VARIATIONS IN THE ROOT SYSTEM OF THE COMMON EVERLASTING (GNAPHALIUM POLYCEPHALUM).

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It has been observed that the root system of the common everlasting (Gnaphalium polycephalum) has a different behavior when it is grown in different habitats. On well-drained, sloping areas the roots show positive geotropism, that is they grow down, while on poorly drained flat areas the roots show plagiotropism or diageotropism, that is they turn at right angles.

The sloping areas from which the roots were collected were well-drained and consequently well aerated; the flats were either clearings or meadows of the uplands and consequently undrained. In these flats the water table was not far from the surface in late fall, winter, and spring (1). The soil was largely Cincinnati silt loam and Clermont silt loam. The Cincinnati silt loam consists of eight to twelve inches of grayish yellow or light yellowish brown silt loam, having a characteristic mealy or velvety feel. This soil plows up readily and is formed by the weathering of loess on rolling uplands along with the aeration of the soil. Clermont silt loam consists of a layer of seven to twelve inches of light gray or nearly white silt loam. When typically developed it is very ashy, and on the flattest, most poorly drained areas iron concretions are frequently scattered over the surface. The subsoil is of an impervious and compact nature. It possesses practically no power of granulation. Clermont silt loam always develops by the weathering of loess on flat uplands, where there is a deficiency of oxygen. The difference between this soil and the Cincinnati silt loam is due entirely to the difference in drainage. Owing to the level character of the surface on which Clermont silt loam is produced and the impervious nature of the subsoil, natural drainage is very deficient. Hence, there is often found water standing on the surface and this prevents aeration. As a result, humic acid is produced and there is the precipitation of lime, iron, and phosphorus of the soil. Since the soil is limestone, this results in acid on limestone soil (4). The flatness together with the fine impervious soil make the flats very wet. Along with the excess of water in the soil there is a deficiency of oxygen. Therefore, it is probable that the poor drainage together with the deficiency of oxygen caused the everlasting roots growing on flats to turn. It has been reported (5) that roots show aerotropism, that is, when oxygen diffuses against young roots from one side, the root curves toward the source of the gas.

The everlasting is a winter annual. The seeds germinate very soon after ripening in late fall. The rosettes remain through the winter and spring. In the summer the tall stalks and the flowers of the plants develop. The development of the root system precedes this; therefore the tap root must have developed when the water table was near the surface. The high water table at this time probably accounts for the turning of the roots. The factors which determine the turning of the roots may be an excess of water, deficiency of oxygen, or both. A secondary factor resulting from these two may be soil acidity.

SOIL REACTIONS.

Two hundred and twenty-two roots from various areas—steep slopes, gentle slopes, even flats, and irregular flats, or flats made irregular because they had been plowed at some time—were collected in the late fall after growth had been completed. These roots were observed and placed in one of three classes: I, roots showing positive geotropism; II, roots showing diageotropism; III, roots showing less pronounced diageotropism.

In order to determine whether soil reaction is a factor in deciding direction of root growth, at the time the roots were collected, soil samples were taken from above and below the point of turning if the root turned, or at the top and bottom of the root system if the root did not turn. Later the specific acidity or alkalinity of the soils were determined according to the Wherry field method (6). The results of the observations are given below:

I. Roots Showing Positive Geotropism. (Fig. 1).

Number	Nature of Area	Reaction at Top	Reaction at Bottom
21	gentle slope	neutral	neutral
15	gentle slope	neutral	sp. acid. 30+
9	gentle slope	sp. alk. 3+	neutral
3	gentle slope	sp. acid. 3+	sp. acid. 3+
16	steep slope	neutral	neutral
16	steep slope	sp. acid. 30+	sp. acid. 30+
1	even flat	sp. acid. 10+	sp. acid. 10+

Of the eighty-one roots showing positive geotropism, eighty of these grew on slopes and one on an even flat. Of these eighty, thirty-two grew on steep slopes (two areas) and forty-eight on more gentle slopes (seven areas). The slopes were well-drained and consequently well aerated.

At the top of the root systems the conditions varied from specific alkalinity 3+ to specific acidity 30+. At the bottom the conditions varied from neutral to specific acidity 30+. From these data it can be seen that there was no relation between the soil reaction and the fact that the roots grew down. Positive geotropism is not due to the specific alkalinity or acidity of the soil.

II. Roots Showing Diageotropism. (Fig. 2).

Number	Nature of Area	Reaction Above Turn	Reaction Below Turn
32	even flat	neutral	neutral
7	even flat	neutral	sp. alk. 10+
7	even flat	sp. alk. 10+	sp. alk. 10+
4	even flat	sp. acid. 10+	sp. acid. 10+
12	even flat	sp. acid. 30+	sp. acid. 30+
6	even flat	sp. acid. 100+	sp. acid. 100+
7	irregular flat	neutral	sp. acid. 30+
6	slope	neutral	sp. acid. 3+

Of the eighty-one roots that showed diageotropism, seventy-five grew on poorly drained flats and six on a slope. Of these seventy-five, sixty-eight grew on even flats (nine areas) and seven on an irregular flat. The slope on which the six roots grew was the extreme base of a steeper slope, and hence almost a flat. Therefore, the water table was not far from the surface.

III. Roots Showing Less Pronounced Diageotropism. (Fig. 3).

Number	Nature of Area	Reaction Above Turn	Reaction Below Turn
10	even flat	neutral	neutral
1	even flat	neutral	sp. alk. 3—
4	even flat	sp. alk. 10+	sp. alk. 10+
5	even flat	sp. acid. 10+	sp. acid. 10+
5	even flat	sp. acid. 30+	sp. acid. 30+
6	even flat	sp. acid. 100+	sp. acid. 100+
3	irregular flat	neutral	sp. acid. 30+
6	gentle slope	neutral	neutral
7	gentle slope	neutral	sp. acid. 3+
9	gentle slope	neutral	sp. acid. 30+
4	steep slope	neutral	neutral

Above the turn of the roots, the conditions varied from specific alkalinity 10+ to specific acidity 100+. Below the turn, the conditions varied from specific alkalinity 10+ to specific acidity 100+. As there is such wide variation in soil reactions, it seems evident that diotropism is not due to the specific alkalinity or acidity of the soil.

Of the sixty roots that showed less pronounced diageotropism, thirty-four grew on flats and twenty-six on slopes. Of these thirty-four on flats, thirty-one were found on even flats (nine areas) and three on an irregular flat. Of the twenty-six on slopes, twenty-two grew on very gentle slopes (five areas) and four on a steep slope. The slopes were gentle, with the exception of one, so that in them the water tables were not far from the surface, though lower than on the flats.

Above the turn of the roots, the conditions varied from specific alkalinity 10+ to specific acidity 100+. Below the turn, the conditions varied from specific alkalinity 3+ to specific acidity 100+. Hence, as before, there is no relation between soil reaction and diageotropism.

EXPERIMENTAL GROWING OF SEEDLINGS.

From field observations on the root systems of the common everlasting, it was not possible to determine whether diageotropism of roots in poorly drained areas was due to an excess of water in the soil, to a deficiency of oxygen, or to both. The growing of seedlings under controlled conditions in the laboratory was undertaken in order to separate these two factors.

It proved to be unsatisfactory to grow seedlings of the everlasting because of the extremely small size of the young plants, and also because the short period of viability made it impossible to make consecutive plantings. For this reason, a number of other plants were substituted. These were sunflower, Helianthus annuus, chosen because of its rapid growth and therefore short observation period; three varieties of tomato, Globe Tomato, Chalk's Early Jewel Tomato, and Trucker's Favorite Tomato, chosen because the tomato is one of the important truck crops of the undrained upland flats; and Bidens aristosa, a plant abundant in some of the upland flats (2).

Seedlings of these plants were grown under three conditions: I, in well-drained soil; II, in soil with excess of water; III, in soil with excess of water, into which air was introduced. In all cases the soil used showed a specific alkalinity of 10+.

I. Plants grown in well drained soil.

(Figs. 4–5.)

Seeds were planted about one inch deep in ordinary flower pots and germinating boxes which were supplied with good bottom drainage and kept only moist enough to insure germination and prevent wilting. The results were as follows:

TABLE SHOWING CHARACTER OF ROOT GROWTH IN WELL-DRAINED SOIL.

Name of plant	No. days to appear above ground	Days in soil after above ground	No. of plants examined	Character of root-growth
Pot 1 Sunflower	4	8	6	Down, few short laterals
Pot 2 Sunflower	4	10	3	Down, almost no laterals. (Fig. 4)
Pot 3 Sunflower	4	10	5	Down, three plants: numerous long laterals; two plants: short roots and few short laterals
Pot 4 Sunflower	6	8	5	Down, numerous long laterals
Pot 5 Sunflower	6	8	4	Down, numerous long laterals
Pot 6 Sunflower	7	19	6	Down, numerous long laterals (Fig. 5)
Pot 7 Globe Tomato	13	8	6	Down; single tap; no laterals
Pot 8 Trucker's Favorite Tomato	15	34	15	Down, single tap root
Pot 9 Bidens aristosa	15	36	6	Down, fine roots
Pot 10 Chalk's Early Jewel Tomato	15	41	18	Down; long tap root, few laterals

Seventy-four plants were removed from the pots and examined. The roots of all of them showed positive geotropism, (Figs. 4–5). Of these seventy-four roots, twenty-nine were sunflowers, thirty-nine were tomatoes (6 Globe, 15 Trucker's, 18 Chalk's Early Jewel Tomatoes), and six were Bidens aristosa. Of the twenty-nine sunflowers, eleven had few or no laterals, (Fig. 4), while eighteen had numerous long laterals, (Fig. 5). Of the thirty-nine tomatoes, the six Globe and the fifteen Trucker's Tomatoes had single tap roots, and the eighteen Chalk's Early Jewel Tomatoes had long tap roots and few laterals; the six Bidens aristosa had few laterals. There was no change in soil reaction during the growth of the plants. From these results, the conclusion is drawn that plants grown in well-drained soil develop positively geotropic single tap roots with comparatively few or no laterals.

II. Plants grown in soil with excess of water.

(Fig. 6.)

Seeds of the same kinds as were planted in well-drained pots in Group I were planted in pots which were placed in a large pan filled with water having a constant level. Thus a high water table one and one-half inches below the soil surface was produced. Water was constantly flowing out through an overflow. The results are shown in table on following page.

Thirty-two plants were removed from the pots and examined. All the roots showed diageotropism, turning at the water level, (Fig. 6). Of these thirty-two roots, seventeen were sunflowers, twelve were tomatoes (eight Globe, two Trucker's, two Chalk's Early Jewel Tomatoes) and three were Biden's aristosa. The seventeen sunflowers (Fig. 6) had numerous, long laterals, while the three kinds of tomatoes and Bidens aristosa developed tap roots with no laterals. There was no change in soil reaction during the growth of the plants. It has been found by other workers (3) that Helianthus plants undergo a retardation in growth in length of their main roots when cultivated in water. In the case of the plants grown under poor drainage conditions, there are two factors involved that might have caused the roots to turn: First, excess of water, and second, lack of oxygen.

TABLE SHOWING CHARACTER OF ROOT GROWTH IN SOIL WITH EXCESS OF WATER.

Name of plant	No of days to appear above ground	Days in soil after above ground	No. of plants examined	Character of root-growth
Pot 1 Sunflower	7	5	2	Tap root turns at right angles; numerous long laterals (Fig. 6)
Pot 2 Sunflower	7	7	3	Turn, numerous long laterals
Pot 3 Sunflower	4	10	3	Turn, numerous long laterals
Pot 4 Sunflower	6	8	2	Turn, numerous long laterals
Pot 5 Sunflower	6	8	2	Turn, long laterals
Pot 6 Sunflower	7	19	5	Turn, numerous laterals
Pot 7 Globe Tomato	13	8	8	Turn
Pot 8 Truckers Favorite Tomato	15	34	2	Turn, single tap root; no laterals
Pot 9 Bidens aristosa	20	31	3	Turn
Pot 10 Chalk's Early Jewel Tomato	15	41	2	Turn, poorly developed

III. Plants grown in soil with excess of water, into which air is introduced.

(Fig. 7.)

In order to separate the two factors which may have been responsible for the turning of the roots under poor drainage conditions, seeds were planted under high water table conditions, but air was introduced into the pots. From the air pump there was a hose leading through a paraffined cork into an air-tight bottle. From this vessel, air was conducted to the bottom of each of two pots, by means of rubber tubing connecting with L-shaped tubes, which opened at the bottom of the pot. The open ends of the glass tubes were protected with cheese cloth. Air thus passed upwards through the soil. The two pots and the air container were placed in water and thus a high water table one and one-half inches below the soil surface was produced. The seeds were planted one and one-half inches below the top of the pot and one inch below them was the water table. Thus, the seeds were grown under poor drainage conditions, but did not lack air. The results were as follows:

TABLE SHOWING CHARACTER OF ROOT GROWTH IN SOIL WITH EXCESS WATER INTO WHICH AIR IS INTRODUCED.

Name of plant	No. of days to appear above ground	Days in soil after above ground	No. of plants examined	Character of root-growth
Pot 11 Sunflower	6	8	6	Down, long tap, numerous long laterals (Fig. 7)
Pot 12 Sunflower	6	8	5	Down, numerous long laterals
Pot 13 Sunflower	6	8	6	Down, long tap, long laterals
Pot 14 Sunflower	6	8	6	Down, three plants; long laterals; three plants; short laterals
Pot 15 Chalk's Early Jewel Tomato	18	22	6	Down, single tap, no laterals

Twenty-nine plants were removed, twenty-three of which were sunflowers, and six were Early Jewel Tomatoes. All the roots showed positive geotropism, penetrating the soil below the water level, (Fig. 7). Of the twenty-three sunflowers, twenty had long tap roots and numerous, long laterals, and three had short or no laterals. The Chalk's Early Jewel Tomatoes had single tap roots and no laterals. It has been found by other workers (3) that the rate of growth in roots of Helianthus was faster when atmospheric air was bubbled through a solution.

There was no change in soil reaction during the growth of the plants.

All the roots grown with excess of water and lack of air showed diageotropism; while all the roots grown with excess of water through which air was continuously bubbling showed positive geotropism. Therefore, it was the lack of air in the soil that caused the roots to turn.

The controlled conditions produced in the laboratory were similar to those in the field. The roots of the everlasting growing on well-drained, sloping areas showed positive geotropism. The roots grown under good drainage conditions in the laboratory also showed positive geotropism. The roots of the everlasting growing on poorly drained flats with excess of water in the laboratory also showed diageotropism. In the case of the roots that turned, both in the field and in the laboratory, the conditions of growth were similar. In the field the roots were found on undrained flats. The flatness, together with the fine, impervious clay soil made the flats very wet. Along with the excess of water in the soil there was a deficiency of oxygen. But it has been shown in the laboratory that when air was supplied to soil with an excess of water, the roots did not show diageotropism, but instead showed positive geotropism. Hence we conclude that it was the lack of oxygen in the soil that caused the roots of the common everlasting growing on poorly drained flats to show diageotropism.

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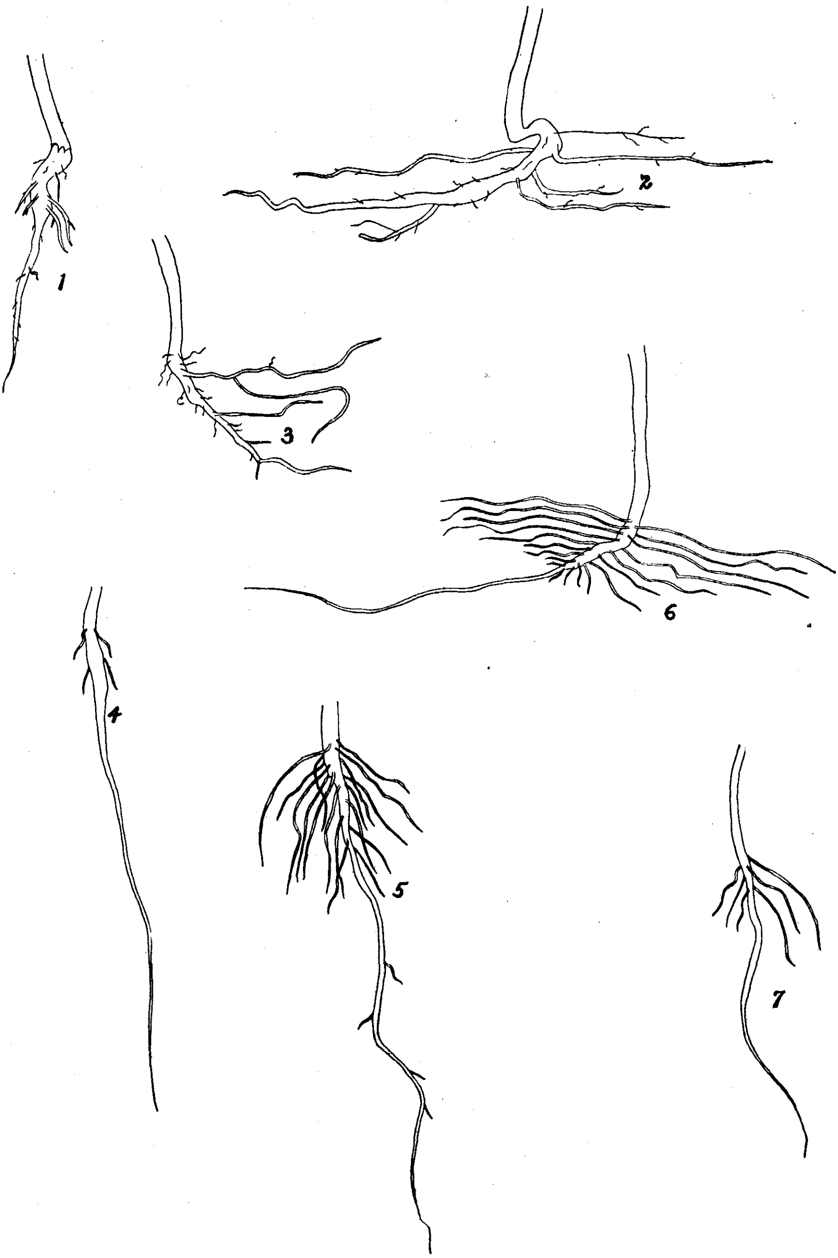

Figure 1. Roots of everlasting showing positive geotropism.
Figure 2. Roots of everlasting showing diageotropism.
Figure 3. Roots of everlasting showing less pronounced diageotropism.
Figures 4–5. Roots of sunflowers grown in well-drained soil show positive geotropism. Fig. 4, Sunflower showing positive geotropism and with few laterals; Fig. 5, Sunflower showing positive geotropism and with long, numerous laterals.
Figure 6. Roots of sunflower grown in soil with excess of water show diageotropism and numerous long laterals.
Figure 7. Roots of sunflowers grown in soil with excess of water into which air is introduced show positive geotropism.