SOIL SCIENCE IN CONNECTICUT, U.S.A.

BODEMKUNDIG ONDERZOEK IN CONNECTICUT, U.S.A.,

by/*door*

H. C. de Roo[1])

This is a sketch of the history of investigation of soils in Connecticut and their management. Although necessarily about a particular state, it derives broader interest from the international recognition of M. F. Morgan and the relative maturity of this small industrial state.

Connecticut, one of the Northeastern States of the United States of America, covers an area of about 5,000 square miles with a population of some 2.3 million. Its name is derived from an Indian word meaning "beside the long tidal river". It early developed into an industrial state, especially with the opening of the western prairies. Of old, however, Connecticut had a well developed and prosperous agriculture, which "put Science to work for Agriculture" in 1875, by founding the first agricultural experiment station in the United States, The Connecticut Agricultural Experiment Station. Samuel W. Johnson (Osborne, 1913) became director in 1877 when the Station was moved from Middletown to New Haven.

In this country state agricultural experiment stations have been leaders in research in soil science since their establishment. Their object, in general, has been to develop methods of soil management that make agricultural production more efficient and maintain soil fertility. Johnson had a great interest in soils and wrote extensively on the physical and chemical properties of soils. He discussed the reasons for tillage, and emphasized the importance of the falling raindrop in the compaction of the surface soil. In 1923 The Connecticut Agricultural Experiment Station formed a Department of Soils to intensify its research in soils, and M. F. Morgan was appointed as the first Chief of this Department. Morgan's contribution in the field of soil testing, the "Universal Soil Testing System", is a monument to his researches, known and used in many parts of this country and the world. He made many other contributions during his 22 years career with the Station (Salter, 1945) which we shall outline.

Interest also derives from the colorful practice of growing tobacco beneath shade tents (Anderson, 1953). This practice, characteristic of the intensive and highly specialized agriculture of Connecticut, has had a profound influence on the development of soil science in Connecticut, and also was the object of some early work on the control of climatic factors for the production of the highest quality of tobacco.

On this highly specialized agriculture, mainly concentrated along the Connecticut River in Hartford County, is being superimposed an expanding industry and a rapidly growing population (Ritchie and Swanson, 1957). The resulting pressure of suburbanization on the land, the intensity of land use, furnish circumstances which are somewhat comparable to those in the "old countries" of western Europe. Thus, a comparison of the development of the different fields of soil science in Connecticut and Europe has a more realistic basis than a comparison between the American farm belt and Europe.

[1]) Tobacco Laboratory, Windsor Conn. U.S.A. Formerly pedologist of the Netherlands Soil Survey Institute.

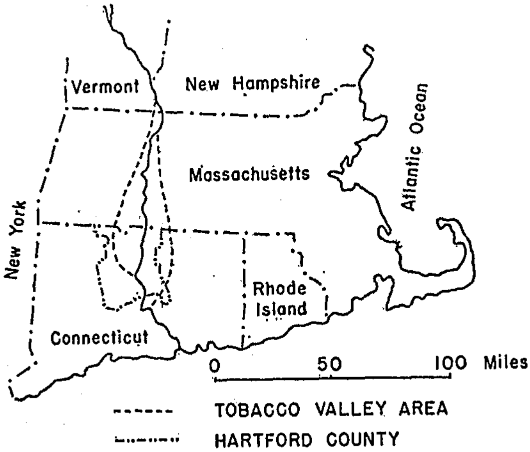

Fig. 1.
Map of southern New England showing the location of the "Tobacco Valley" and of Hartford County, Connecticut.

Connecticut soil morphology and classification studies are also interesting to compare with those in Europe because Connecticut lies within the zone of the Brown Podzolic soils (Lyford, 1946). In recent years this zonal great soil group, as well as other major great soil groups of the Northeastern States of America, namely the Podzols and the Gray-Brown Podzolic soils, are being correlated between the soil classification in the United States and in western Europe (Tavernier and Smith, 1957).

Now, let us first take a brief look at the *tobacco culture and the studies of the climatic and edaphic factors influencing its growth.* The tobacco industry is an interesting and prominent feature of the agriculture of the Valley of the Connecticut River. It antedates the first white settlements in Connecticut at Windsor in Hartford County in 1633. The tobacco growing area, often called Tobacco Valley, is a narrow strip of land extending northward from Portland, Connecticut, through Massachusetts, to the bordering towns of Vermont and New Hampshire. It occupies only about 61 square miles (fig. 1).

Three varieties of leaf are now grown for cigars. Cigars are usually made of three kinds of tobacco, corresponding to the three parts of a cigar. The filler is the central portion, covered and held in place by the binder, which in turn is covered with the wrapper. Broadleaf and Havana Seed are commonly called "outdoor" or "sun-grown" tobacco. As a general rule, Broadleaf and Havana Seed are used for binders, although certain grades are good enough for wrappers on less expensive cigars. Some grades become fillers (Anderson, 1953).

The third type is known as "shade tobacco" because it is grown in fields covered, or shaded, by tents of specially woven cotton cloth (Fig. 2 and 3). Shade tobacco was first grown experimentally by this Station in Hartford County in 1900. By 1912, the crop was well established. At first, seed from Sumatra was used. Later, seed of a Cuban variety was secured. By selection and breeding at the Windsor Tobacco Sub-station, the Station has developed from this imported Cuban seed the strains now used.

Shade tobacco is used primarily for wrappers, and appears as such on most cigars in America. Its only competitor is the imported Sumatra wrapper. Competition from Sumatra wrapper, however, practically disappeared with the troubles in Indonesia and the nationalization of the Dutch interests, some

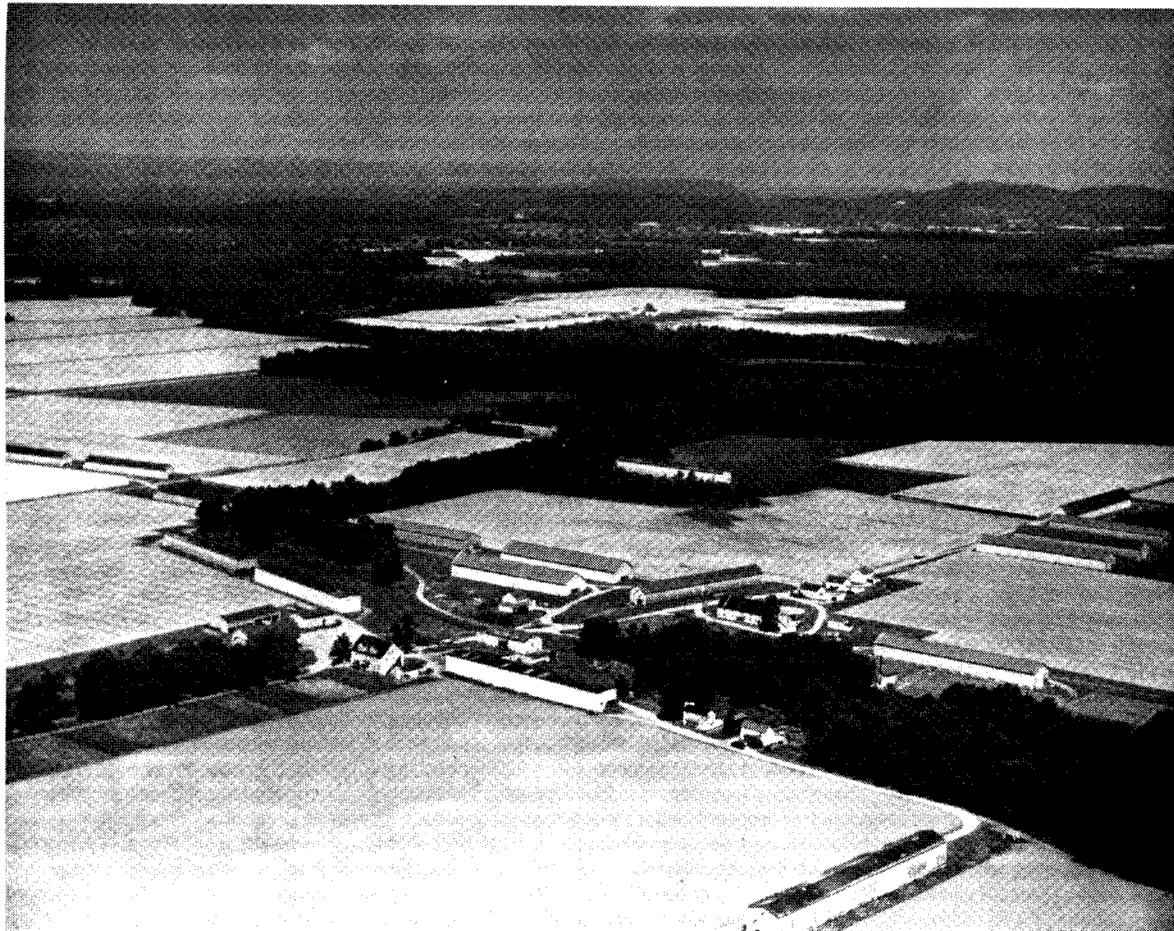

Fig. 2.
Aerial view of a shade tobacco farm in the Connecticut Valley, its fields covered with tents of cotton cloth.
(Photograph by courtesy of the Hartman Tobacco Company.)

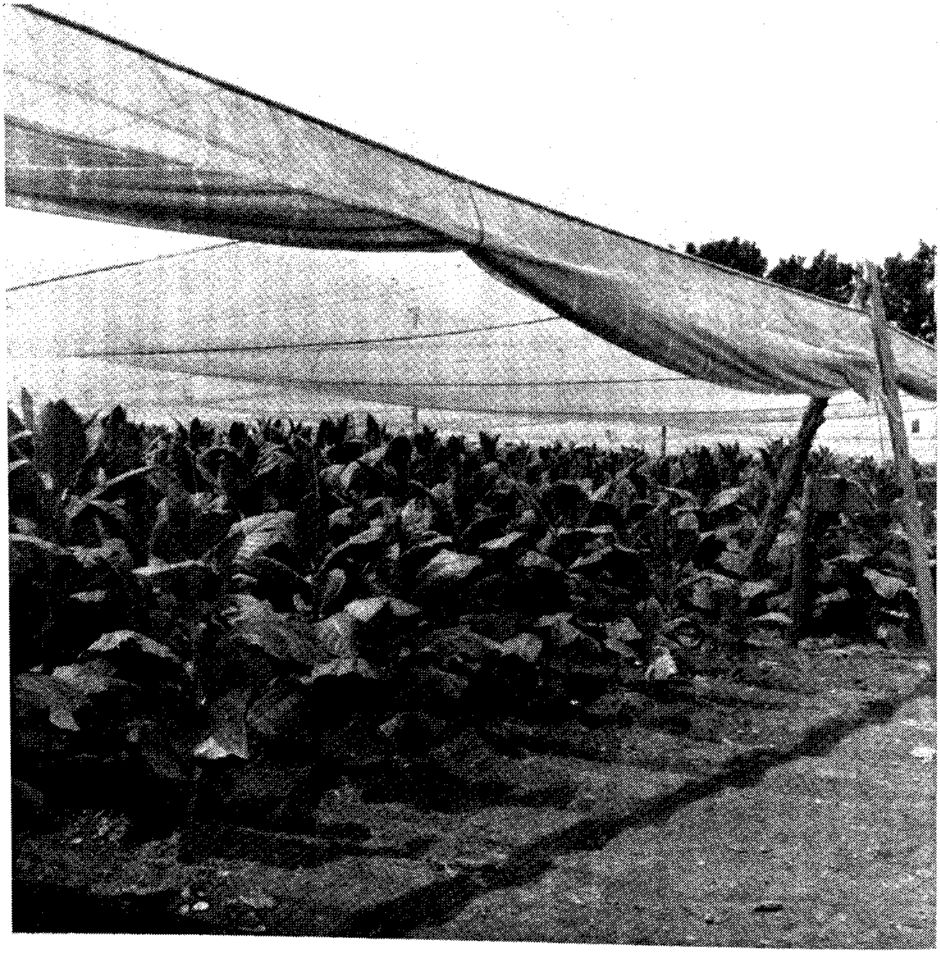

Fig. 3.
Inside view of shade tent at the time of the first of weekly primings, i.e. picking two to four leaves from the stalks. The plants will eventually grow to the top of the tent, about 8 to 10 feet high.

of which shifted their wrapper growing activities to the Connecticut Tobacco Valley during and shortly after the war. The production of shade tobacco involves a heavy investment in cloth, poles, and wires for the large cloth tents. Heavy outlays for fertilizer and labor add to the cost and make this the most expensive of all types of tobacco to raise; it costs as much as $ 2,600 to $ 3,000 an acre to grow and process shade tobacco on the farm. These factors have made shade tobacco a corporation or contract enterprise from the beginning.

The shade tent provides a "climate" that produces the thinner, smoother, lighter colored leaves, with small and inconspicuous veins, now desired for cigar wrappers. The original experiments to study and control *climatic factors* by the Division of Soils of the U.S. Department of Agriculture and The Connecticut Agricultural Experiment Station at the beginning of this century were designed to reproduce the growing conditions that are natural in Deli, Sumatra, with its hazy, humid climate. The changes in leaf characteristics, physical as well as chemical, induced by the shade effect are as yet not precisely known. Whatever the exact changes in the tobacco plant are, it is clear that they are brought about by the changes in the environment; not only by reduced visible light intensity (Osborne, 1913; Anderson, 1953), but equally by the increased air humidity, the reduced evaporation (Osborne, 1913; Lyford, 1946) and the more uniform temperature. These latter changes, the effect of the shade tent on the complexity of climatic factors and soil conditions (Stewart, 1907) affecting plant growth, has been an object of investigation since the early days of the introduction of the "cheesecloth" tent. This work culminated under P. E. Waggoner (1958), head of the Soils Department since its reorganization into the Department of Soils and Climatology in 1956. With this reorganization the Connecticut Station officially expanded its research activities into atmospheric environmental factors of soil and plant and thus was one of the first agricultural experiment stations in the United States to affect this change.

Recently, plastic films as shelters above the plants, as a means of changing the energy balance and, hence, the climate about the plant are being investigated (Waggoner, 1958). The physics of plastic mulches is also under study.

Soil and climate, as is generally conceived, exert a dominant role in determining quality of tobacco. Thus, the early efforts to improve the quality of wrapper tobacco were not limited to the alteration of some climatic factors by erecting cheesecloth tents. Knowing that tobacco is also unusually sensitive to soil conditions, scientists early realized the great need for more complete knowledge about the edaphic factors affecting tobacco production. The Division of Soils of the U. S. Dept. of Agriculture, under M. Whitney, participated in the study of the *tobacco soils in the Connecticut Valley* and the *quality of the tobacco* produced on them. These investigations expanded into the comparison of these soils and climatic conditions during the actual growing season with the soils and climatic conditions of Sumatra, Cuba, and Florida. And thus, the *first soil survey* by the United States Bureau of Soils began in the summer of 1899 in the Tobacco Valley area. Ten distinct types of soil were recognized and mapped, on a scale of 1 inch to the mile, and many observations were made of the influence of the different soils on the quality and "style" of the tobacco produced (Dorsey and Bonsteel, 1900). In 1903, this survey was extended to cover practically all of the valley of the Connecticut River in Connecticut and Massachusetts.

The object of the work was primarily to investigate and map the different tobacco soils. Notes were taken as to the general condition of agricultural practice in the Valley, the condition of labor, the implements used, the construction of curing barns and other farm buildings, transportation, and other matters contributing to the agricultural features of the locality. Particular attention was paid to the kind of tobacco and the influence of the different soils upon the texture and quality of the tobacco. This soil work formed the basis of a very extensive and systematic investigation into the physiology of tobacco and into the possibilities of changing the type and character of the tobacco through cultural methods and fermentation. Furthermore, it made the soil work intelligible and interesting. Thus, in Connecticut, the *use of soil maps and knowledge of soils in agriculture* is about as old as the soil surveying activities.

Morgan's first undertaking after being charged in 1923 with organization of a department at the Station for the study of soils and their use was a revision and completion of the Connecticut soil survey, out of which his contributions on soil classification and land use developed. At first the work was confined largely to detailed soil surveys of selected areas of the state in co-operation with the Economics Department of the Storrs Agricultural Experiment Station of the University of Connecticut, in order to ascertain the distribution of the various soil types and their importance in determining the distribution of land cover and the type of agriculture. First mapping with an aerial photograph took place in 1924, greatly adding to the accuracy. Morgan was thus one of the first soil scientists to make use of aerial photographs in soil and cover mapping. In 1930, Morgan published a reconnaissance map, a catena key and a description of Connecticut soils; in 1939 a second soils map and report followed (Morgan, 1930; 1939).

Meanwhile, because Morgan never lost sight of the ultimate goal of soil science, he brought the soil types of the state together in a greenhouse and determined their natural nutrient deficiencies and the response of important crops, such as tobacco, to lime (Morgan, Anderson and Dorsey, 1929) and fertilizers (Anderson, Morgan and Nelson, 1927). Tobacco plants proved an ideal crop for the revelation of differences in the supply and availability of plant nutrients contained in the important soil types differentiated and mapped in the field (Morgan, 1930; 1939). At the same time the usual *physical and chemical properties* were determined in the laboratory.

In 1926, work on *forest soils* was started. A project "Soil as a site factor" was undertaken jointly by the Soils and Forestry Departments of the Station for intensive studies of the nature and properties of the soil in relation to the growth of trees. In 1928, H. A. Lunt was charged with these investigations. Over the years many studies on the physical, chemical, and biological properties of forest soil and humus types were made, including forest lysimeter and pot culture studies, and studies of root development of trees in relation to soil properties. Most of these forest soil investigations were compiled by Lunt (1948) into a report. Well managed forests would be an asset to Connecticut. With two-thirds of the state occupied by woodland, this woodland is now in such poor condition that it yields less than 10 per cent of farm income.

Morgan was killed by enemy action on Leyte Island in the Philippines on January 15, 1945, where he was serving as a Lieutenant Colonel in the United States Army. C. L. W. Swanson, the new Chief of the Department of Soils, in search for a better knowledge of *soil genesis*, increased the studies of the physicochemical properties of soils important in Connecticut and New England. These soils are considered to belong to the Brown Podzolic and Sols Bruns Acides great soil groups (Bourbeau and Swanson, 1954; Bauer and Lyford, 1957).

Studies of the *clay minerals* showed that the mild acidic weathering reaction in this brown podzolic soils region leads to the formation and stabilization of a peculiar mineral in the clay fraction. This mineral exhibits a 14A. spacing and could be vermiculite or – as was shown in several brown podzolic soils – montmorillonite (Tamura, Hanna and Shearin, 1959). The space between the layers of both of these clay minerals becomes occupied and stabilized by aluminum and the interposition of the aluminum proceeds as the soil is weathered. The formation of aluminum interlayers is essentially chloritization of the expanding type 2 : 1 layer silicates in soils. Therefore, the self-explanatory terms "chloritized montmorillonite" and "chloritized vermiculite" are proposed (Sawhney, 1958). Interlayer aluminum may contribute to the low cation-exchange capacity, toxicity of aluminum and fixation of phosphate so commonly encountered in these soils.

With the gathering of new basic information about soil formation and soil-plant relationships, essential as a sound basis of soil classification, the soil survey and land classification of Connecticut entered its third phase, a new detailed and systematic soil classification and mapping of the whole state of Connecticut. This was started in 1948 with a detailed soil survey, near the town of Windsor, in the Valley. Again, as you will notice, the beginning was made in this area to serve the needs of highly specialized agriculture. The Station and the Soil Survey Division of the U. S. Department of Agriculture co-operated in this work and are still doing so, the latter presently under the name of Soil Conservation Service. With this renewed and more detailed soil survey activity, studies of the *formation of the soil material, in particular Quartenary geological processes* have been intensified, resulting for example in new concepts of the importance of post pleistocene eolian activity. Soils developed from eolian deposits and those with some eolian influence are much more common in southern New England than was previously realized (Ritchie et al., 1957). Studies of the distribution of eolian influenced soils in Connecticut and their chemical and mineralogical properties were used as keys to profile mixing, possibly by tree uprooting (Tamara et al., 1957). The problems of utilization of the soil, however, also received attention. A case study was made of the relation of the modern soil survey to land use, demonstrating the changes that are now occurring in Hartford County and may be expected to occur soon in many parts of the nation (Ritchie and Swanson, 1957). As far as Connecticut is concerned, time is running out, but there is still a margin of freedom to plan for the future.

The goals of the new soil survey activities, of source, were the same as with the older surveys, namely to show and to map the characteristics of soils important in determining the producing capacity or their suitability for the cultivation of specific crops. The first report and maps of this new survey of Connecticut, that is of Hartford County, are in the process of being published. The soils of Hartford County are generally developed on glacial drift, both stratified and unstratified, deposited by the late Wisconsin stage of glaciation. The soil materials were accumulated as glacial till, outwash, lacustrine, eolian, and more recently, as alluvial deposits (Shearin et al., in ms.).

Soil fertility research in Connecticut also showed an early and fast development, again largely due to the intensive culture of tobacco, potato and vegetable crops. In the early years of the Station, the scope of soil science was quite narrow, as at most experiment stations in this country at that time. It consisted mainly of chemical analysis of fertilizers. Out of this inspection work grew the concept of combining intensive laboratory studies with systematic and continued field trials to help farmers solve their problems.

A classic series of fertilizer experiments for tobacco was made by Jenkins (1893–1898). These ran for five years and the results became the guide for tobacco fertilizing in the Tobacco Valley for many years. In later years studies were made of the effect of fertilization with micronutrients, such as boron, copper, and molybdenum. Boron and copper found their place in the production of quality cigar tobacco (Swanback, 1950).

At the Storrs Agricultural Experiment Station the molybdenum status of some Connecticut soils (Rubins, 1955) and the boron content of certain forage crops, vegetables and soils (Brown, 1953) were studied. At the Storrs Station intensive investigations also have been made on soil reactions at various depths as influenced by time since application and amounts of limestone (Brown et al., 1956).

Beginning in 1929, *extensive lysimeter studies* were conducted by Morgan and co-workers at the Tobacco Sub-station, now called the Tobacco Laboratory, at Windsor. The object was to provide fundamental data in fertilization and plant nutrition problems. Four types of nitrogenous fertilizers, on four different soil types, were compared through analysis of drainage losses and chemical soil analyses (Morgan, 1936). In the second report on this series – Windsor Lysimeter Series "A", particular attention was given to the amounts and distribution of leaching of water and nitrogen during various seasons of the year (Morgan and Street, 1939). In series "B" soil and crop inter-relations of various sources of nitrogen were compared (Morgan and Jacobson, 1942). Series "C" involved comparisons under both cropped and uncropped conditions, with and without nitrogen treatment and cover crops; a study of fractional nitrogen treatment was included (Morgan, Jacobson and LeCompte, 1942). Series "D" compared under uncropped conditions, the effect of three typical acid-forming fertilizer materials on two soils, differing chiefly in initial base status. Furthermore, this comparison was made with and without neutralization of potential acid-forming capacity of the treatment (Morgan, Jacobson and Street, 1942). Series "E" was a comparison of the interaction of various common fertilizer ions in relation to the nitrification of urea (Uramon), and to the reaction of a bare soil (Jacobson et al., 1948). Several investigations are unpublished: Series "F" is a study of nitrogen utilization as affected by rates of application, soil reaction adjustment, and source of nitrogen; series "G" is a study of residual soil nitrogen, reaction adjustment, and protection against leaching by cover crops on soils to which different nitrogenous fertilizers had been applied for 15 previous years; series "H" was designed to furnish information on nitrogen losses from soils which received different organic materials.

The same scrupulous care was applied by Morgan to the development of *quick soil tests* for estimating the fertility status of soils for crops (Morgan, 1941). This work began in 1927, when Morgan designed a porcelain soil test block for determining soil reaction in the field by means of indicators. Gradually, new tests were added until in 1935, he introduced the buffered "Universal" extracting solution, which permitted all of the principal tests to be made on portions of one extract, and substituted the filter funnel for the Morgan test block. Tests were included for nitrate, nitrite, and ammonia nitrogen, phosphorus, potassium, calcium, aluminum, magnesium, manganese, iron, sodium, chlorides, and sulfates. Subsequent development took the form of added tests – boron, zinc, copper, mercury, lead and arsenic.

Throughout its development, the results of the "Universal System of Testing Soil" were extensively compared with the growth of the plants in the soils tested. Later on, *methods for plant tissue testing* were combined with the soil tests for obtaining more information on the relationships between plant growth, fertilizers and soils (Lunt et al. 1958).

Notable work was also done by Morgan and his associates (Morgan and Jacobson, 1940) on maintenance of soil organic matter, on fertilizer requirements of vegetables (Morgan and Jacobson, 1940), and on the simplification of the commercial grades of fertilizers.

The use of fertilizers in the tobacco culture in the Connecticut Valley and some areas of intensive market gardening has been relatively high for many years. At present, only slight increases in yields of such crops as vegetables, potatoes, and tobacco can be expected from improved fertilization practices. The fertilization of tobacco, however, did not emerge, as yet, from the controversies of synthetic organic and inorganic sources of nitrogen versus nitrogen derived from natural organics, such as cottonseed meal, castor pomace, linseed meal, soybean meal and dry ground fish. This is the state, in spite of the fact that for more than 65 years the Station has conducted field experiments, comparing all kinds and types of tabocco fertilizers (De Roo, 1959).

The intensive fertilization practices automatically helped to shift attention to the *physical properties of the soils*. The problem of soil structure is now considered one of the most pressing soil problems in Connecticut and in the Northeastern United States. *Soil compaction* by tillage and implement traffic is particularly serious in weakly structured, coarse to medium textured soils under intensive tobacco, potato and vegetable culture.

Over the years, many extensive studies have been made for the improvement of the physical condition of soil. Organic matter in the form of manure, a combination of green manuring, winter cover crops and liberal rates of application of well-balanced complete fertilizer (Jacobson, 1952), and more recently, sources such as composts, woodchips, sawdust, and sewage sludge (Lunt, 1959), were shown to be useful soil improvers. Soil conditioners were intensively tested, in field trials, greenhouse and laboratory investigations (Jacobson and Swanson, 1958). Still too costly to be of any practical use, these materials proved to be a very useful research tool, even with sandy-textured soils like ours. They enable us to set up different structural conditions in soils, without altering the fertility status of the soil.

At first, the effect of such soil amendments on the structure of the soil were primarily measured by the results of numerous physical soil analyses, such as wet sieving analyses. More recently, soil structure, in particular of tobacco soils, has also been described in terms of visual characteristics and *soil-root relationships* (De Roo, 1957). The problem of securing optimum root development is closely linked with soil management. Deep tillage, reduction of machine traffic and plowing under special rotation and cover crops will overcome most of the traffic and tillage pans. Lighter weight tractors were shown to have definite advantages over heavier ones for cultivation purposes

(Swanson, 1954). Excessive cultivation appears to be detrimental, thus, some supplement to cultivation, chemical weed killers or a mulch, should be used to advantage (Swanson and Jacobson, 1956). Root penetration and distribution are important measures of the effectiveness of these management practices (De Roo, 1957).

Intensive research on *irrigation fundamentals* is under way: the consumption of water by tobacco and its rooting habits; the seasonal variation in the plant injury caused by drought is being estimated with Broadleaf tobacco in a partially controlled environment; and the moisture holding and release characteristics of the most important agricultural and forest soils is being surveyed.

Finally, let us take a look at the *biology of the soil.* This field of soil science is the one least developed in Connecticut. Some early work on the nitrification of organic fertilizers in the soil is closely related to the research on the fertilization of the tobacco crop (Swanback, 1952). Further, some knowledge has been gathered on the soil organisms injurious to the crops, such as *Thielaviopsis basicola* (black rootrot) and nematodes (brown rootrot) on tobacco. Studies of the biological properties of forest soils (Lunt, 1948) and a chemical investigation of the composition of earthworm casts (Lunt and Jacobson, 1944) offer somewhat more fundamental aspects. Recently, extensive studies have been made of the nature of root growth and its relationships to natural soil profile characteristics and soil management practices, such as tillage, placement of fertilizers, depth of setting of tobacco transplants, mulching, and irrigation.

Brief as its history is, the influence of Connecticut's soil science is detectable in the state and nation and even in the world at large. Through such studies and many others not mentioned here, The Connecticut Agricultural Experiment Station hopes to be of greater service to Connecticut in improving use of the soil by providing sound technical information on which sound economic use of the land depends.

(August, 1958)

SAMENVATTING

Een overzicht is gegeven van de ontwikkeling van de verschillende takken van de bodemkunde in de Amerikaanse staat Connecticut waaruit blijkt, dat grote vorderingen werden gemaakt door de aansporingen van eminente wetenschappelijke onderzoekers als S. W. Johnson, E. H. Jenkins and M. F. Morgan van het Connecticut Agricultural Experiment Station in New Haven. Vooral Dr. Morgan gaf een voorbeeld voor andere onderzoekers in zijn laboratorium- en veldonderzoek van de gronden van Connecticut.

Met bodemkartering werd reeds vroeg begonnen en deze kwam daarna tot bloei als gevolg van de zeer gespecialiseerde landbouw – in dit artikel als voorbeeld de tabakscultuur in de schaduw – de zich uitbreidende industrie en de sterk toenemende bevolking, tot uitdrukking komende in een toenemende verstedelijking van het platteland.

Dit alles heeft ook geleid tot belangrijke bijdragen van de onderzoekers van genoemd proefstation op het gebied van bodemchemisch onderzoek, bosgronden, bodemgenese en mineralogie, bemestingsonderzoek voor tabak en groenten en uitspoeling van plantenvoedingsstoffen, bodemstructuur en wortelontwikkeling en klimatologie.

LITERATURE

Anderson, P. J., M. F. Morgan and N. T. Nelson, 1927: C.A.E.S. Tobacco Sta. Bul. 7.
Anderson, P. J., 1953: Conn. Agr. Exp. Station (C.A.E.S.) Bul. 564.
Bauer, A. J., and W. H. Lyford, 1957: Soil Sci. Soc. Amer. Proc. *21* (5), 533–536.
Bourbeau, G. A., and C. L. W. Swanson, 1954: C.A.E.S. Bul. 584.
Brown, B. A., 1953: Storrs Agr. Expt. Station Inf. 47.
Brown, B. A., et al., 1956: Soil Sci. Soc. Amer. Proc. *20* (4), 518–522.
De Roo, H. C., 1957: C.A.E.S. Bul. 608.
De Roo, H. C., 1958, 1959: Bul. 613 and Bul. 623.
Dorsey, C. W. and J. A. Bonsteel, 1900: Field Operations of the Div. of Soils, 1899. Report No. 64, U.S. Dept. Agr.
Jacobson, H. G. M., et al., 1948: Soil Sci. *65* (6), 437–460.
Jacobson, H. G. M., 1952: C.A.E.S. Bul. 560.
Jacobson, H. G. M. and C. L. W. Swanson, 1958: Soil Sci. *86* (4), 216–219.
Lunt, H. A. and H. G. M. Jacobson, 1944: Soil Sci. *58* (5), 367–375.
Lunt, H. A., 1948: C.A.E.S. Bul. 523.
Lunt, H. A., et al., 1958: C.A.E.S. Bul. 541.
Lunt, H. A., 1955, 1959: C.A.E.S. Bul. 593 and Bul. 622.
Lyford, W. H., 1946: Soil Sci. Soc. Amer. Proc. *11,* 486–492.
Morgan, M. F., P. J. Anderson and H. Dorsey, 1929: C.A.E.S. Bul. 306.
Morgan, M. F., 1930, 1939: C.A.E.S. Bul. 320 and Bul. 423.
Morgan, M. F., 1936: C.A.E.S. Bul. 384.
Morgan, M. F. and O. E. Street, 1939: C.A.E.S. Bul. 429.
Morgan, M. F. and H. G. M. Jacobson, 1940: C.A.E.S. Bul. 439.
Morgan, M. F., 1941: C.A.E.S. Bul. 450.
Morgan, M. F. and H. G. M. Jacobson, 1942: C.A.E.S. Bul. 458.
Morgan, M. F., H. G. M. Jacobson and S. B. LeCompte Jr., 1942: C.A.E.S. Bul. 466.
Morgan, M. F., H. G. M. Jacobson and O. E. Street, 1942: Soil Sci. *54* (2): 127–148.
Osborne, E. A., 1913: From the letter – files of S. W. Johnson. Yale Univ. Press, New Haven.
Ritchie, A. Jr., et al., 1957: Soil Sci. Soc. Amer. Proc. *21* (4), 428–433.
Ritchie, A. Jr., and C. L. W. Swanson, 1957: C.A.E.S. Bul. 606.
Rubins, E. J., 1955: Soil Sci. Soc. Amer. Proc. *19* (2), 207–209.
Salter, R. M. 1945: Soil Sci. LIX: 417–418.
Sawhney, B. F., 1958: Nature, 182, 1595.
Shearin, A. E., et al.: Soil survey of Hartford County, in ms. Aerial photo mosaic maps, scale 1/20,000.
Stewart, J. B. 1907: U.S. Dept. Agr. Bur. Soils Bul. 39.
Swanback, T. R., 1947, 1950: Bul. 504: 12–14, and Bul. 535.
Swanback, T. R., 1952: C.A.E.S. Bul. 559.
Swanson, C. L. W., May 1954: Journal Soil & Water Conserv.
Swanson, C. L. W. and H. G. M. Jacobson, 1956: Soil Sci. Soc. Amer. Proc. *20* (2), 161–167.
Tamura, T., et al., 1957: Soil Sci. Soc. Amer. Proc. *21* (5), 536–539.
Tamura, T., R. M. Hanna and A. E. Shearin, 1959: Soil Sci. *87* (4), 189–197.
Tavernier, R. and G. D. Smith, 1957: Adv. in Agron. Vol. IX, 217–289.
Waggoner, P. E., 1958: C.A.E.S. Bul. 614.
Waggoner, P. E., A. B. Pack aud W. E. Reifsnyder, The climate of the shade tent, C.A.E.S. Bul. in ms.