III. PRELIMINARY OBSERVATIONS ON THE DEPTH, SPREAD, AND CHARACTERISTICS OF THE ROOT SYSTEMS OF OUR COMMON GARDEN PLANTS

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Observations on the root systems of garden plants was begun in 1925. These observations were carried out in part as field work in Ecology and in part with home garden work.

Observations have been made on the root development of each of the following plants:

Phaseolus vulgaris	Navy bean
Pisum sativum	Pea
Lycopersicum esculentum	Tomato
Solanum melongena	Egg plant
Capisicum annum	Pepper
Brassica oleraceae (Var. capitata)	Cabbage
Brassica oleraceae (Var. condensa)	Cauliflower
Cucumis pepo (Var. condensa)	Pumpkins Squashes
Cucumis melo (Var. reticulatus)	Mushmelon
Citrullus vulgaris	Watermelon
Allium cepa	Bermuda onions
Allium sativum	Garlic
Allium pirrum	Leek
Hibiscus esculentus	Okra
Rheum Rhaponticum	Rrubarb
Asparagus officinalis	Asparagus
Lactuca sativa	Lettuce
Zea mays (Var. Saccharata)	Sweet corn (Evergreen)

Ordinary garden varieties were planted in the customary manner in a fertile somewhat sandy loam, and root development was correlated with soil and air conditions. Some spread laterally near the surface, others make a general downward growth. Details cannot be given at this time but the depth spread and number of branches in the root system was remarkable. There may

be a strong tap root or no tap root at all. Tender fleshy roots and rootlets are characteristic of some while others are tough and woody. Some have a striking characteristic of developing laterals at right angles to the main root while this feature is not so noticable in other cases. A study of the characteristics of the roots enables one to tell the roots of one plant from the roots of another plant even near the extremity of the roots. The present plans are to continue observations for another year to check the results secured in 1925.

THE ROOT DEVELOPMENT OF GARDEN CROPS

An intensive study of the root system of a large number of native plants and many crop plants has been made. Doubtless the most intensive and thorough studies were made by Weaver and those working with him. In his two books, Root Development in the Grassland, and the Ecological Relation of Roots, he pictures the root development of numerous native species growing in widely separated and distinctly different habitats. Some crop plants were also included but the most notable papers on the root development of crop plants are found in the Development and Activities of Crop Plants, and in Root Behavior and Crop Yield Under Irrigation. Cannon and Ten Eyck and others have also made valuable contributions to our knowledge of roots.

The roots of garden plants have received little or no attention up to the present time. An understanding of the depth spread and character of the root system of a plant is essential to its proper cultivation. The writer has therefore undertaken a study of the root development of the garden root crops. Those selected for the experiment are as follows:

Raphanus sativus	Radish—scarlet turnip
	long scarlet
	icicle
	winter varities.
Brassica rapa	Turnips—flat dutch
Beta vulgaris	Beet—early blood turnip
	Swiss chard
Daucus carota	Carrot
Pastinaca sativa	Parnsips—hollow crown

The soil selected for the observation plots was of sandy nature especially below thirty or thirty-six inches. The surface soil was a dark sandy loam while the subsoil was a reddish brown clay, which varied somewhat being more sandy below. The soil

TABLE I. SUMMARY OF HABITAT FACTORS

	APRIL				MAY				JUNE				JULY	
Average day temperature	65	74	87	73	66	64	76	80	80	82	85	86	85	81
Average night temperatures	51	63	77	68	64	59	72	70	71	73	73	74	75	70
Soil temperature at 18 in.	49	49	51	48	44	45	48	50	52	57	60	65	67	68
Weekly rainfall in inches	1.71	.24	2.2	1.76	.22	4.69	2.6	.63	.48	.81	.00	.25	.00	.00
Weekly evaporation in cc.	175	194	470	141	80	41	119	290	289	316	314	414	420	325
Weekly humidity readings	52	64	58	44	49	68	60	69	70	69	69	64	65	67

the best of shape for planting. The depth and rate of planting was at least of ordinary fertility. The soil was prepared by plowing and harrowing. The seeds were drilled in at the proper depth.

The winter of 1924-25 was warm and dry and in the spring the soil warmed quickly but it had been so thoroughly and deeply dried by the winds and warm weather that it was not in was that ordinarily used in planting these crops. The seeds were planted in April. On April the 8th a good rain moistened the upper layer of soil and started the seeds. Once started the seedlings had rather unfavorable conditions throughout their entire development.

The temperature for the entire period was much above normal. This would not have been unfavorable had the other factors been ideal for growth. Table I shows very warm day and night temperatures for April and June but lower for May. Weather records from the Norman station show that the mean temperature was 6.5 degrees above normal for April, 0.9 degrees below normal for May, and 7.2 degrees above normal for June. The soil temperature was favorable for root development at the average working depth for the entire period (Table I).

The high temperatures were accompanied by a moderately low relative humidity. Excessively low relative humidity was not common. Psychrometer readings made in the field during two years of experimental work seldom gave readings less than 40 per cent. High winds were common and the warm air desiccated the soil and vegetation rapidly. Evaporation rates were recorded by means of Livingstons standardized porous cup atmometers. These records show high evaporation during the entire period, (Table I). There was sufficient rainfall during this period for good growth but much of it fell in torrents on a dry soil and there was no thorough wetting of the soil in the lower depths. There had been no rain in March and little moisture had fallen during the preceding fall and winter. The rainfall for April was 8.7 inches which is 3.3 below normal, while in June it was 1.3 inches which is 2.6 inches below normal. Data of the available moisture in the soil was not secured frequently enough to be of great value and it has not been included in the table. However on the three occassions when samples were taken some water in excess of the hygroscopic coefficient was found at all levels to a depth of seven feet. Th surface soil was moist in the spring but became very dry later. From a depth of 18 to 36 inches the

TABLE II. ROOT DEVELOPMENT IN MAY, 1925

Depth in feet	0 to 1	1 to 2	2 to 3	3 to 4
Long scarlet, Icicle and, White radish	Strong tap root, numerous laterals, 12 to 24 inches long	Tap root branching laterals numerous	Only an occasional root.	
Scarlet turnip radish.	Strong tap root laterals 12 in.	Tap root enters this region but lost in branches.		
Winter radish.	Strong tap root, horizontal laterals 12 inches long.	Distinct tap root but some strong 1 laterals.	A few roots enter this layer.	
Turnip.	Usually no strong laterals	Roots developing strongly, longer than turnip or radish	Some roots penetrate 30 in.	
Beet.	No strong laterals Spread 10 inches.	Layer of root growth.	A few roots found.	
Swiss chard.	Branching with strong laterals 15 inches long.	Some roots penetrate nearly two feet.	Slender roots piercing this layer.	
Carrots.	Lateral spread 10 in abundantly branched	Maximum depth about two feet.		
Parsnips.	Branches 10 in. with few laterals.			

soil was only slightly moist and very compact during the whole period. It was more moist and friable below 36 inches. There was no time during the growing season that the wilted plants did not revive after the heat of the day had passed. This fact indicated the presence of available water.

This combination of high temperature, wind, evaporation, and torrential rainfall several inches below normal occuring when the soil was already dry had a marked influence on the growth of the plants. Growth of the tops and the storage parts was very slow. The feeding roots were well developed. They penetrated especially deeply and branched profusely because of the rather dry condition of the soil. This was to be expected but since plants were not raised under other conditions of moisture it is perhaps speculation.

On May 15-19 when the radishes were of a suitable size for table use the first root examinations were made. Trenches were dug beyond the depth of the root penetration, four inches away from the plants to be excavated. The roots were then studied by carefully picking away the soil from the side of the excavation at the bottom and working carefully upward. In this manner the roots could be excavated with the smallest amount of mutilation. Drawings of the roots were made in the field and later traced in ink.

The radishes had all reached a size that is desirable for table use when the roots were examined. The scarlet turnip radish had a delicate, finely branched system of roots. The tap root gave rise to many finely branched laterals in the first foot layer which thoroughly permeated the soil in the bed. The tap root and many of its branches permeated the second foot of soil filling it fairly well with roots. A few even penetrated into the third foot of soil. The lateral spread was slightly over 12 inches in the first foot, and was less than that in the second foot. Laterals of the second order were largest near the plant, none were present near the tip of the roots. Many of these features are shown in figure II.

The roots of the Long scarlet and Icicle varieties were so nearly alike that they do not require separate discussions. The roots of the Long Scarlet were somewhat more strongly branched. The first foot of soil was well filled with roots and a lateral spread of 18 inches was common. The tap root was strong when it entered the second foot of soil and gave rise to several laterals (4 to 6) to the inch in the upper part of this layer.

Only unbranched laterals penetrated the third foot of soil.

Winter radishes as would be expected had not begun to develop a storage tap root. The slender laterals were red in color except near the tip. The depth and spread was the same as for the scarlet radish.

Turnips by this time had developed 6 or 7 leaves 5-8 inches long and the tap root was just beginning to store food. The turnip roots gave rise to many slender laterals and permeated the first foot of soil thoroughly. There was a lateral spread of 15 inches. The turnip roots were larger in diameter than the radish roots. The tap root penetrated the second foot and occasionally some roots reached a depth of 30 inches.

Beets had developed slowly up to this time. The tops were not over six inches high and the plants were not vigorous in appearance. The tap root was less than five inches in diameter near the surface of the ground. The lateral roots were red in color except at the tip and were more fleshy than the turnip roots. They were more easily broken than the turnip roots and it was difficult to get unbroken roots out of heavy soil. Roots were developing rapidly in the second foot and a few penetrated the third foot. The maximum spread of 10 inches was in the first foot.

Swiss chard had developed in much the same manner and about the same rate as the beets. The root gave rise to 3-6 strong laterals in the first foot of soil and the tap roots were not much stronger than the side branches. The white delicate roots filled the first foot of soil and spread 15 inches to the side. Roots were developing rapidly in the second foot but many pierced the third foot layer.

Carrots and parsnips had developed very slowly, the roots were not abundantly branched. A lateral spread of ten inches was observed while a penetration of only 20 inches was found.

From May 19 to July 1 the plants grew more rapidly and on this date all had attained a size suitable for use with the exception of the parsnip. Excavations were begun on July 1, but it was not until July 15 that it was completed and the plates and tables indicate the development at this later date.

After the roots had penetrated 30 inches they entered a moist and somewhat more sandy soil in which the roots developed vigorously.

Turnips weer found to have a strong tap root which was followed to a depth of 34 inches. Beyond this depth it could be

TABLE III. SUMMARY OF THE ROOT DEVELOPMENT OF MATURE CROPS

Depth	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6
Turnips	Tap strong laterals 1 to 2 feet long.	Strong tap laterals 2 to 3 feet	Distinct tap root lost in its branches 34 inches.	Downward penetrating branches, few laterals.	A few unbranched roots.	
Beets	Tap usually strong, laterals numerous spread 36 inches	Numerous laterals from strong tap, 24 inches.	Tap root usually about 36 inches	Laterals branching and filling the soil about 1mm. in diameter	Soil not completely filled, red pigment in roots.	A few unbranched roots.
Swiss chard	Many strong laterals, many finely divided branches, 36 inches.	Many strong laterals and branches.	Tap root lost in branches.	Soil filled with branche 1mm. in diameter.	A few delicate roots.	Only unbranched roots.
Winter Radishes	Numerous slender laterals.	Strong tap good sized laterals spread 36 in.	Roots 1mm. in diameter seven laterals per inch.	No prominen tap root red color and hot taste	Roots very slender few laterals 5mm. in diameter.	A few slender roots.
Carrots	Strong tap root. laterals one half to 2.5 feet long.	Strong tap medium size laterals. Numerous.	Tap root distinguishable to 36 in.	Very delicate laterals.	Roots not so abundant laterals short.	Not many roots in this layer.
Parsnips	Some fair sized branches common. spread 24 in.	Many strong laterals spread 36 in.	Strong tap well developed laterals 15 per inch.	Soil well filled with roots.	Roots common not many laterals	Some roots in this layer.

traced to a depth of four feet or more but it no longer had the appearance of a tap root. Well branched laterals filled the first three feet of the soil and spread to the side as much as 36 inches. In the fourth foot most of the roots were working generally downward in the direction of growth and few laterals had developed. An occassional root was noticed in the fifth foot. Figure IV shows the root system of a mature turnip.

The beet was found to have a distinct tap root 36 inches long, a lateral spread of 36 inches in the first foot, and 24 in the second foot. The soil was filled with branching rootlets 1 mm. in diameter to a depth of four feet. In the fifth foot the soil was not so well filled with roots, and the laterals had only begun to develop, and an occasional root was found in the 6th foot. The depth spread, and branching of the root systems is shown in figure I.

The roots of the swiss chard were very similar to those of the beet in depth and spread, and in the size of the rootlets. They were strong and white in color and easily distinguished from those of the beet. The root is a branching tap root, and strong branches given off in the first foot of the soil.

The winter radish had numerous slender laterals in the first foot and stronger laterals in the second foot. The lateral spread was 22 inches and a distinct tap root penetrated the soil to a depth of three feet. The first four feet of soil contained numerous rootlets 1 mm. to 5mm. in diameter. The fifth foot contained only roots with short branches or no branches at all, while a few slender rootlets entered the sixth foot.

Carrots were found to have a lateral spread of 2.5 feet and a tap root that was distinct in the third foot. The main roots were yellowish in color but the slender laterals contained no pigment. The first two feet were well filled with roots. The fifth foot did not contain many roots and most of these were unbranched. A drawing of the carrot root system is shown in figure III.

Parsnip roots were characteirzed by having a strong tap root which maintained its diameter to a greater depth than any of the other root systems. A strong tap root penetrating 36 inches was common in well developed plants. Strong branches were not uncommon in the first foot. These branches turned downward and penetrated the soil to a depth about equal to that of the tap root. Smaller laterals in the first foot spread to a distance of 24 inches going off 10 to 12 laterals to the inch. The soil was filled with roots to a depth of four feet and root development

was progressing in the fifth foot. The parsnip color was present in the fourth foot. It occurred in all roots having well developed laterals.

Roots of the common garden root crops have a lateral spread varying from 15 to 36 inches and a maximum depth of 30 inches to nearly six feet. The smaller, shorter lived, plants had the least extensive root systems. The main root, and the rootlets as well, vary in size, color, texture, and method of branching. The root characters of the different plants are quite as distinctive as the characters of the above ground parts and in some cases more so.

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PLATE I.

Fig. I. Drawing of the root system of a mature beet.

Fig. II. Drawing of the root system of a scarlet turnip radish on May 15, 1925, when the radishes were of a size suitable for use. The squares indicate feet.

Fig. III. Drawing of the root system of a mature carrot.

Fig. IV. A drawing of the root system of a turnip, showing depth and spread in feet and manner of branching.

Fig. V. Turnip roots spread upon a glass showing root development on May 15, 1925. The extensiveness and number of branches in proportion to the size of the top is shown. The roots are not quite in their proper positions.

PLATE I

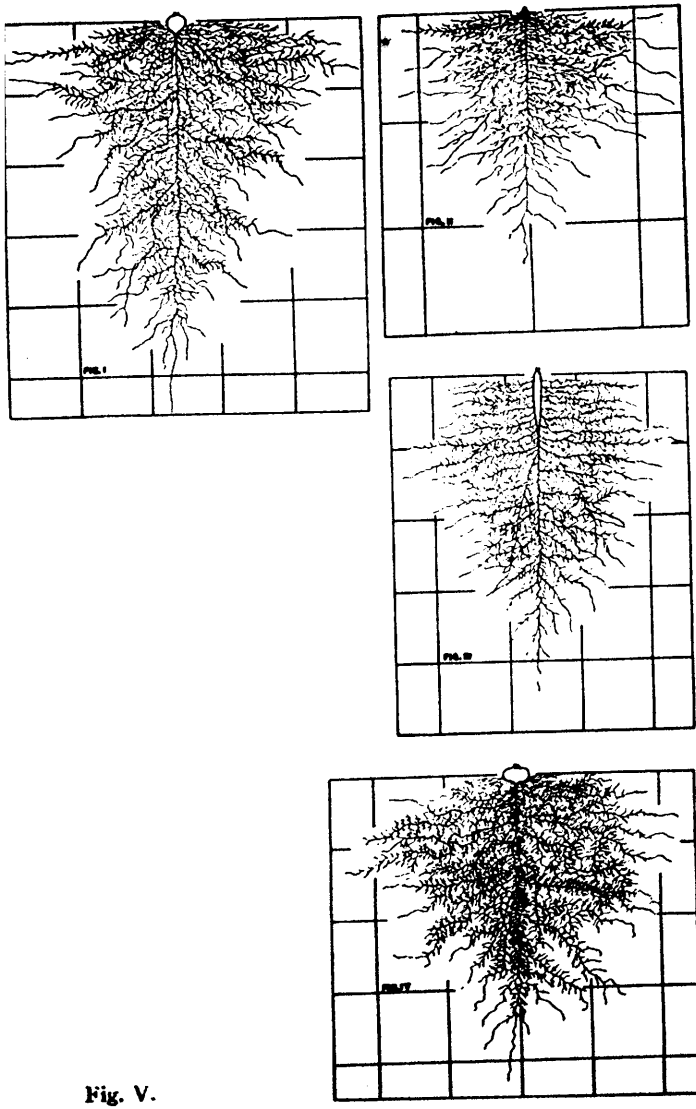

Fig. V.