# PART I

## AN ACCOUNT OF THE SOIL

### CHAPTER I

### WHAT THE PLANT NEEDS FROM THE SOIL

It is impossible for anyone to know all about any natural object, however simple it may appear. A wheat plant looks at first sight as if it were an easy thing to study, yet in spite of years of work a chemist would have to confess himself unable to give a complete account of the substances it contains, and a botanist would have to admit that much of its structure is unknown to him. And so it is with the soil. Chemists, physicists, geologists, bacteriologists and others have all studied it, but those who have done most would be the first to admit that we really know very little about it, and much still remains to be discovered.

The farmer or the gardener is chiefly interested in soil as the place where his plants grow, and this aspect of the soil, its relation to plant growth, is particularly investigated in agricultural laboratories. Before it can seriously be studied we must first know what the plant requires from the soil: we can then proceed to see how and in what way the soil fulfils these requirements. It is the business of plant physiologists to ascertain plant requirements, and we must therefore start out with the information they have provided.

Six conditions or factors are known to be necessary before the plant will make good growth: the soil must supply a suitable amount of: (1) food, (2) water, and (3) air; (4) it must be at a proper temperature; (5) there must be enough of it to afford adequate root room; (6) it must be free from injurious conditions or pests. What exactly is a suitable amount cannot be stated beforehand but can only be found out by trial; because different plants, and even different varieties of the same plant, have different requirements. Thus an azalea needs all the six conditions and so does a barley plant, but the suitable amount is very different in the two cases. Unfortunately, no way of finding out the suitable amounts has yet been discovered, except actual trial, and this, though it looks straightforward, is really cumbersome and liable to give misleading results.

### LIMITING FACTORS

No one of these six conditions can take the place of any other. If a plant is dying for lack of water it will not recover by receiving more food or more air. A proper supply of all the factors must be maintained, and if any one is insufficient or excessive the plant suffers. It is convenient to use a special name for the condition the insufficiency or excess of which is preventing the plant from making better growth, and to speak of it as the "limiting factor". Thus on a dry chalky soil the water supply is often the limiting factor; if more water is got into the soil a bigger crop will be obtained. In a cold summer the temperature is not infrequently the limiting factor; had the days and nights been warmer the plants would have made more growth. On poor soils the food supply is the limiting factor, and addition of more food in the form of manure will increase the crop. The problem of successful management of soil fertility resolves itself into finding out what is the limiting factor and then correcting it as cheaply and completely as possible. This is easy on paper but often difficult in practice.


Pot No. 47 55 63

Fig. 1. Tomatoes growing on a light sand with varying food supply. Pot 47, without manure. Pot 55, one dose of manure. Pot 63, two doses of the same manure.

Where no limiting factor is operating it frequently happens that if one of the necessary factors is increased in amount there will be an increase in crop growth. This is shown in Fig. 1 illustrating three pots of tomatoes growing in the same soil, sown at the same time and

Plot 3 5 6 7 8
6·7 7·8 12·5 17·6 20·1

Mean yield of grain, cwt. per acre

Fig. 2. Effect of increasing dressings of fertilisers on the yield of wheat, Broadbalk, Rothamsted.

Plot 3. No manure.

Plot 5. Manure complete except for one constituent—nitrogen is omitted.

Plot 6. Complete manure containing 43 lb. nitrogen per acre.

Plot 7. Complete manure containing 86 lb. nitrogen per acre.

Plot 8. Complete manure containing 129 lb. nitrogen per acre.

treated alike in every respect except one. The soil is a very light sand; in one pot there has been no addition of plant food; in the second the crop has received a dose of manure, and in the third it has received a larger dose. A similar result is obtained in the field as shown in Fig. 2; the shortest wheat plant is a representative specimen of the crop on the unmanured land; the next plant shows what happens when an almost but not quite complete manure is added, the really essential constituent being left out; the third shows the marked gain when one dose of complete manure is given; next comes the effect of two doses; and the last shows the effect of three doses. In all cases an increase in the amount of plant food has led to an increase in the crop.

Very similar results are obtained when the water supply is varied. In Fig. 3 are shown tomato plants growing in a good soil, sufficiently and equally manured, and under the same favourable conditions of light, temperature, air, etc. All the conditions, excepting one, are the same for all pots: the water supply only varies. When only little water is given the growth is poor in spite of the presence of food and the favourable temperature and light conditions; when more water is added there is better growth; finally with adequate water supply growth is really good.

### THE LIMIT OF PLANT GROWTH

But growth will not go on indefinitely. A limit is reached sooner or later beyond which the plant will not make any more growth no matter how much food or water is given. Indeed it is easy to overstep the limit and give too much so that the yield actually suffers.


Pot No. 17 19 21 24

Fig. 3. Tomatoes grown in good soil, all equally manured, but receiving different quantities of water.

Pot 17. No water added.
,, 19. 5 per cent added, and the moisture then kept constant.
,, 21. 10 per cent added ,, ,, ,,
,, 24. $12\frac{1}{2}$ per cent added ,, ,, ,,

Pot No. 47 55 63 72 79

Fig. 4. Tomatoes supplied with increasing doses of manure.

Pot. 47. No manure.
Pots 55 to 79. Increasing dressings of manure. This increases the amount of growth and of fruit up to pot 72 but it depresses yield of fruit in pot 79 where too much is given. The middle pot, 63, is best for fruit.

This has happened in the experiment recorded in Fig. 4. Here, as in Fig. 1, tomatoes are shown growing in soils provided with different amounts of manure. The first and second doses of manure resulted in an increased crop: the third dose caused no further increase: while the fourth actually caused a decrease, the excess of food now acting as an injurious substance. This is well seen also in pots 27 and 36, Fig. 5 (top row). The lodging of wheat through excess of nitrogenous manure is another example.

The limit reached in any particular instance, however, is not necessarily the best growth that can be obtained. It may be set by the insufficiency of water, of temperature, etc. Fig. 5 shows in the upper part a set of tomato plants supplied with successively increasing amounts of manure and 5 per cent of water; in the middle a set supplied with the same amounts of manure and 10 per cent of water; and in the lower part a third set also receiving the same quantities of manure but 12·5 per cent of water—this being as much as the soil would hold. The limit of growth reached in the first case is clearly due to a deficiency of water, for it is raised considerably when more water is added. But a still further increase in the supply of water does not lead to more growth, the limit being now set by something else. It is possible that by increasing the temperature or the root room we could get more growth out of this last series, but the process comes to an end before long and the final limit is set by the sheer inability of the plant to grow any bigger. If larger crops are wanted it becomes necessary to try some bigger yielding variety, i.e. some plant with more power of growth.

Pot No. 3 11 20 27 36

5 per cent water.

Pot No. 5 13 21 30 38

10 per cent water.

Pot No. 7 15 24 32 39

12½ per cent water.

Fig. 5. Tomatoes grown in soil receiving successively increasing doses of manure in pots passing from left to right. Pots 3, 5, 7, no manure; pots 36, 38, 39, ten doses manure.

Top row: moisture maintained at 5 per cent.
Middle row: ,, ,, 10 ,,
Bottom row: ,, ,, 12½ ,,

All these results are shown in the curves of Fig. 6. But there is something more than actual weight. The student who carries out the experiment will observe that some of the plants differ very much in appearance and agricultural or horticultural value even when their weights are not unlike. Between pots 3 and 7 (Fig. 5), for instance, there are great differences in appearance and habit of growth. Pot 3 (5 per cent of water and

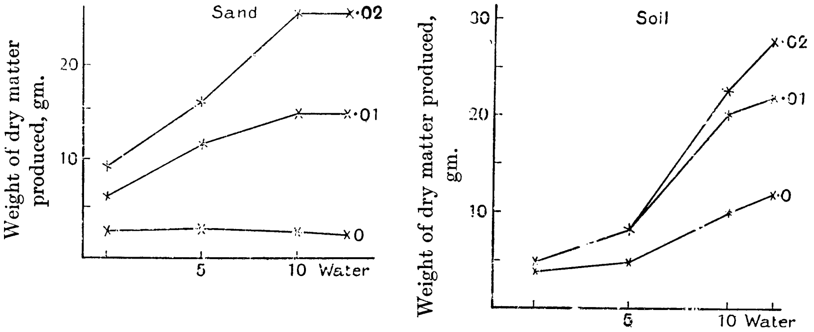


Fig. 6. Curves showing weights of crop produced with varying supplies of water and 0, 0·01 and 0·02 g. of nitrate of soda per pot.

no nitrate) contains sturdy plants capable of great development if transplanted into more favourable conditions, while pot 7 ($12\frac{1}{2}$ per cent water and no nitrate) contains "leggy" plants that would never be of any value. Similarly the wetness of the soil affects the root development: in a dry soil there is more root than in a wet one: von Seelhorst showed that barley growing in a soil watered only to half its full water-holding capacity produced twice as much root as when the water was maintained at three-quarters the full capacity.

Another important result of differences in moisture content is the effect on ripening of cereal crops. In very dry conditions cereals ripen early and the grain may be small and shrivelled: in good moist conditions ripening is much better, especially if the water supply is reduced at the end: but in continuous wet conditions it is delayed: less grain is formed and more straw. This is well shown by growing barley in place of tomatoes in the experiment shown in Fig. 5. The experiment was made many years ago by a German agriculturist Hellriegel, and the results are plotted in Fig. 7. With no water supply there was no growth: with low supply there was a little but not much; as the water supply increased the plant growth increased also. But the grain increased more than the straw: the weight per corn went up also. Then came the turning point: beyond about 40 per cent of saturation less grain was formed. The straw, however, still continued to increase, but when the water exceeded 60 per cent of saturation that also began to suffer.

These qualitative differences are highly important from the practical point of view but they are much more difficult to investigate than mere changes in weight.

From these and similar experiments we may deduce three general principles of the highest importance in the study of soil fertility:

(1) Six separate soil factors are necessary for the successful growth of the plant: there must be an adequate supply of food, water, air, a suitable temperature, sufficient root room and an absence of harmful substances. If any of these conditions is not complied with the plant fails to grow well: the lacking condition is called the *limiting factor*, and it must be supplied before further growth takes place.