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I am submitting herewith a problem in lieu of thesis written by Sunanda Sakharam Rao entitled "A Study of Root Development of Crop Plants in Relation to Soil Characteristics." I recommend that it be accepted for three quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

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Major Professor

We have read this thesis
and recommend its acceptance:

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A STUDY OF ROOT DEVELOPMENT OF CROP PLANTS IN RELATION TO SOIL CHARACTERISTICS

Agronomy 501a

A Problem
in Lieu of Thesis
Presented
In Partial Fulfillment
of the Requirements for the Degree
Master of Science

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by
Sunanda Sakharam Rao

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CHAPTER I

INTRODUCTION

Soil is the environment for many plant activities. It is needless to emphasize the importance of root studies in crop plants, since it is well known that top growth is dependent on root development to a large extent. Although much work has been done on the root habits of crop plants, it is desirable that more detailed studies be undertaken.

Although there exists considerable difficulty in exposing and studying root systems of different crops, such studies will help a great deal in setting out irrigation schedules, fertilizer placement and avoidance of root pruning during cultural operations. Many authors have contributed to the study of root development of crop plants but most studies have been general treatments without emphasis on the soil environment. Soils vary remarkably in their crop production capacities and different soils support different types of vegetation and crops. The diversity in texture, chemical composition and depth, origin and richness of different soil types have their individual influence on rate and habit of root growth of crop plants. Some of the soil factors affecting profoundly the development of roots are: (1) water holding capacity, (2) temperature, (3) soil air and (4) nutrients. Water absorbed by roots is important to the plant in many ways and constitutes 80 to 90% by weight in most herbaceous plants. The heavy soils generally promote shallow rooting habits while roots penetrate deeper on sandy soils. Unsuitable soil temperature affects the development and function of roots. Extremes of soil temperature are inimical to root hair development. The amount of soil air varies from soil to soil depending on texture, structure and water status, and the dependence of root development upon aeration of the soil is well recognized. In development, a particular species exhibits different patterns of root systems or root habits which are conditioned by the soil factors indicated above. The chemical content of the soil exerts a major influence, being responsible for promoting or retarding root development of crop plants. Crop plants also vary in their capacities and in their tolerance to alkaline or acidic nature of the soil. It is not uncommon to find that a concentrated soil solution may inhibit water absorption temporarily or permanently. Root hairs, being the gateway for the entry of water and salts, are very important to plants. Their development and activity is controlled by soil temperature, water holding capacity, and the nutrient solution in soil, besides other factors.

It has been established beyond doubt that there is a close similarity between the distribution of major vegetation types and zonal soil types. A critical study of the root development of crop plants in relation to soil types will not only give a detailed knowledge of the root system but also enable agricultural workers to determine the suitability of particular crop plants to a given soil. There is no doubt regarding the importance of edaphic factors to the root development and ultimately the crop yield.

It may require a thorough study of form, structure, physiology and life history of the plants in a particular soil to explain how plants are fitted to subsist in a given soil environment. The several individual and associated factors condition the crop growth in a region, the dominant factors impressing them strongly, resulting in alteration of morphological features of roots and tops in different soils. Very often the nature of the root system is an indicator of the soil condition.

The object of the present paper is to make a brief review of the work done on the root development of crop plants in relation to soil types. Besides reviewing the studies made on the subject the various factors influencing the root habits are discussed briefly.

CHAPTER II

MATERIAL AND METHODS

The present study was made with a view toward summarization of the effect of soil environment on the root development of crop plants. The work encompasses a brief review of the work done in this field in the latter part of the last century as well as in the 20th. century. Emphasis has been laid on the effect of soil factors such as texture, chemical composition, depth, origin, water holding capacity which are known to affect profoundly the external and internal character of the plant root system. This study has been confined to crop plants, with particular reference to corn, cotton, wheat, and forage plants.

Although much work has been done to investigate root habits, only part has direct bearing on the chosen subject. In the preparation of this review over 50 books and contributions were referred to and only those directly connected with the subject and considered important have been reviewed. However the review has been compiled, taking care to cover the different aspects and soil factors conditioning root development.

CHAPTER III

REVIEW OF LITERATURE

Knowledge of the soil as a medium for growth of roots has increased greatly in the past three decades. With the rapid advancement of soil science and emphasis on edaphic factors and vegetation a distinct need has arisen for a better understanding of intimate relationships of roots and soils. According to Pavlychenko (1937), Hales in 1727 was perhaps the first to realize fully the value of root studies of agricultural plants from the standpoint of production. Stoeckeler, and Klenender (1938), Pavlychenko (1937), Upchurch (1951) and Weaver and his associates (1926, 1945, 1949, 1950) designed many techniques and methods for exposing and studying the root systems of crop plants. The foremost among these is J. E. Weaver of the University of Nebraska. He and his associates contributed enormously to root studies, particularly of the grasses of North America. His studies have been compiled and summarized recently in two books, Weaver (1954) and Weaver and Albertson (1956).

Amongst other important early workers on the subject, mention may be made of Goff from 1883 to 1886 (Sperry 1935) who made extensive studies at New York Agricultural Experiment Station. Fruwirth in 1895 (Sperry 1935) apparently did the first work of this kind in Europe. However Weaver's initial contribution to this subject was outstanding, serving as basic material and information for further research. Russell (1950) gives a general treatment of plant growth in relation to soil conditions which is an outstanding contribution in this field of study.

It is the intention here to give a brief review of some of the important investigations and contributions in the field of root studies in relation to different types of soils. The review encompasses those projects of study which deal with the effect of soil environment on the root development and root patterns of certain crop plants. The review, besides reporting of the work done in early part of the century, includes the recent work done on the subject, more elaborately.

Snow (1905) records that the amount of soil moisture in general has its influence on root hair development. Soils with heavy clay content offer considerable resistance to root penetration, which results in poor root development. Harris (1914) has indicated that, in vineyards and orchards planted in areas of high salt content, the root systems had a tendency to establish in a non-toxic lower layer of the soil, which is less alkaline than the surface. In later publications he further observes that layers of compact soil often play an important part in influencing the morphology of the roots, after his trial with plants in compact and loose soils.

Several authors have investigated the individual effects of water content, temperature, aeration, acidity, alkalinity of the soil on root development of plants. Cannon (1915, 1917) believes that an adequate supply of air to the roots, favors a high degree of branching and also accelerates root growth. He mentions that in mesquite, root development continued indefinitely in a soil atmosphere containing 2.67% oxygen. Deep rooted species like alfalfa are able to grow in an atmosphere containing about 2% oxygen. Cannon (1924) has worked on the fundamental relationship between rate of root growth, aeration and soil temperature.

Noyes et al. (1918, 1920) are of the opinion that a high carbon dioxide content of certain gardenland soils retards root development to some extent in some species. It has been shown by Holbert and Koehler (1924) that certain inbred strains of corn differ in the character of their root systems. In the above study they remark that roots of certain species or strains are unable to function in July and August when soil moisture happens to be very low. Root hair development in crops in general as recorded by Jeffs (1925) is retarded by higher concentrations of salt solutions. The higher concentration outside interferes with the absorption of water. Extremes of temperature are also inimical to root hair development. Great amount of work has been done on the quality and yield of different species as affected by fertilizer treatments and soil conditions. Carlson (1925) made a study of the soil structure on the root development of alfalfa. He provided different kinds of soil structure in tanks filled with different classes of soil, as well as water cultures. The study was made with particular reference to the influence of soil structure with other factors considered and controlled wherever possible. He used five varieties of alfalfa viz., Grimm, South Dakota,Common, Kansas Common, Siberian, and Baltic. His observation was that in compact soils, all varieties and strains developed branched roots while in open soil, tap root development was very pronounced. Besides these general characteristics the individual character of strains and varieties was different. The study seemed to indicate that the representatives of hardy and non-hardy alfalfas, viz., Grimm and Common have inherently different root characteristics but that soil structure determines root branching in terms of development after root initiation.

Weaver (1926) was well known for introducing what was known as "Weaver's technique" for the elaborate study of the root systems of crop plants under field conditions. In his monumental work "Root Development of Field Crops" (1926) the author gives a comprehensive account of the root system of many plants under different soil environments. He was among the first to record that, within a species or variety, root modifications are brought about by such factors as water content, aeration, soil texture and temperature. He goes further to state that the character of a root system often times indicates the soil conditions. He made a detailed study of 28 species of grasses in two or more widely separated habitats. Twenty-five of these species showed very remarkable variation in the depth of penetration, morphology of roots, and position of branches. He noted that the low water content of certain soils enhances root development.

The effect of different spacing on the root development of alfalfa, sweetclover and clover was studied by McCool (1928). He observed and recorded marked differences in the nature and extent of root development when these crops were grown under different conditions. Close planting resulted in smaller and fewer roots while wide planting enabled roots to penetrate deeply. Taubenhaus et al. (1931) made a study of the root system of cotton. The study indicated that root strangulation of cotton occurs in Texas, Arkansas and Mississippi where the soil is poorly drained. The soil is compacted by heavy continuous rain, and in dry weather becomes very hard. The direct cause of the strangulation is that the upper portion of the tap root and laterals are caught early in the season in a layer of hard, dry clay. Further development is affected and, in extreme cases, plants sometimes die. Farris (1934) with a view to find out the relationship between soil characteristics and root development studied root habits of potato, red clover and corn in humid soils of New Jersey. Root systems of all these crops were less extensive than those in the subhumid and semi-arid regions. Corn roots spread no further than 2 feet either vertically or laterally in humid soils. The author's observation was that soil acidity, percent of organic matter, pore space and soil texture have little influence on root development. However in seasons of high rainfall pore space may be important since with reduced aeration plant roots do not penetrate lower soil layers.

Pavlychenko and Harrington (1935) studying the root development of weeds and crops in competition have observed that moisture may be the predominant limiting factor in plant growth. Due to competition in soil, root systems overlap resulting in reduced top growth. Murphy and Arny (1939) have studied in detail the emergence of alfalfa, red clover, biennial white sweet clover, brome grass, crested wheat grass and reed canary grass on five soil types namely (1) Carrington heavy silt loam, (2) Clinton silty clay, (3) Clarion silt loam, (4) Fargo silty clay and (5) Merrimac loamy fine sand and have recorded that surface plantings gave highest percentage of germination on Carrington heavy soil and Clinton heavy loams. Spurway (1941) has explained in detail that the various plant species have their minimum, maximum and optimum pH requirement for their optimum growth. Probst (1944), studying the emergence of soybeans in two soil types, recorded that there was no difference in the emergence of soybeans.

A detailed study of the influence of soil profile characteristics upon the distribution of roots of grasses was made by Fox, Lipps and Weaver (1953). In this study the physical and chemical properties of five

Nebraska soils were correlated with the distribution of grass roots. Limited root development and surface spread were associated with low exchangeable calcium and low nitrogen content. Root branching was restricted when available phosphorus was limited. Kentucky blue grass exhibited deep rooting habits in soils that presented a favorable supply of plant nutrients at all depths. Fox and Lipps (1955), in another experiment, studied the influence of exchangeable calcium, available phosphorus, and soil structure in four Nebraska soils and root development and nodulation of alfalfa and sweetclover. Alfalfa exhibited more nodulation and abundant fibrous roots in a surface soil which contained a small amount of available phosphorus and less in the calcareous subsoil where no available phosphorus could be detected. On the other hand, sweetclover roots were better developed and nodulation was more prominent in the clay subsoil of a Crete profile than nearer the surface, even though the physical environment was more desirable, presumably because the nutrient content was higher. The above authors in their alfalfa root and subirrigation studies stated that root development is in part governed by nutrient availability. Alfalfa roots showed extensive root penetration in the region of high sodium, where calcium and magnesium were present in abundance.

Penetration of corn roots on three Illinois soils, namely Muscatine, Elliot and Cisne, was investigated by Fehrenbacher and Snider (1954). Corn roots attained 7 feet in length in Muscatine silt loam while in Elliot silt loam root development of corn was retarded due to low aeration of soil. In Cisne silt loam, a soil of low fertility, very poor root development was observed. But when this soil was fertilized and legumes turned under, corn roots were highly developed throughout the compact, slowly permeable clay pan. Evidently soil treatment and legumes turned under induced corn root penetration into lower soil horizons, enabling corn roots to utilize moisture available in lower strata. Fehrenbacher and Rust (1956) in their investigation of corn root penetration in soils derived from various textures of Wisconsin-Age glacial till found greater depth of root penetration in the lighter soils and concluded that the greater yield of corn on these soils was related to a great extent to the greater amount of soil moisture available to the plant in the deeper rooting zones of the lighter soils.

Knoch et al. (1957) reported that the root system of wheat was extensive and penetrated as deep as 13 feet where moisture conditions were favorable. Addition of nitrogen fertilizer not only resulted in increasing the root weights at all moisture levels but brought about better utilization of subsoil moisture. Bertrand and Kohnke (1957) suggested that high soil moisture content intensified the effects of dense subsoils on oxygen diffusion rates and ultimately the root growth of corn. However subsoil fertilization in loose soils increased corn root growth. Experiments with partial fertilization of corn plants were carried out by Duncan and Ohlrogge (1958) who record that proliferation of roots occurred in the fertilized zones only. The appearance of smaller roots around a fertilizer band was not affected by salt concentration which normally exists near the band.

A study of the fertilizer placement on cotton and corn with four soil types was made by Patrick et al. (1959). They recorded in these studies that deep fertilizer placement as well as deep tillage influenced greater root development. In soils with traffic pans this was particularly noticeable in years of low rainfall, when root development was enhanced by deep placement of fertilizer and deep tillage. This enabled plants to withstand the dry months effectively. Oswalt et al. (1959) arrived at a conclusion that the roots of orchardgrass and bluegrass penetrated deeper when nitrogen was applied. Nitrogen increased the diameter of roots. Defoliation resulted in stopping root growth within 24 hours and subsequently decomposition of the roots started within 36 to 48 hours.

Long[1] investigated the depth of rooting and weight of roots of cotton, corn, alfalfa, wheat, soybeans and a clover-grass pasture mixture in some major soil series of Tennessee. The investigations were made at 14 separate locations where the soils varied in more than one character. Among the crops studied, roots of cotton exhibited the least amount of spread and depth of penetration. Roots reached depths of from 18 to 37 inches and produced from 297 to 3,229 pounds per acre of root yields on an oven-dry basis. Fertilizer and lime incorporations to a depth of 30 inches in soils with acid subsoils of low nutrient status resulted in deeper penetration of the root system and better yields of cotton, as contrasted with incorporations in the plow layer only.

With regard to corn, the depth of root penetration ranged from 32 to 46 inches and root yields ranged from 2,046 to 3,023 pounds per acre. Root yields in a dry summer were greater on well-drained soils.

In a trial with corn, cotton and soybean side by side, mature

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1/Unpublished Ph. D. thesis, University of Tennessee, Knoxville, Tennessee. 1958.

corn roots penetrated more than twice as deep as cotton and soybeans. Among the crops studied, roots of alfalfa not only penetrated deeper than any other crop but the root weight was also the highest. The depth of penetration was 7 feet and roots weighed 11,912 pounds per acre in Pembroke silt loam, while on Dickson silt loam the penetration was only 22 inches. Root penetration and root weights in a few soil types have been recorded by the author. No definite correlation could be established between root development and yield of the above ground portion of the plant. A study of the grass-clover pasture mixture indicated that roots of tall fescue attained a depth of 48 inches while roots of Ladino white clover reached not more than 18 inches.

The studies indicated that among all the physical properties studied, available water capacity and aeration of the soil played a predominent part in conditioning the pattern of root development in the crops studied. Long concludes: "While the nutritional status of the soil is an important factor in root development, the data obtained in these studies indicate that the physical system plays a more important role, with moisture content and aeration the dominant factors."

CHAPTER IV

DISCUSSION

The results of the studies in the field have shown that differences in edaphic conditions are accompanied by considerable variation in root development and ultimately the yield of a particular species. From the several investigations it is an established fact that soil factors do play an important part in the pattern in root development exhibited in crop plants. This necessarily indicates that an ecological approach becomes necessary and indispensable whenever plant behavior is studied in relation to the production of cultivated crops. The existing intimacy of contact between soil and plant is so great that soil differences affect the plant in more than one respect such as ability to germinate, vigor, depth of root system, susceptibility to drought and other characteristics.

The fact that the same species shows great variation and diversity of root development in different soils indicates the great influence exerted by the soil factors. The following discussion will indicate that an ecological approach is certain to result in better crop production by evolving and establishing suitable successful varieties and strains of crop plants taking into account soil type and other factors of the environment.

The available soil moisture has a major influence on root development. Soils with high clay contents offer varying amounts of resistance which restrict root development. Mention can be made here that in soils with high water content root hair development is retarded. Obviously heavy and sandy soils vary in their capacity to hold air which modifies the structure of root development. The studies indicate that an increased supply of air to the roots favors a high degree of branching as well as growth in general. As contrasted with this there is good agreement among workers in this field that a high carbon dioxide content of the soil retards root development.

Poor drainage has another influence in altering the root development patterns. Roots of certain species are inactive in July and August when soil moisture happens to be very low, and higher concentrations of salt solutions are inimical to root hair development. Soil structure has been known to influence root development in various ways. In compact soils many crops develop more branched roots, while in open soils tap root development is characteristic. Root strangulation in cotton has been reported in poorly drained and heavy clay soils. The spread of corn roots was much limited in humid soils.

In grasses limited root development and surface spread are often associated with low exchangeable calcium and nitrogen contents. When available phosphorus was limited branching of roots was restricted in grasses. It has been shown that alfalfa roots exhibited greater root penetration in the region of high sodium where calcium and magnesium were present in abundance.

The roots of wheat crop responded well to favorable moisture conditions and high nitrogen content of the soil.

CHAPTER V

SUMMARY

In this paper, a review of the literature on the effect of soil types on the rooting pattern of important crop plants has been made. The edaphic or soil factors, such as structure, water holding capacity, and chemical composition, influence enormously the root characteristics of plants. Owing to the intimacy of contact of the root system with the soil, root development presents an interesting study. The root patterns of corn, cotton, wheat, grasses and legumes, when grown on different soil types, present numerous variations. The different root characteristics of the same species in different soil types suggest that soil type is the guiding factor with regard to root development of crop plants. The root systems of the above crop plants as affected by soil temperature, soil air, water retaining capacity, texture and chemical composition of soils have been discussed.

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