SOIL AERATION

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My crops aren't doing as well as I know they should be. The fertility levels are good; I know this because I have had the soil tested. They are getting enough water and our temperature control is good so these things can't be the problem. But still they are not growing as well as they should be; they lack vigor, when they finish the flowers aren't as large as they should be nor is the stem strength good.

If the foregoing are statements that you have made about a crop or crops at some time or other perhaps you may be overlooking a very important factor necessary for optimum growth of plants and that is soil aeration. The role of good or poor soil aeration in the life of plants is one that is frequently neglected when trying to determine the reasons for poor crop growth. However, it is of great enough importance that commercial flower growers should be more aware of this environmental factor.

Before we can discuss the importance of soil aeration there are some questions that should be answered first. Among these are: 1. How does the soil atmosphere differ from the atmosphere we know as air? What effect does a difference in soil structure or type have on soil aeration? How about the pore space (or the area where air and water is held) of the soil, what is best, many small pores or a few large pores? How can we increase the air capacity of heavy soils or perhaps decrease the air capacity of extremely sandy soils if we should so desire? What effect do soil moisture levels have on aeration? Finally, how does poor aeration affect plant growth? Are the effects direct or indirect, are they large or small?

Perhaps with the answers to these questions plus additional information a better understanding of the importance of soil aeration may be forthcoming.

Composition of the Soil Air

Many research workers have studied the composition of the soil air and depending on the method of measurement, the depth of measurement and many other things a whole host of variable figures have been obtained. To avoid confusion let us use the following figures as representing the average composition of the soil air; the percentages are by volume: N_2=79.2, O_2=20.6 and CO_2=0.25; for atmospheric air the percentages are N_2=79.0; O_2=20.97 and CO_2=0.03. From this comparison it can be seen that the CO_2 content of the soil air is about 6 to 7 times greater than that of the atmosphere. The oxygen content is slightly less than that of the atmosphere.

Factors Affecting Composition

Knowing the make up of the soil air we can discuss the factors affecting its composition. The first factor that should be considered is the properties of the soil itself. The major effects of the soil properties are associated with these factors that increase the air capacity and the air permeability of the soil. They are texture, structure, moisture content and the amount of organic matter present. Granular soils contain less than one half as much carbon dioxide as powdery soils. Loams contain more carbon dioxide than sands, the amount of carbon dioxide increasing with depth. Since we shall be confining our thoughts to the soil depth as found in a greenhouse bench we may discount the effect of depth in itself.

As a general statement it may be said that any soil characteristic that is responsible for a large air capacity, such as a coarse texture or granular structure and which is maintained relatively free of water, usually favors a lower carbon dioxide and a higher oxygen content of the soil air. This relationship is associated with the easy renewal of soil air in soils with large pore spaces. It would be useless to have a soil environment that had a large air capacity initially such as may be found at the time of benching plants following steam sterilization, and then after a few waterings have the conditions for easy air renewal be destroyed. The plants would do well for a short period of time, but very quickly they would begin to lose vigor and die.

The presence of growing plants tends to reduce the oxygen content of the soil air and increase the amount of carbon dioxide. Plants are like humans in that they require oxygen to breath the same as we do. The ordinary respiration activities of the plant cause an intake of oxygen and an outgo of carbon dioxide. Since plants require large amounts of oxygen from the soil air and since carbon dioxide is given off by the roots during plant growth it becomes obvious that adequate aeration is necessary to permit the replacement of accumulated quantities of carbon dioxide around the plant roots.

If the gas exchange between the soil air and the atmosphere is cut off for any reason, the carbon dioxide concentration at a depth of approximately eight inches will double in one and one-half hours and increase 10 times in 14 hours. One investigator determined that approximately two gallons of carbon dioxide were produced per square yard per day. Using this figure we find that for the soil air to maintain its usual average composition there must be a complete renewal of the soil air every hour to a depth of eight inches. Need we point out here the importance of good drainage? A layer of water standing on the surface of the soil is a very effective seal against the renewal of air within the soil.

The diffusion of air into the soil is correlated with the free pore space (total pore space not filled with water). Addition of water to the soil layer cause large decreases in the rate of diffusion. The only controlling soil factor on the rate of diffusion is the free pore space since the nature, texture, granulation and moisture content of the soil materially affect diffusion only as they alter the free pore space. Diffusion is a continuous process only as long as the free pore space does not become zero. Changes in the free pore space may result from compaction or saturation of the pores with water. Compaction of a powdery loam soil reduced diffusion by 40 per cent. The impact of rain drops on a granular well-aerated soil tends to disperse the

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soil particles and cause a compaction of the immediate surface. The same thing may be said for a heavy stream of water from a hose.

In studies of the effect of moisture it was found that moistening sands to 40 per cent of their total water holding capacity resulted in about a 40 per cent decrease in the rate of diffusion. At a saturation of 80 per cent diffusion was practically stopped. The high water holding capacity of fine textured soils restricts the diffusion process considerably under natural conditions. Under the artificial conditions found in the greenhouse this diffusion process would be even more restricted especially if conditions of poor drainage existed.

So far we have discussed only the free pore space, that is the total pore space not filled with water. In a soil containing no moisture, the total pore space will be filled with air. The pores of a moist soil are filled with both water and air. The relative amounts of the air and water present will depend largely upon the size of the pores. Since soil is not a uniform mass it can be readily seen that both large and small pores exist.

The large pores are termed non-capillary pores. These are the ones which will not hold water tightly by capillarity. They are normally filled with air and are responsible for the air capacity and ready percolation of water through the soil. The small pores are known as capillary pores and these are responsible for the water holding capacity of the soil.

For the ideal soil we would normally expect that the pore space should be equally divided between large and small pores and this is true. With such a soil there would be sufficient aeration, permeability and water holding properties. However, our soils are not ideal in this respect.

Clay soils possess a large number of small pores which contribute to a high water holding capacity and slow permeability. When a clay soil is watered it takes a comparatively long time for the water to penetrate, but once the soil is wet it stays wet for a long time. Sands, on the other hand, have a large number of large pores which are responsible for rapid drainage and a low moisture holding capacity. However, there are also differences in sands. In comparing soil types of different textures it was found that coarse sand was 1000 times more permeable to air than fine sand. Thus we can see that the choice of a sand to be added for improving drainage and aeration must be based on whether it is a fine or coarse particle size material. The use of a fine sand may actually be harmful in that it will tend to fill the already existing large pores of the soil and result in reduced drainage and aeration.

The presence of many large pores in sands means they have high non-capillary porosities. Because of this most sandy soils have too much aeration at the expense of an adequate water holding capacity. Clays with their large number of small pores have rather low air capacities.

If the individual clay particles are closely packed together, there are no large pores for aeration. But if the clay soil is well granulated, or we might say, if the individual particles are stuck together in small groups, there will be a sufficient number of large pores between the granules to give an air capacity that will be satisfactory for plant growth.

Should our soil be of the clayey type, there are steps that can be taken to remedy the problem. The air capacity of heavy soils can be increased by the addition of organic matter, cinders or sand. Organic matter additions in the form of crop residues, manure or peat moss would appear to be the most practical means of improving the air relations of clay soil. Additions of organic matter, cinders and sand not only improve the air capacity of the clay soil but increase the drainage capacity.

The addition of organic matter to sandy soils may decrease the air relations somewhat, but the beneficial effects of increased water holding capacity more than offset this disadvantage.

Effects on Plant Growth

Many hundreds of studies have been made on the effects of soil aeration on plant growth. These studies have been carried out in solution cultures, sand cultures and soils with various modified soil atmospheres. The soil atmosphere was modified by the use of carbon dioxide. nitrogen and oxygen gases introduced in various concentrations together or individually. Some investigators have submerged pot plants in water for differing periods of time to observe the effect of reduced oxygen levels on subsequent growth.

Although many specific effects have been noted it is possible to make some general statements about the gross effects of poor aeration on the growth of plants. The first observable effect is usually a wilting of the plant with the condition being noted in the lower leaves first. Should the poor aeration conditions continue the wilting finally occurs over the whole plant. Following wilting the leaves may turn brown or yellow and eventually curl up and drop. The speed with which the wilting occurs depends on the duration of the reduced aeration and the type of plant being grown.

Impatiens in a water-logged soil wilted in two days and in four days was beyond the point of recovery. Geraniums began to wilt in four days and two days later the leaves turned yellow and dropped. A very slight deficiency of oxygen resulted in the death of Coleus plants in two days time.

When the soil is only slightly deficient in oxygen death may not occur but the final result is a plant that has exhibited a reduced growth rate, is small in size compared to one grown with good soil aeration, it has a less vigorous top and a reduced root system.

Seeley, working with various oxygen concentrations in the soil found that roses grown in soils with a reduced oxygen content were retarded in growth and were smaller than those grown with greater concentrations. He states "the foliage color was good and unless compared with other treatment it would have been difficult to determine that these plants were being affected by a lack of sufficient oxygen. This is of utmost practical importance because in the greenhouse the soil oxygen status may be such that growth and flower production is being retarded, but it would be difficult to recognize the cause of retardation."

Miller submerged young potted snapdragon seedlings for various periods of time before benching. Although this condition was only temporary snapdragons that had

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been submerged for as short a period as 12 hours had a reduced fresh weight, less total linear growth and fewer florets produced on the mature plants than those that were not submerged. This short exposure to poor aeration with the subsequent long lasting effects gains added significance when it is realized that the time of submergence represents less than three tenths of one percent of the total growing time of these plants. The crop was grown for approximately five and one-half months from the time of sowing seed until first cut.

The effects on the root system are particularly important since they are not readily discernible to the eye without removing the plant from the media in which it is growing. Growth of the root is generally reduced in size and form. A lack of oxygen results in a limited branching of the root and a great reduction in the number of root hairs produced.

Sunflowers grown in normally aerated soils which were subsequently deprived of oxygen produced new roots after the old roots had died. The anaerobic roots that developed differed from normal roots in being shorter, thicker, less branched and almost completely lacking in root hairs. Thus these plants had made a physiological readjustment to the anaerobic conditions making it possible for continued existence of the plants.

With apple trees root initiation, growth of existing root tips and the absorption and accumulation of nutrients were all suppressed at reduced oxygen levels.

Lack of oxygen has also been shown to seriously affect water absorption and translocation within the plant. An increase in the carbon dioxide content of the soil had a greater effect on the plants in that it reduced water uptake faster than a simple decrease in the oxygen level of the soil.

Poor soil aeration reduces the absorption of transpiring plants not only by decreasing the absorbing surface as a result of death of roots and cessation of plant growth, but also by causing a decrease in the permeability of the roots. A decrease in permeability means that less water can get into the roots to be transported to the upper portions of the plant.

The effect of poor soil aeration on the uptake of nutrients is not one that can be readily attributed to any simple factor. In addition to the reduction in ion uptake caused by a physical change or diminution of the root system such as death of the roots or reduced permeability a more complex process is involved. The absorption and accumulation of ions are dependent on the metabolic processes of the cells which in turn are affected by aerobic or anaerobic conditions. In order to function properly the cells must have a high rate of aerobic respiration. Salt accumulation within the roots demands this.

Where plants are being grown at warm soil temperatures the metabolic processes within the plant are being carried on at a rapid rate. Under cool soil temperature conditions metabolism is not as rapid. From this it can easily be seen that soil aeration must be better under warm soil temperature conditions than cool soil temperature conditions.

Soil Aeration and Plant Diseases

Although poor soil aeration does not increase the incidence of disease in plants it can be said that in the absence of good aeration a weak pathogen that is normally not too harmful may become extremely destructive. The water molds pythium and phytopthora are favored by high soil moisture and lack of soil aeration. The disease attack by these pathogens is greater where poor soil aeration conditions exist. Growers' experience has shown that some root rots can be suppressed or restricted by providing good aeration. This is essentially done by running the plants on the dry side to check the spread of the disease if it once starts. This is not true of Rhizoctonia however. This disease is favored by good aeration and saturation of the affected area restricts its growth.

Summary

As a brief summary we may say that soil aeration is affected by many things. They are: 1. the structure or texture of the soil, whether it be a fine clay or coarse sand; 2. the moisture content of the soil; 3. the amount of total pore space and the distribution of small and large pores; 4. the presence of living plants coupled with the ease of replacement of soil air with atmospheric air; 5. the extent of compaction whether it be from machinery or splattering of rain drops; and 6. the modification of the original soil by the inclusion of organic matter, cinders or sand.

The effects of poor soil aeration on plant growth are generally a reduction in growth followed by death, or merely a general reduction in growth. These conditions are brought about by: 1. A death or reduction of the root system; 2. modification of the root system to one which is less active in its absorbing capacities; 3. the effect of anerobic conditions on the metabolic processes within the plant which in turn affects the absorption and accumulation of ions.

Poor soil aeration improves the environment for plant diseases so that their attacks are much more severe than they would be under good soil aeration conditions.

The effects of poor soil aeration on plant growth may vary in their intensity from severe to what we might call "fringe deficits." Severe effects may be readily discerned by the grower when he sees his plants wilting and dying. When such a condition exists he is stimulated into correcting it at once. With the severe effects there are losses in plants and money which can be seen and are appreciated. The greatest concern of the grower should not be with these effects when he knows something is wrong and corrects it, but with the "fringe deficits." It is with these conditions that the plants look normal, they are growing fairly good and they are producing flowers so the grower is not too concerned. However, the subtle effects of poor aeration are at work reducing the vigor of growth, number of blooms and size of blooms, so instead of getting top quality and production from his crops he gets mediocre quality and reduced production.

There is no easy simple way to determine whether the soil aeration potential is good or poor. Personal knowledge of the soil and the response of plants grown in it are the best sources of information for the grower.

Good soil aeration conditions are to be strived for and where poor soil aeration exists corrective measures should be taken.