greater and probably cheaper supply of products which we need and cannot produce because of climatic requirements.

Costa Rica is indeed rich in its agricultural potentials. But the "practical" methods in use since the 16th century must be supplemented by mechanization and the findings of modern research in order that increased production may be achieved at lowered costs. Most work is done manually rather than by machine. Less than 500 tractors are in use. Most of the plowing is with oxen and nearly all tillage is by hand labor. Organized agricultural research was initiated by the Costa Rican Government only some three years ago, and the need for investigational work is similar to and as great as that of Florida's. With limited exception, it is to be stressed that the efficient agriculture which Costa Rica must develop is dependent in great measure on an adequate and forceful program of agricultural research, extension and education. Such a program is now established and Costa Ricans may be depended upon to maintain and enlarge it.

SOIL MICROBIOLOGY CONTRIBUTES TO FLORIDA AGRICULTURE

F. B. Smith

Head, Department of Soils

University of Florida, College of Agriculture

Gainesville

Thank you for the opportunity to tell you of some of the work we have been doing in soil microbiology in recent years. But first, let me discuss with you briefly the practical importance of soil microbiology to our agriculture and review some of the recent advances in basic soil microbiological research.

Everyone is familiar with germs and the diseases they cause in humans, the lower animals, and plants. The importance of medical microbiology is easily understood and appreciated by everyone, but soil microbiology and the part it plays in crop production are not so well understood. To the layman microbes, germs, or bacteria mean test tubes, microscopes, masks, white-coated laboratory technicians, and sometimes anxiety. This is also probably one of the largest stumbling blocks to the soil microbiologist. He isolates the soil microbes, grows them in pure culture on artificial media, and then expects them to perform the same way in the soil as they do under laboratory conditions.

This is not to say that the pure culture study of soil microorganisms is not necessary nor desirable. However, it would appear that the soil microbiologist needs to reorient himself occasionally. He must study the microbes in their native habitat—the soil—and devise soil management practices which will produce desired reactions. The soil microbiologist must learn to control soil conditions much as the chemical engineer controls temperatures and pressures, to use catalysts, to stimulate one portion of the soil population while another is checked, to promote desired reactions and depress undesirable products. Until we learn to do some of these things better than at present, soil microbiology will, no doubt, remain less well known than some other phases of soil fertility.

Florida Agricultural Experiment Station Journal Series, No. 204.

Importance of Soil Microbiology

It isn't necessary to dwell on the importance of soil microbiology to convince anyone of the necessity for our attention to the subject. That has probably been done too well. We find our public disappointed because the science has not revolutionized agriculture as microbiology did the practice of medicine soon after Koch discovered that bacteria can produce disease. However, it will not be considered out of place, I believe, to call attention to the diverse soil population and the activities of the soil microorganisms that may be applied to the maintenance of soil fertility and the economic production of crops.

It staggers the imagination when one considers that the population of the soil microorganisms is more diverse than that of all the animals on the earth. Think for a moment of all the hustle and bustle at the rush hour in a big city—the hum of the motors, the screeching of brakes, the blasts of horns of automobiles, trucks and buses, the roar of the elevated and the subway trains, and the airplanes, and add to this the myriad activities of all the lower forms of animal life. Then say to yourself that all these are as nothing when compared with the activities of microorganisms which inhabit a fertile soil under favorable conditions.

We see and hear the traffic in the street, but the soil microorganisms go about their work unheard, rarely ever seen, and for the most part unappreciated. We are more conscious of their effects when, because of unfavorable conditions, they are inactive than when they are healthy and perform their normal functions. If all microbial life should cease, it would be but a very short time before the earth would be covered with refuse and waste products of all kinds. There are, of course, chemical means of disposal of residues, but think of the great waste of energy, synergetic and vital by-products when refuse is disposed of this way, to say nothing of the great inconvenience involved.

The removal of waste products is only one of several results of decomposition. The important thing about decomposition is the release of combined elements. Some of these elements are often in short supply. Carbon as carbon dioxide dissolved in soil solution has important solubility effects on the soil minerals. It is also readily available for growing crop plants. The importance of carbon dioxide released from organic matter for photosynthesis has not been clearly established. However, numerous investigations (17) have shown beneficial effects of carbon dioxide added to the atmosphere on crop yields.

The release of minerals in the decomposition of organic matter under some conditions might not be of any great significance. On the other hand, it may have a very practical bearing on succesful soil management, especially under certain soil and climatic conditions such as inherently poor soils, during periods of heavy rainfall and mild winters where no cash crop is grown, and under forest conditions. Plant food elements applied in excess of immediate needs may be held in the soil for the next cash crop by use of cover crops. Deep-rooted green manure crops may be used to concentrate the fertility constituents of poor soils in the surface layers to be released by decomposition in available forms where needed. These elements may be locked up in the bodies of soil microorganisms and conserved for later use by proper soil management practices.

The decomposition of organic matter and the release of carbon and minerals—or conversely, their assimilation and synthesis into microbial protoplasm—are obviously important functions of the soil microorganisms. But perhaps more important than these are the ill-defined and vaguely understood biological interactions usually referred to as symbiosis, mycorrhiza formation, antagonistic action, the production of antibiotics, vitamins, biotin and auxins or plant growth-promoting substances. Except for legume inoculation, very little basic research has been conducted along these several lines.

It is not at all unlikely that as soon as sufficient fundamental knowledge regarding the production of antibiotics in the soil is available, soil management practices for the control of certain plant diseases will be developed. This development will not come tomorrow. The easy work has already been done. Remember that the antagonistic action of microorganisms was observed three-quarters of a century before antibiotics were applied in medicine. The problem is just as complicated when antibiotics are applied in the soil. Some organisms are sensitive and others are not. Some soils will adsorb the antibiotics. This will be affected by the mineral composition of the soil, its pH and physical properties. There are a great many different soil types, soil microbes and antibiotics, and much time and research will be required to work out all the combinations.

Recent Advances in Soil Microbiology

The outlook for early application of soil microbiology to problems of soil management is not so dark as the statement just made implies. In spite of the large gaps between basic research on fundamental problems and applications to practical soil management, one cannot help but be encouraged when one considers some of the recent advances in soil microbiology. In spite of the difficulties encountered in making quantitative studies of the soil microflora by methods adapted from the medical microbiologist, a great deal of useful information has accumulated. For example, by use of these methods it has been found(20) that when a fumigant is applied to the soil, the number of organisms is initially reduced. Insects and nematodes are readily killed. Fungi, bacteria and actinomycetes are reduced in number or completely eliminated depending upon amount and kind of fumigant used.

After the initial reduction in number of bacteria and actinomycetes, the total number of these forms rapidly increases. The number of soil fungi may or may not be affected by fumigants as are bacteria. The kinds of fungi that become re-established after fumigation usually represent fewer species than were present in the soil before fumigation, but the fungus flora of the soil does finally become re-established. The respiration rate of soils by manometric means is now used to measure quickly and conveniently the effect of certain insecticides, herbicides and soil fumigants on the heterotrophic soil micro-flora. Enumerations (11) of the bacteria by plate counts have been found to agree closely with respiration rates.

The numbers and kinds of microorganisms in soils variously treated with manures and fertilizers and under various cropping systems have been determined. The results of some of these experiments are often difficult to interpret and the possible significance of the effects is often obscured for the lack of soil management practices for altering the microbial balance. It is not the purpose of this review to relate the details of such experiments. Suffice it to say that fertile soils are usually supplied with many kinds of microbes; whereas, poor soils contain fewer numbers and fewer species, and good soil management enhances microbial activity (25).

Perhaps the most important feature of the study of the soil population is the new approach to the problem. Significant is the work of the last decade on the population of the rhizosphere; that is, the population of microbes living on and around the roots of plants. It has been found (16, 37) that the population of soil microbes is not evenly distributed throughout the soil. Larger numbers are found around the roots of growing plants than at some distance, indicating a greater abundance of food or some other favorable condition not found in the soil where there are no plant roots.

Bacteria in soil samples from a fertile field between the rows and from the roots of beets were found to differ in their nutritional requirements. Those that require amino acid supplements for maximum growth were stimulated most of all and their numbers were found to be increased proportionally in the rhizosphere. No similar effect was observed with respect to bacteria that respond to growth factors such as vitamins. Bacteria isolated from the rhizosphere of wheat, oats, red clover, timothy, alfalfa and flax, as well as from uncropped soils, were grouped according to their nutritional requirements. A general rhizosphere effect was indicated by a much higher percentage of bacteria with the simplest nutritional requirements in the rhizosphere than in soil without crops.

The biological oxidation of ammonia to nitrite and nitrate in soil is called nitrification. Because of the general deficiency of available nitrogen in most Florida soils, this is one of the most important of the microbiological processes affecting crop production. Time and space do not permit of more than a superficial coverage of recent work on nitrification.

Jensen and Frith (14) determined the rate of nitrification when tops, roots and nodules of legumes were mixed in the soil. Nearly 90 percent of the nodule nitrogen, 50 percent of the nitrogen of the tops, and 33 to 45 percent of the nitrogen of the roots were converted into nitrates within five weeks. The rate of nitrification showed a significant negative correlation with the carbon-nitrogen ratio. Experiments on the availability of the root and nodule nitrogen to young wheat plants gave results in agreement with the nitrification tests. The nitrogen of dead root nodules appeared to be readily available to non-leguminous plants.

Fuller (8) studied the effect of purified lignin on the nitrification of dried blood and ammonium sulfate in a sandy loam. It was found that lignin definitely reduced the amount of nitrate recovered from either dried blood or ammonium sulfate. The effect was much more marked with the dried blood than with the ammonium sulfate.

The two references just cited were selected from a large number of recent papers on nitrification in soils to show the diametrically opposite effects obtained by use of different materials easily available and to emphasize how readily basic research may be utilized in practical soil management.

The value of legumes in soil building has been appreciated for over two thousand years. That legumes, by the aid of bacteria in the root nodules, can utilize free nitrogen of the atmosphere has been known for 115 years. However, the mechanism of fixation is not definitely known yet. Volumes have been published on the results of experiments to explain the process of biological nitrogen fixation during the past 15 years. The development of the tracer technique and its application in studies on the nitrogen-fixing enzyme system of rhizobia and other nitrogen-fixing organisms has advanced our knowledge of the process greatly.

The results (2) of certain experiments seem to indicate that the characteristics of the nitrogen-fixing enzyme systems of all nitrogen-fixing microorganisms are quite similar. A theory (21) has been advanced that atmospheric nitrogen is absorbed by an enzyme of the type of hemoglobin in the activated form and then hydrogenated. The hydrogen used is taken from the substrate by the microorganisms forming ammonia as an intermediate product in the fixation. The process is by no means as simple as it might appear from this explanation and all soil microbiologists are not agreed that this is the correct explanation.

It has also been known for a long time that some legumes, even though well nodulated, are not benefited by the inoculation. Recent work (34) has shown that some strains of rhizobia are not as efficient as others and some even may be parasitic on the host plant. Smith, Blaser and Thornton (27) observed a variation in the legume bacteria. The cause of the inactivity of certain strains is not definitely known and, undoubtedly, is a result of various causes in different strains. One theory (34) has been advanced that the inactive strains can fix nitrogen but do not make it available to the host plant. Work by Lynch and Sears (18) on the differential response of strains of lotus nodule bacteria to soil treatments show that maximum effectiveness of the nitrogen-fixing function is dependent upon the maintenance of an adequate supply of nutrients in the soil and upon favorable pH. This appears to be a good explanation for, at least, those instances where an inefficient strain was converted into an efficient strain by repeated inoculations of new plants and under different soil conditions.

Nitrogen fixation by the aerobic, non-symbiotic Azotobacter and the anerobic, free-living Clostridia was proven 70 or 80 years ago. The ability to fix atmospheric nitrogen has been claimed for many other soil microorganisms but there has been reasonable doubt as to the validity of some of these claims. Recent work (15, 24), however, seems to show without a doubt that species of Chromatium and Chlorobacterium, the green and purple sulfur bacteria, and species of the blue-green and green algae, Nostoc Anabaena, and Protosyphon are able to fix nitrogen. The amount of nitrogen fixed in the soil by these organisms has never been accurately measured.

Bertholet (1), who is usually credited with the discovery of nitrogen fixation in soils, found that 16 milligrams of atmospheric nitrogen was fixed per kilogram of dry sandy loam soil in 67 days. Calculated on an annual acre basis, this would amount to several tons. On the basis of the most recent estimates of the role of nitrogen fixation by the Azotobacter, Fedorov (6) found that under favorable conditions two milligrams of atmospheric nitrogen were fixed per kilogram-calory of chemical energy substrate, or approximately one milligram of nitrogen per 3000 square meters of catalytic surface. When one considers the rapid rate of multiplication of these organisms under favorable conditions, and the enormous surfaces developed, the amount of nitrogen which might be fixed in the soil reaches a fantastic figure. If only a fraction of the theoretical amount possible could be fixed in the soil, it would be an outstanding performance.

We have not yet learned how to manage soils in practice to maintain favorable conditions over a long enough period to obtain these results. However, soil inoculation with free-living nitrogen-fixing microorganisms offers interesting possibilities for the application of results of basic research in soil microbiology to soil management. Bacterized peat and other cultures containing the nitrogen fixing bacteria have appeared on the market from time to time with impressive claims for their fixing atmospheric nitrogen and other beneficial properties. Unfortunately, these claims have not yet been verified in actual practice. Recent work by Gainey (9, 10) of Kansas indicates that the process of non-symbiotic nitrogen fixation may be of limited importance in many soils because of excess acidity. It is rather difficult to find Azotobacter in many virgin Florida soils, presumably because of the low pH and deficiency of available phosphorus.

When organic matter decomposes in the soil, mucilaginous or gummy poly-saccharides appear to be the first products formed (19). These materials may have a cementing action on the silt and clay particles of the soil causing the formation of aggregates. Aggregation in heavy textured soils greatly improves their physical condition. This effect may not persist long as other microorganisms utilize these products. It is a case of not being able "to have your cake and eat it, too." A soil microbiologist came up with the idea of using one of the synthetic plastics which could not easily be decomposed by soil microorganisms and the new soil conditioner, Krilium, was born.

Today, less than two years since the first of these new soil conditioners was announced, there are a number of them on the market. The idea is fundamentally sound and amazing results have been obtained with their use under certain conditions. However, we do not yet know the correct combination of conditions for the use of synthetic soil conditioners on light textured soils so common in Florida. Since soil organic matter is to a considerable extent composed of carbon compounds of microbial origin and the rhizospheres of different plants harbor and stimulate different species of microbes, there seems to be good possibility of developing improved structural conditions even in light textured soils by the right combination of soil management practices.

Soil Microbiology in Florida

In the remainder of the time allotted to me, I would like to present a brief summary of the soil microbiological work contributed by the Florida Agricultural Experiment Station in recent years. Although we are proud of our record, this is not offered in boasting; likewise, no apologies are made for the size or quality of the contributions. This is not intended as a complete coverage of our work, but only representative findings will be reviewed.

Most of you are familiar with the work by Volk and Gammon (35, 36) on nutritional leaf roll of potatoes in the Hastings area during the past three or four years. This is perhaps one of the most outstanding examples of basic soil microbiology as applied to soil fertility and management. The cause, prevention and cure of the disease are fundamental soil microbiological principles. The results of carefully planned experiments over a period of years show that the condition occurs when the soil becomes too acid for nitrification (the biological oxidation of ammonia nitrogen to nitrate nitrogen), and that the condition disappears when the soil acidity is neutralized, provided there is sufficient organic matter or ammonia nitrogen present. Temporary relief from the condition is obtained by side dressing with nitrate nitrogen. A permanent cure is effected by correcting the cause; that is, restoring and maintaining favorable soil conditions for microbiological action.

It was mentioned above that Florida did pioneer work on strain variation of bacterial cultures for legume inoculation. The superiority of strains of *Rhizobium trifolii* isolated from white clover grown in Florida over those obtained from commercial sources outside of the State was an outstanding result of our inoculation work in 1942. As a result of that work, many commercial cultures for legume inoculation now offered for sale in the State contain Florida strains of the organisms. The success of clover-growing in Florida in the past 10 or 12 years has been phenomenal. We think at least a small part of this success may be duly credited to improvement of cultures for inoculation.

One difficulty in legume inoculation observed in our early work, for which we still have no satisfactory explanation, is the necessity of using two or three times the manufacturer's recommended amount of inoculum for satisfactory inoculation. Results (28, 31) of experiments by Thornton showed that rhizobia died rather quickly in some of our soils. At first (27) it was thought to be caused by the rapid drying out of the light textured soils, since rhizobia are especially sensitive to drying. Coating the seeds with methocel, a hydro-phyllic colloid, to prevent the culture from dessication, the use of clay and peat for altering the texture and water-holding capacity of the soils were all ineffective in increasing the efficiency of inoculation.

A study (32) was made of the soil microorganisms associated with the roots of sweet clover. Six out of seven cultures of streptomyces and two out of six cultures of fungi isolated, showed antibiotic properties toward *Rhizobium meliloti*, the root nodule bacteria of sweet clover. An antibiotic substance was extracted from the culture of *Streptomyces albus* and a probiotic substance in the filtrate of the culture was also demonstrated. In other words *Streptomyces albus* found abundantly on the roots of sweet clover produced in pure culture both harmful and beneficial substances to the root nodule bacteria which inoculate this clover. The practical value of this discovery is not yet known, but experiments are now under way to test the effect of several chemically pure antibiotics on rhizobia, inoculation, and growth of clovers.

Studies by Neff (22) of the factors affecting the physiology of legume bacteria showed that vitamins B_1 and B_2 produced a marked stimulation in oxygen consumption of *Rhizobium meliloti*. Apparently the vitamins reduced the lag-phase of the growth of this organism. Whether or not these vitamins would continue to increase the activity of the rhizobia under actual practice and result in increased nitrogen fixation is not known, but the practical value of this finding is of wide interest and would justify further investigation.

The general effects of partial sterilization of the soil by steam and by volatile antiseptics have been known for many years; but many new fumigants, insecticides and herbicides have been developed in recent years. It is very important that we know the effect of these materials on microbial action in soils. We (29, 13, 23, 33) have tested a number of these materials and have found that some are quite effective in decreasing microbial action temporarily; whereas, others are without effect when used at recommended rates. The important finding is that the soil population does come back where it is depressed and normal microbial activity is re-established after the use of these materials. Some of these substances do tend to accumulate in the soil. Tests are being continued to determine if harmful residues may be built up in the soil after their prolonged use.

The effects of minor elements on nitrification have been studied in several soils (28), Boron and copper in small amounts, 10 and 25 pounds per acre, respectively, increased nitrification. Both materials decreased nitrification at higher concentrations, 25 and 100 pounds per acre, respectively. Manganese and zinc sulfates at 100 and 200 pounds per acre did not affect nitrification in Lakeland fine sand. Recent work by Eno (3) with soils containing from 5 to 1600 pounds of copper per acre showed that nitrification does not seem to be inhibited to any great extent, providing the pH is maintained above about 5.5. Fiskel (7) found that the sodium, iron, copper, zinc and manganese salts of EDTA used at the rate of 2000 pounds per acre had little or no effect on ammonification, nitrification, or carbon dioxide production in Lakeland fine sand. Eno and Blue (5) found that high concentrations of anhydrous ammonia depressed nitrification initially but that nitrification proceeded normally as the concentration of anhydrous ammonia decreased. They also found important population changes in the soils treated with anhydrous ammonia. There was a drastic reduction in numbers of fungi, indicating the possibility of using anhydrous ammonia as a fungicidal agent in the soil.

Extensive studies (26) have been made on the production of artificial manure and the use of compost. Results of these experiments show that a good grade of compost can be made from a variety of materials easily available in Florida and that these materials when applied to soils stimulate microbial action. Experiments by Eno (4) are currently under way to test the value of certain compost accelerators or cultures for the quick rotting of plant residues. Any prediction on the outcome of these experiments at this time would be premature. However, I have always had the feeling that even though a culture may be found which will quickly decompose a given material, the organisms will soon die if placed under unfavorable conditions and in all probability sufficient organisms are already present in most composts if only conditions were favorable for their growth.

This, of course, does not mean that the use of accelerator cultures may not eventually prove extremely valuable in initiating decomposition and decreasing the time now required to produce compost under ordinary conditions. Smith and Batista (30) found that the measure of nematode control obtained from the use of a mulch appears to be the result of lower soil temperatures, higher moisture content of soil, and the release of fertility constituents in the decomposition of the mulch. Good (12), in a study of the characteristics and occurrence of certain nematodes in Florida soils, has found indications of important relationships between plant root injury which is reflected in lower crop yields and the numbers of these species. This work has just been initiated and the results do not warrant definite conclusions at this time.

Conclusions

Everyone will probably agree that the majority of chemical reactions taking place in the soil are of biological origin; that soil microbiology is a great deal more important in soil fertility and management than is usually given to it; and, that the work should receive more support than it gets. The Florida Agricultural Experiment Station is the only station in the South, and one of the few in the United States, which has a full-time Soil Microbiologist on its staff. However, this is not much to boast about. We should rather regard this as a modest beginning and implement it in every way possible. This was not intended to be a detailed survey of the field of Soil Microbiology nor a complete listing of our contributions to the science. However, sufficient evidence has been reported to show that we have made significant contributions in this field; that we should continue to support basic research in Soil Microbiology; and begin to devise more soil management practices to fully utilize the results basic research has made available to us.

LITERATURE CITED

1. Bertholet, M. Fixation directe de le'Azote Atmospherique' par certains terrans argileux. (Compt. Rend. Acad. Sci. Paris, 101: 775, 1885). Abs. in Bacterial Metabolism, Marjorie Stephenson, Longmans, Green and Co., London, 391 pp., 2nd Ed. 1939.

2. Burris, R. H. and P. W. Wilson. Characteristics of the nitrogen-fixing enzyme systems in **Nostoc Muscorum.** Bot. Gaz. 108: 254-262. 1946.

3. Eno, C. F. The effect of copper on nitrification in some Florida soils. Fla. State Hort. Soc., Proc., 1953 (in press).

4.———, ———. Compost accelerator cultures. Unpublished data. Department of Soils, Fla. Agr. Exp. Station, 1953.

5. ———, ——— and W. G. Blue. The effects of anhydrous ammonia on nitrification and the microbiological population in sandy soils. Soil Sci. Soc. Amer., Proc. 18 (in press).

6. Federov, M. V. Effect of surface active substances upon intensity of fixation of atmospheric nitrogen by nitrogen-fixing bacteria. (Compt. Rend. Acad. Sci. U.S.S.R., 49: 605-608, 1945). Abs. in Chem. Abs. 40: No. 9, p. 5867, 1946.

7. Fiskel, J. G. A. Availability and leaching of minor elements in Florida soils. Fla. Agr. Exp. Sta., Ann. Rpt. 1953 (in press).

8. Fuller, J. E. Influence of purified lignin on nitrification in soil. Science 104: 313-315, 1946.

9. Gainey, P. L. and Eric Fowler. Growth curves of Azotobacter at different pH levels. Jour. Agr. Research 70: 219-236, 1945.

10. ———, ———. The significance of available calcium as a factor limiting growth of Azotobacter at pH levels below 6.0. Agr. Research 76: 265-269, 1948.

11. Gamble, S. J. R., C. J. Mayhew and W. E. Chappell. Respiration rates and plate counts for determining effects of herbicides on heterotrophic soil microorganisms. Soil Sci. 74: 347-350, 1952.

12. Good, Joseph M., Jr. The characteristics and occurrence of certain nematodes in Florida soils. Fla. State Hort. Soc., Proc. 1953 (in press).

13. Horn, Granville C. The effects of certain insecticides on the flora of Arrendondo fine sand. Soil Sci. Soc. Fla., Proc. 12, 1952 (in press).

14. Jensen, H. L. and Dorothy Frith. Production of nitrate from root nodules of lucerne and subterranean clover. (Proc. Linnean Soc. N.S. Wales 69: 210-214, 1944). Abs. in Chem. Abs. 39: No. 11, p. 2309, 1945.

15. Lindstrom, E. S., Shirley R. Tove and R. W. Wilson. Nitrogen fixation by the green and purple sulfur bacteria. Science 112: 197-198, 1950.

16. Lochhead, A. G. and R. H. Thexton. Qualitative studies of soil microorganisms. VII. "Rhizosphere Effect" in relation to the amino acid nutrition of bacteria. Can. Jour. Research 25C: 20-26, 1947.

17. Lundegardh, H. Carbon dioxide evolution and crop growth. Soil Sci. 23: 417-454, 1927.

18. Lynch, D. L. and O. H. Sears. Differential response of strains of lotus nodule bacteria to soil treatment practices. Soil Sci. Soc. Amer., Proc. 15: 176-180, 1950.

19. Martin, James P. Microorganisms and soil aggregation. I. Origin and nature of some of the aggregating substances. Soil Sci. 59: 163-174, 1945.

20. ———, ———. Effect of fumigation and other soil treatments in the greenhouse on the fungus population of old citrus soils. Soil Sci. 69: 107-121, 1950.

21. Moore, M. G. Theory of the fixation of atmospheric nitrogen by micro-organisms. (Doklady Akad. Nau. U.S.S.R. 58: 249-252, 1947.) Abs. in Chem. Abs. 44: No. 20, p. 9510, 1950.

22. Neff, S. Frank. Physiological effects of growth promoting substances on **Rhizobium meliloti.** Master's Thesis, University of Florida. 1943.

23. Ross, Harold F. The effect of certain insecticides on nitrification in Arredondo fine sand. Soil Sci. Soc. Fla., Proc. 12, 1952 (in press).

24. Singh, Rama Nagina. The fixation of elementary nitrogen by some of the commonest blue-green algae from the paddy field soils of the United Provinces and Bihar. Indian J. Agr. Sci. 12: 743-756, 1942.

25. Smith, F. B. and Owen E. Gall. Types and distribution of microorganisms in some Florida soils. Fla. Agr. Exp. Sta. Bul. 396, 1944.

26. ———, ——— and G. D. Thornton. Production of artificial manure. Fla. Agr. Exp. Sta. Bul. 415, 1945.

27. ———, ———, R. E. Blaser and G. D. Thornton. Legume inoculation. Fla. Agr. Exp. Sta. Bul. 417, 1945.

28. ———, ——— et al. Interrelationships of microbiological action in soils and cropping systems in Florida. Fla. Agr. Exp. Sta., Ann. Rpts. 1944, p. 93; 1947, p. 97.

29. Smith, F. B., G. D. Thornton, H. F. Ross, and C. F. Eno. Effect of certain insecticides on microbiological action in soils. Fla. Agr. Exp. Sta., Ann. Rpt. 1953 (in press).

30. ———, ——— and J. W. Batista. The nematode problem from the soil microbiological standpoint. Soil Sci. Soc. Fla., Proc. IV-B: 144-147, 1942.

31. Thornton, G. D. Some factors affecting the longevity of rhizobium in Florida soils. Soil Sci. Soc. Amer., Proc. 8: 238-240, 1944.

32. ———, ———, Jose' de Alencar, and F. B. Smith. Some effects of **Streptomyces albus** and **Penicillium** spp. on **Rhizobium meliloti.** Soil Sci. Soc. Amer., Proc. 14: 188-191, 1949.

33. ———, ———. The effect of D-D, Chloropicrin, 2,4-D and EDB on microbiological action in some Florida soils. Soil Sci. Soc. Fla., Proc. 12, 1952 (in press).

34. Virtanen, Artturi I. and Hilkka Linkola. The activity of various strains of leguminous bacteria. (Suomen Kemistilehti 17B, 22, 1944). Abs. in Chem. Abs. 40, No. 21, p. 6547, 1946.

35. Volk, G. M. and Nathan Gammon, Jr. Effect of low nitrate nitrogen on growth of potatoes. Fla. State Hort. Soc., Proc. pp. 112-115, 1950.

36. ———, ——— and Nathan Gammon, Jr. Effects of liming and fertilization on yield and the correction of nutritional leaf roll of Irish potatoes. Fla. Agr. Exp. Sta., Bul. 504, 1952.

37. Wallace, R. H. and A. G. Lochhead. Qualitative studies of soil microorganisms. VIII. Influence of various crop plants on the nutritional groups of soil bacteria. Soil Sci. 67: 63-69, 1949.