumed, therefore, that the plants produced in such areas might not furnish certain of the important minerals and compounds needed for the best development and health of man and animals.

This fact takes on considerable significance when we realize that large segments of the population in certain areas of this and other countries obtain practically all their food directly from the plants or from animals that eat the plants produced in their own local communities. Although food products are better distributed to-day than ever before and more variety is available from a much larger area, thus lessening but not eliminating the possibilities of certain deficiencies, there are still great groups of people who are not in a position to purchase much food in addition to that which they produce. Accordingly, in such groups the diet is limited. Even in cities, certain low income groups have a restricted diet. Such dietary deficiencies no doubt result primarily from too low an intake of certain classes of foods, as milk, green vegetables, fish and lean meats. If such foods are also deficient in certain essential elements, the probability of physiological disturbances and reduced vitality is increased. The incidence of anemia has been reported to be especially high among school children in areas where soil deficiencies are known to be responsible for "salt-sick," an anemia-like condition in live stock.

In the past, serious bone, skin, digestive and nervous disorders, among other maladies, occurred in certain localities. It is now known that many of these troubles resulted from restricted diets or from eating plant and animal products produced on soils either deficient in certain elements or containing elements injurious to health. Even to-day there are regions where such troubles as goiter, skin diseases, weak and deformed leg bones, mottled and furrowed teeth and nervous disorders are all too common. A book by J. R. de La H. Marett,[3] entitled "Race, Sex, and Environment," should be read by those interested in this general field.

Another condition, not so striking as those just mentioned but still serious, is the lowered efficiency of certain groups of improperly fed people—people who, although they have no specific disease, have a lowered vitality and, in common parlance, are not up to par. The point I am trying to make is that there are degrees of health, and if conditions of lowered health exist in part because of low quality plant or animal products produced on deficient soils, then the plant, animal and soils investigators have a challenge and responsibility that can not be shirked.

I am well aware that dietary deficiencies among large groups of people can be traced to economic causes—the lack of sufficient income to obtain a good diet easily. But this rather emphasizes than minimizes the responsibility of the agricultural scientist to discover ways of improving limited diets. He may feel rather helpless when it comes to the question of how to increase the purchasing power of large numbers of people, but the other problem, improving the quality of the foods they do get, should be within his grasp.

FACTORS AFFECTING THE VALUE OF PLANTS AS FOOD

It is well recognized that the composition of plants grown on different soil types in the same climatic region varies in both organic and inorganic constituents. Analyses of the same kind of plant grown in different regions and showing striking differences in composition are recorded. It is realized that differences in climate existed, and in many cases evidence is lacking relative to the past and present soil-management practices, the species of plant, including the particular variety, its age and the stage of growth at sampling time as affecting composition. But even making such allowances the differences in percentages of some elements are so large as to leave little doubt that they are due to the presence or absence of certain elements in the soil.

It is well known that the chemical composition of plants, with respect to both their mineral and organic content, may be greatly changed by modifying various

[3] J. R. de La H. Marett, "Race, Sex, and Environment," a Study of Mineral Deficiency in Human Evolution. Published by Hutchinson's Scientific and Technical Publications, 32–36 Paternoster Row, London, E. C. 4. 1936.

treatments, such as fertilizer, irrigation or pruning practices. It is thus possible to change the food value of the plants in either the fresh or the cured condition through methods of treatment and handling of the soil and plants. The nutritive value, succulence and crude fiber of crops may thus vary greatly, depending upon the amount and kind of fertilizer applied or the amount and time of applying irrigation water. In general, there is not a direct simple relation but a complex one between water supply and available nutrients. Increasing the amounts of mineral nutrients if water is deficient, or the available water if minerals are deficient, is ineffective in promoting crop yield. An abstract of a recent paper by Thomas, of the Ontario Agricultural College in Canada, entitled, "The Influence of Soil Type and Climate on the Chemical Composition of Fodder Plants," and presented before a symposium of the summer meeting of the American Association for the Advancement of Science at Ottawa in 1938, is significant in this connection. Among other things, he found that there were wide differences in the chemical composition, the crude fiber and ash of plants grown on different soil types, that there was a direct relation between the soil reaction and the percentage of calcium in plants, and that the composition of plants was decidedly influenced by the character of the season. An excellent discussion of this whole problem is presented in the book written by Orr[4] with the assistance of Helen Scherbatoff, entitled, "Minerals in Pastures." Various publications record differences in composition similar to those shown for forage crops in the case of plants used for human consumption.

In addition to considering methods of handling the soil as regards the absorption and utilization of minerals, the synthesis of foodstuffs and energy accumulation by plants, attention must also be given to the way in which the top of the plant is managed as affecting these processes. Too often practices applied to the soil have been antagonistic in their effects to those applied to the part of the plant above the soil. Thus, the time of pruning or cutting plants in relation to their stage and type of growth as affecting later composition and response is important. The differences in palatability and composition of certain vegetables grown by different methods and at various stages of growth are well known. Investigators of the Bureau of Dairy Industry of the United States Department of Agriculture state: "Early-cut hay is more palatable, digestible, and nutritious. Protein content decreases and crude fiber increases with maturity. Proper curing and storage keeps leaves from shattering and retains a good green color—the best indicator of high vitamin A content."

[4] J. B. Orr and Helen Scherbatoff, "Minerals in Pastures." Published by H. K. Lewis and Company, Ltd., 1929.

It is important to recognize that, in addition to water and soil nutrients, attention must also be given to the quantity and quality of light received by the plants during their growth period. Thus by such practices as spraying, pruning and shading the horticulturist can influence the capacity of plants to synthesize, translocate and store carbohydrates. The agronomist accomplishes the same end by cutting, mowing, pasturage and other practices. The interrelation of the various cultural and management practices as affecting the composition and growth of plants has been well described by Kraus and Kraybill[5] and need not be discussed here.

SUGGESTED INVESTIGATIONS AND OBJECTIVES

Scientists have used water cultures for many years to determine those elements essential for plant growth and will continue to make valuable contributions by this method. Even though some food may be produced by this method in the future, still the great bulk of food needed for human and animal consumption must continue to be produced from the soils of the nation.

The importance, then, of knowing more about the soils of the country, with particular reference to their origin, chemical and physical composition, amenability to various treatments and effectiveness in producing plants of high quality seems clear. Much information on these points is already available, but one of the great needs now appears to be that of making accurate studies and complete analyses of agricultural soil types and areas and the crops that grow upon them under known conditions of climate, fertilization, variety, irrigation and stage of maturity, to determine if deficiencies or excesses of certain elements occur in such soils and plants, and, if so, to correct the conditions with the ultimate view of improving the health of human beings.

The fact that many of the sandy soils of the Coastal Plain, certain calcareous soils and the muck soils, as well as other types, are deficient in some of the minerals essential for plants, animals and man has been pointed out. Similarly, the presence of toxic elements such as selenium and fluorine in certain soil areas has been noted. Doubtless elements not now known to be essential may be found to be so in the future.

There is need for a concerted attempt to correlate composition of foods with soil type, climatic conditions and the practices followed in their production. In addition to those elements whose presence in food is of vital necessity, the fact that certain elements used in combating plant pests may be taken up from the foliage or the soil by the growing plant or may be found in solution in the water supply suggests the urgent need of investigation. A survey should be made of the occurrence of the various elements in fertilizer

[5] E. J. Kraus and H. R. Kraybill, *Oregon Exp. Station Bull.* 149, 1918.

materials, sprays, dusts and the like. Such substances may definitely modify the composition of plants so that the plants either are more nutritious or become toxic to man or animals consuming them. Research should be pushed on the physiological effects of the so-called "rare" or "trace" elements previously mentioned and others not yet studied.

Little is known in detail of the functions of most of these elements. Some of them may have subtle and far-reaching influences. Investigations should be made, therefore, of the nature or availability of the compounds occurring in soils and how they are affected by chemical and biological processes in the soil, of the periodicity of their intake or distribution within the plant, of the differences among species of plants or among strains within a species in their need for mineral elements and their ability to accumulate them and of the effects of chemical additions to the soil upon the composition of the plant.

Thorough plant physiological and anatomical studies should be conducted with reference to the absorption and effects of the various mineral elements, with special reference to the minor elements, including their effect on the elaboration of vitamins, hormones and other compounds. Studies should also be made of the factors influencing availability to the plants of these elements in various soils. The forms in which these various elements occur in plants and the tissues of the plant in which they are stored should be determined. This will involve both field and pot culture studies under carefully controlled conditions, and the further development of special techniques in handling such cultures and of improved analytical methods for the detection of minute quantities of the elements under study.

Consideration should also be given to the digestibility and utilization in the body of the various plant compounds in relation to other factors affecting metabolism and growth.

Studies should be made of the form in which the fertilizing elements are supplied—whether organic, inorganic, colloidal or otherwise and their effects on plant growth and composition. The claim is made that great differences result in the plants used as food, if the fertilizers used are "colloidal."

Consideration should also be given to the influence of such factors as light intensity, length of day, temperature, atmospheric humidity and inherent varietal differences in the plants, in order to learn how to distinguish their effects in relation to various soil factors. Eventually it may be found desirable to conduct breeding investigations for the purpose of developing special strains or varieties of plants in relation to nutritional value.

Effects of degree of maturity, age and kind of plant, rate of growth, harvesting and storage conditions and manufacturing processes on the quantity and availability of the nutritionally essential elements should be investigated.

While the effects of the various minerals, soil conditions, management practices and environmental factors upon plant growth and development are being determined, plants produced in controlled experiments or in various soil areas should be fed to the usual laboratory test animals in order to determine how their rate of development, general health and behavior are affected.

Eventually it should be possible to test the effects of plants of known composition on human beings. In the meantime, studies of the diets of various population groups, especially those dependent upon locally produced food products, with respect to the adequacy of the various mineral elements and growth substances should be enlarged.

The limited status of much of our present knowledge of mineral nutrition with both animals and plants can be explained partially by the extremely small quantities of many elements required to be effective and the lack of sufficiently refined quantitative chemical procedures. The recent development of quantitative spectrographic and polarigraphic methods adapted to the determination of minute amounts of many of these elements is removing an important limiting factor to such studies.

Now the point of this discussion of the interrelationship between soils, plants, animals and human beings can be summed up briefly so far as agricultural research is concerned. The suggestion I would like to convey is this:

There is a mass of material relating to the physiological needs of human beings. It throws new light on what we in agriculture have always known—that the soil and the plant are the primary sources of what might be called the fundamental well-being of people.

Agricultural scientists are taking cognizance of the nutritional studies in their own and related fields. Should we not intensify these efforts and through cooperation of all agencies interested in such studies make greater progress in these fields? Although the problems concerned in such investigations are extremely complex and will require considerable time and funds for their solution, still their great importance in our national life well justifies and in fact demands that such studies be made. Instead of waiting for others to conduct such studies in the future, I think we ourselves should continue to take a leading part in this field. There is need, however, for a closely coordinated scientific attack on the problems. Research on the individual phases should be coordinated and each contribution pointed to the same final objective.

Basically, what is this problem of human nutrition, which is so vital in human well-being? It is a problem of crop production, of food production. That is the most familiar of all problems to agricultural scientists. But hitherto we have thought of it too largely in terms of quantity—including factors that interfere with quantity production, like plant diseases and insects. It would be no revolutionary step for us to think in terms of *nutritional* quality as well. We have demonstrated that we have the personnel, the training, the facilities and the equipment to make some very significant contributions. We agricultural scientists have felt a strong responsibility for quantity production in the United States. Surely it is just as much our responsibility to further the production of foods of the highest *nutritional* quality—in other words, to dovetail agricultural production with human physiological needs; to move toward the ideal of a better nourished nation.

I shall not attempt here to suggest exactly where such lines of research would lead. But I am sure that one of the most fundamental steps would be a thorough study of our soils from the standpoint of their suitability or unsuitability for the production of certain foods—including the possibility of amending them, if it can and should be done, so that they will give the people who live on them, not just so many pounds of food, but all the complex and subtly balanced nutrients we human beings need. Certainly by this means, general health will be improved and there should be little if any need for adding supplements to the daily diet, except temporarily in certain cases.

It may also mean, among other things, that after thorough surveys and investigations certain soil areas may be found inefficient and undesirable for the production of food, although possibly suitable for the production of crops for certain industrial uses or for forests, parks or recreational centers. It may mean that only certain crops should be grown in certain areas or that it will be necessary to add small quantities of essential but deficient elements in a routine way through fertilizers, irrigation water or sprays to the soil or plants in some areas, so that the people dependent upon the crops in such areas will, automatically and perhaps unknowingly in most cases, have food of high *nutritional* quality. Any foods shipped from such areas would be equally valuable to consumers everywhere.

My thought can be very simply stated. Human well-being is the drive-wheel of agricultural research and this is basic to a prosperous and efficient nation. Here in this realm of nutrition we can get valuable new insights into the true meaning of our work from the standpoint of human well-being. And with new insights will come new objectives.

OBITUARY

JOHN HENRY SCHAFFNER

THE passing of Professor Schaffner from active work in the field of botany means more than the usual sadness experienced in the loss of a friend. He contributed notable papers in a prodigious number and trained a number of prominent botanists who now occupy responsible positions in several of our leading colleges and universities. There are two outstanding traits of character that all who were fortunate enough to know him have commented on—his everlastingly great patience in attempting to solve a problem or to offer explanations to questions and his ability to discover and relate in simple terms many of the problems on which his mind was constantly at work.

In a sense an era has passed with Professor Schaffner. He could be at once a pioneer in the field of cytology, in which his early observations of the reduction division in plants helped establish the firm foundation on which Mendelism now rests, and also to a striking degree a pioneer in the controversy over sex inheritance. He approached this problem in a most unbiased manner, beginning with definitions of primary and secondary sexual states. Even when many geneticists were turning toward a rather rigid Mendelian scheme of sex inheritance, he began gathering the evidence that certain restricted organisms were not safe for the purpose of basing general conclusions on sex inheritance. As a result, his papers threw the whole field open to wider experimentation and to the formulation of broader and more fundamental concepts.

His work in the field of taxonomy also pioneered in the rearrangement according to a phylogenetic system. His system proceeded from morphological studies. It, however, was confirmed in a large measure by serological studies carried out by Metz and his coworkers.

Probably the most patience-trying of his works were those dealing with the problem of sex-reversals and rejuvenation. He succeeded in obtaining four separate rejuvenations in a plant which normally dies after flowering. The spectacular success in this work did not change his habits of work nor cause him to delve as a specialist might into this field to the exclusion of all others.

This leads to the second great trait of his character. All ideas were grist for his mill, to be specifically weighed and tested. It was the simplicity with which he approached each problem that led to his solutions. His observation of minute details often led specialists in certain fields of plant identification to exclaim with surprise at his grasp of a subject. He had a marvelous memory, but his keenness of observation led to his dis-