Organic Plant Poisons.

II. Phenols.

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With eighteen Figures in the Text.

THE phenols form a group of organic compounds that suggest possibilities with regard to the partial sterilization of soils. On this account experiments have been carried out to gain some idea of the action of these substances on the plant itself, apart from the partial sterilization effects which occur in treated soils. In soil culture the action is largely, if not chiefly, indirect, by way of the increase of the available food supply; this indirect action is usually so strongly marked that any direct action, whether beneficial or adverse, is masked. In water cultures the partial sterilization effect is absent on account of the lack of available organisms in the shape of protozoa and bacteria, so that the direct action of the phenol on the plant may be observed.

The whole series of experiments were carried out systematically on parallel lines, to admit of comparisons between the action of one phenol and another. The solutions in each case were made up on the basis of the molecular weights of the poisons, the strongest solution in each case containing M/100 grammes per litre, each of the succeeding strengths being one-fifth of that preceding—i.e. $M/100 \times \frac{1}{5}$, $M/100 \times \frac{1}{5^2}$, . . . $M/100 \times \frac{1}{5^6}$ —all being matched against controls receiving no poison. In most cases the usual Rothamsted solution was used, but occasionally comparisons were made with results from a weak nutrient solution.

<i>Strong nutrients (Rothamsted solution).</i>					<i>Weak nutrients.</i>
					gram.
Potassium nitrate				1.0	0.2
Sodium nitrate				—	0.5
Magnesium sulphate				0.5	0.1
Calcium sulphate				0.5	0.1
Potassium di-hydrogen phosphate				0.5	0.1
Sodium chloride				0.5	0.1
Ferric chloride				0.04	0.04
Distilled water, to make up				1 litre	1 litre

Phenol.

Parallel sets of peas were grown with strong and weak nutrients (Sept. 24 to Dec. 5). M/100 proved to be a virulent poison. Within two days of insertion the parts of the roots above the solutions were all utterly shrivelled, whereas within the solution they were very white, rather swollen, and flabby, with a most unnatural appearance. The

shoots seemed to live on for some time longer, though probably this was merely an external appearance of vitality. They remained green for a fortnight in the weak nutrients and for nearly three weeks in the strong. The phenol exerted an antiseptic action for some long time, in spite of the death of the roots, but at last moulds began to form on the surface of the solutions.

With a lower concentration, $M/100 \times \frac{1}{5}$, the difference in the action of the poison in strong and weak nutrients was evident from the first. With the strong nutrients root growth was apparently quite normal for the first few days, after which it was very much hindered, though no constriction

FIG. 1. Average dry weights of ten series of pea plants grown in strong nutrient solutions in the presence of differing amounts of phenol. Sept. 24-Dec. 5, 1914.

FIG. 2. Average dry weights of ten series of pea plants grown in weak nutrient solutions in the presence of differing amounts of phenol. Sept. 24-Dec. 5, 1914.

or unnatural coloration of roots was manifest. With weak nutrients, on the contrary, the roots showed an inclination to be constricted and pink in colour near the tips within two days, the tips themselves being dead white and somewhat swollen. Later on, in both sets the shoots became very weak and the roots bunched owing to the belated formation above water of laterals which showed great reluctance to enter the solutions. After about six weeks the roots began to elongate, but the start into activity occurred some days earlier in the strong nutrients, the ultimate improvement in the type of root being much more marked.

With the next concentration, $M/100 \times 1/5^2$, all the plants started off in a similar way, with shoots much like those of the control plants and roots of a normal type; gradually there was a falling off in the rate of growth. After about three weeks the difference between the sets was more manifest.

The plants in strong nutrients continued to grow in a normal way, forming laterals within the solutions. Those in weak solutions, on the other hand, again formed numerous laterals bunched together above the surface of the solutions, which did not proceed to elongate and enter the water for several days or a fortnight. It is very noteworthy that, in spite of the striking difference in the development of the roots, the ultimate dry weights in each case did not fall very much below the weights of the respective controls, though far greater differences were shown by the shoots.

With all concentrations below the last described the growth of the plants compared very favourably with that of the controls all the way through; there was no abnormality in development or colour, and the dry weights proved to be fairly uniform, giving no signs of stimulation.

A comparison of the dry-weight curves shows that with every concentration, from the least to the greatest, the growth of the plants in strong nutrients was uniformly better than in weak, the curves running fairly parallel. The earlier recovery of the roots in strong nutrients is an instance of the masking action exercised by food salts on the action of a toxic substance, as has been seen with inorganic poisons.¹ It is probable that the phenol is gradually decomposed by oxidation, thereby getting less in quantity, and that the extra energy generated by the more liberal food supply in strong nutrients enabled the roots to overcome the inhibiting action before as much decomposition had occurred as was necessary with weak nutrients.

In another series carried out later in the year (Oct. 15 to Jan. 30) with strong nutrients the toxicity of the higher concentrations of phenol was rather greater than in the previous experiment. This was shown by the abnormal and delayed root growth being developed with less poison, and was probably due to the fact that the vitality of the plants is lower in the depth of winter, so that they had not so much energy to withstand the poison. When once a fair start was made, however, the ultimate recovery was quite good.

An initial series of barley with phenol was grown early in the year—March 5 to April 17. M/100 proved instantly fatal. The day after the plants were started the roots were very translucent and rapidly became flaccid. The shoots kept their green colour for a time without making the least growth, but after ten days they turned an unhealthy yellow brown colour and rapidly died off. M/100 $\times \frac{1}{5}$ permitted a little shoot development, but no root growth took place for a month, and the roots were brownish. By this time the shoots were very small, variable, with the base of the stems deep purple-red in colour—a sure sign of starvation, due in this case to insufficient nutriment being taken by the roots in the midst of plenty. At length the roots began to grow a little; they became bunchy above the solutions without entering, and they maintained this attitude to the end of the experiment, refusing to put out long laterals into the solutions. The

¹ Brenchley, W. E.: *Inorganic Plant Poisons*, 1914, p. 20.

start into activity of root growth was sharply reflected by the shoots, which improved greatly and lost some of their purple colour, though they remained small to the end.

With the next strength, $M/100 \times 1/5^2$, a considerable initial check was evident, the roots being pinkish in colour. In about a fortnight the roots reached the bunchy stage, and after that rapidly improved, sending out long laterals into the solutions and eventually becoming almost normal in type. The effect of the initial check was visible in the brown discoloration which remained in the older part of the root, and also in the depressed dry weight.

Growth steadily improved as the concentration decreased. There is just a hint of a possible stimulation of growth with $M/100 \times 1/5^3$, as the plants are very considerably above the controls in weight. A similar result was obtained with another series later in the year; but there is not sufficient evidence to justify more than a suggestion that some stimulation may possibly occur at this point, *provided the nutrient solutions remain unchanged* throughout the course of the experiment. The rise does *not* occur if the solutions, and with them the supply of phenol, are renewed.

In order to test the hypothesis that the decomposition or oxidation of the poison affects the plant recovery in the higher concentrations, three parallel sets of barley were grown:

- (1) Solutions never changed (Fig. 3).
- (2) Solutions changed once during the experiment (Fig. 4).
- (3) Solutions changed twice during the experiment (Fig. 5).

FIG. 3. Average dry weights of ten series of barley plants grown in strong nutrient solutions in the presence of differing amounts of phenol. Solutions never changed. April 27–June 15, 1915.

FIG. 4. Average dry weights of ten series of barley plants grown in strong nutrient solutions in the presence of differing amounts of phenol. Solutions changed every three weeks. April 27-June 15, 1915.

FIG. 5. Average dry weights of ten series of barley plants grown in strong nutrient solutions in the presence of differing amounts of phenol. Solutions changed every two weeks. April 27-June 15, 1915.

With the controls and with the lower strengths in which the phenol had apparently reached its indifferent point the growth of the barley was much better when the solutions were renewed than when they were never changed. This is in accordance with other work and is independent of the concentration of the nutrient solution.¹ With the higher strengths of phenol, which are toxic, increase of growth did not run parallel with renewal of food solution; but, on the contrary, the actual growth as shown by the dry weight was in inverse ratio to the frequency of renewal.

TABLE I.
Dry Weights of Barley Plants. Mean of ten Plants.

	<i>Sols. never changed.</i> <i>grm.</i>	<i>Sols. changed once.</i> <i>grm.</i>	<i>Sols. changed twice.</i> <i>grm.</i>
M/100 × 1/5	0.525	0.150	0.117
M/100 × 1/5 ²	1.910	1.651	0.871

The figures in Table I show very clearly that root recovery and the ultimate improvement of growth are associated with the decomposition of the poison. With M/100 × 1/5 the decomposition had not proceeded far enough in any case to allow the inhibitory toxic factor to be more than counterbalanced by the inherent vitality of the root. Consequently root recovery could not begin to set in before a fresh supply of phenol was presented to the plant, even when the solution was only changed once. When no renewal was made the roots were able to make some amount of recovery, but the strength of the poison was so great that this was comparatively slight.

With M/100 × 1/5², on the other hand, the decomposition of the poison was counterbalanced at an earlier date by the plant's vitality, so that root recovery set in before the renewal, when the solutions were only changed once. When growth had made a fair start the plants were more resistant to the action of the fresh supply of phenol, so that the ultimate growth was not so very far behind that of the plants with which no renewal had been made. When the solutions were changed more frequently, root recovery was still in abeyance or had only just begun when a fresh supply of poison was presented, consequently recovery was thrown back considerably, and though the roots proceeded slowly to form new laterals a further check took place with the second renewal, and the ultimate growth was much less than that of all the other plants, in which the solutions were changed once or not at all. By the time of cutting the plants had apparently got a grip on life, and judging by their appearance it is possible that if they could have been grown on longer they might have made up their deficiency at a more rapid rate. It seems that when once growth is fairly under way and vigorous, the plants can cope with a strength of poison which is most deleterious at an earlier stage of development.

¹ Brenchley, W. E. : Ann. of Bot., vol. xxx, pp. 77-90.

Cresol.

Very little seems to be known about the occurrence of the cresols in the Vegetable Kingdom, nor of their effect on plant life. Wehmer¹ states that the flowers of *Acacia Farnesiana* yield *p*-cresol, and that certain members of the family Burseraceae contain *m*-cresol. The three cresols are

$$I = \frac{M}{100} \times \frac{1}{5^6}$$

FIG. 6. Average dry weights of ten series of pea plants grown in strong nutrients in the presence of differing amounts of *o*-cresol. Oct. 5–Dec. 21, 1914.

all toxic, but in varying degree. Tollens² indicates that in animal investigations *o*-cresol is about as toxic as phenol, *p*-cresol being more poisonous, *m*-cresol rather less so. No reference to this relative toxicity with regard to plants has so far come to light. Consequently barley and peas have been tested with all three forms in the usual way.

Peas (Figs. 6, 7, 8).

All the plants were started at the same time, and the growth of the series treated with the three cresols was remarkably

$$I = \frac{M}{100} \times \frac{1}{5^6}$$

FIG. 7. Average dry weights of ten series of pea plants grown in strong nutrient solutions in the presence of differing amounts of *m*-cresol. Oct. 6–Dec. 21, 1914.

N.B. 5⁴. Upper curve = mean of plants which made good recovery. Lower curve = mean of plants which made poor recovery.

$$I = \frac{M}{100} \times \frac{1}{5^6}$$

FIG. 8. Average dry weights of ten series of pea plants grown in strong nutrients in the presence of differing amounts of *p*-cresol. Oct. 5–Dec. 21, 1914.

¹ Wehmer: Die Pflanzenstoffe. 1911.

² Tollens, quoted by Kobert, R.: Lehrbuch der Intoxikationen. 2. Auflage. 1902–6.

uniform, so that comparison was much facilitated. In every case the strongest poison, $M/100$, was almost immediately fatal, as within two days the roots were quite flabby and most unnaturally white, no attempt at lateral formation having been made. Within a week the shoots had died off in a way that had never been witnessed before in the greenhouse with any other poison, whether organic or inorganic. The stem shrivelled from the seed to the leaves, the whole plant was prostrate, the leaves limp and wilting, reminding one irresistibly of stale greens in a neglected corner of a greengrocer's shop. The strongly antiseptic action of the cresol was shown by the fact that, in spite of the early death of the plants, no sign of mould growth appeared either on the plants or on the solutions during the six weeks that the cultures were retained in the house.

With the next concentration, $M/100 \times \frac{1}{5}$, all the plants started alike, but differences manifested themselves a little later on. Within two days the tip of the root became constricted and white, and, except in the case of *o*-cresol, somewhat flabby.

With *o*-cresol practically no growth was made, but for some time the plants continued to look healthy, as though their development had been merely arrested, not permanently inhibited. After about a month the roots became flabby, without forming any laterals. Within another fortnight the leaves began to wilt, the roots shrivelled just below the seeds so that the plants were unsteadily prostrate, and mould put in an appearance. Evidently the *o*-cresol was not strong enough to prevent the latter phenomenon from occurring, as with the previous concentration. By the end of the experiment every plant was dead and shrivelled.

With *m*-cresol the shoots made a considerable amount of growth, so that for the first month they were much better than those in *o*-cresol. Nevertheless symptoms of degeneration set in at an earlier date, as by the end of the month many of the leaves were flaccid, the plants were prostrate, and mould formation had begun. In spite of this the plants clung to life more tenaciously than with the *o*-cresol, and at the end of the experiment there were three survivors, with rather dark little roots and very small pale shoots, which had endeavoured to flower.

p-Cresol at this concentration seemed, at one and the same time, to be more toxic than either of the others and yet to allow of greater resistance or recovery. A larger part of the root became flabby at an early date, the shoots were less well developed than any others, and a strong growth of mould appeared on roots and solutions within a fortnight of the start. Most of the plants died fairly soon, the shoots becoming flaccid and shrivelled, the seeds shrivelling also. The development of mould was very strong, far more so than with either of the other cresols. Four plants survived out of ten; these possessed small shoots which had tried to flower. The roots were very poor, brown or black in colour, but they had tried to put out a few short, whitish laterals. Thus, though most of the plants were

killed earlier than with *o*- or *m*-cresol, the survivors with this strength of *p*-cresol were the only plants that had formed even apologies for laterals in the presence of this amount of poison.

The greater toxicity of *p*-cresol was far more evident with the next concentration, $M/100 \times 1/5^2$. The plants started off all right, but very soon both shoots and roots began to fall behind in development. The laterals were at first short, curled, and few in number, and the roots remained poor to the end, and were also hampered by a strong growth of mould. The shoots were variable, some inclined to be flaccid, and all of a sickly green colour. The dry weights of these plants were far below those with the other cresols, as is shown in Fig. 8. With both *o*- and *m*-cresol the ultimate growth of most of the plants was very similar, but the course of development was rather different. With *o*-cresol growth was like that of the controls for about a fortnight, and the shoots continued to keep pace all the way through. The roots, however, became very yellow, bunchy, short, and not at all like the controls in type. This phase lasted for about a fortnight, and then the laterals began to elongate once more. The roots remained somewhat abnormal, being brownish and short at the time of cutting. With *m*-cresol again, the shoots were much like those of the controls all the way through. The roots formed plenty of laterals, but almost from the beginning they were rather short, thin, and of an unhealthy yellowish colour. The roots soon became bunchy and the colour deepened. Eventually the laterals elongated and the roots improved rapidly, approaching the normal more closely; but the final development of the plants was rather variable, some making a good recovery, comparing closely with the controls, others remaining weaker though much stronger than those in *p*-cresol.

With the next concentration, $M/100 \times 1/5^3$, the differences in the action of the various poisons had almost disappeared. The plants with *o*-cresol were similar to the controls from beginning to end, without any abnormality in development. With *m*- and *p*-cresol some trace of poisoning was still evident; with the former some of the laterals tended to be rather thin and of an unusual type, with numerous thin side shoots; while with the latter some of the roots had flabby tips at the first, though lateral formation was normal. All plants pulled up well later on, and the dry weights in all three sets were very similar. Below this strength the action of the poison could not be discerned in any case, all plants comparing well with controls.

On the whole, it may be said that *p*-cresol is more toxic in high concentration than *o*- or *m*-cresol, and that probably *m*-cresol is slightly more poisonous than *o*-cresol, though the difference is not well marked. The apparent anomaly exists, that in spite of this absolute range of toxicity the highest concentration of *o*-cresol (the *least* poisonous) kills all the plants outright, whereas the same strength of *p*-cresol (the *most* poisonous) allows the plants to make a little growth, and also to attempt to put forth laterals, which was not the case with *o*- or *m*-cresol.

Barley (Figs. 9, 10, 11).

M/100. With *o*- and *p*-cresol root growth was checked almost as soon as the plants were put into the solutions, but with *m*-cresol a little root development was made for a few days before growth was inhibited. All roots were very white, and no mould appeared in any case. The shoots did not develop at all, but the single leaf turned a brownish yellow colour and expanded to its fullest extent, contrasting strongly with the usual habit of barley shoots, which when poisoned strongly remain rolled up at death.

M/100 $\times \frac{1}{5}$ was very toxic in every case. The shoots were rather less

FIG. 9. Average dry weights of ten series of barley plants grown in strong nutrients in the presence of differing amounts of *o*-cresol. March 8–April 21, 1915.

FIG. 10. Average dry weights of ten series of barley plants grown in strong nutrients in the presence of differing amounts of *m*-cresol. March 11–April 24, 1915.

checked, and formed two little leaves, but development did not go beyond this. The familiar red coloration due to starvation appeared at the base of the stem. By the end of the experiment the plants were all but dead, the lowest leaves being deep yellow and the root dying. Mould appeared on the roots, being most strongly marked with *p*-cresol.

M/100 $\times 1/5^2$. The greatest differentiation in the action of the cresols occurred with this concentration. With *o*-cresol the roots were some time before they started into growth; when they did begin to develop, stubby laterals were formed. Eventually these began to push down into the solutions, but they were of a thick type, unlike normal barley roots. The

ultimate results were variable, some plants being strong and healthy, others small and weakly, but the general growth was much better than in either of the other cresols. With both *m*- and *p*-cresol root growth was greatly checked at first; the roots became bunchy, not entering the solution for some time, but later on thick laterals were formed, which pushed down into the water. The shoots were small and fairly healthy, but they showed purple coloration in the stem. The recovery was less in both cases than with *o*-cresol.

$M/100 \times 1/5^3$. With *o*- and *m*-cresol growth was normal from the first, though for a time some slight check to the rate of growth was evident. This was overcome later on, and the plants pulled up to the level of the others receiving less poison. With *p*-cresol the roots were very short and bunchy at the beginning, and did not begin to struggle ahead for about a fortnight. When once the long laterals began to form and enter the solutions the improvement in growth was very rapid and the plants made up most of their leeway.

It is noticeable that in all three cases the barley receiving the next strength of poison, $M/100 \times 1/5^4$, made less growth than with the higher concentration just described. This drop was chiefly in the root, being much less marked in the shoot. As the concentration decreased from this point, the dry

FIG. 11. Average dry weights of ten series of barley plants grown in strong nutrient solutions in the presence of differing amounts of *p*-cresol. March 13–April 26, 1915.

weights increased steadily towards that of the control. As this happened consistently with all three cresols it is quite probable that it is a true phenomenon. With the $M/100 \times 1/5^3$ strength the balance of warfare between the plant and the poison is very nicely balanced, and it is possible that in its strong efforts to gain the upper hand the plant developed a very extended root system and made a fuller use of the food supply, resulting in a greater dry weight. Apparently the whole effect of the poison is not lost with rather lower concentrations, but the toxic action is so slight, that the plant does not make the same effort to overcome it by

means of greater root growth, and consequently the dry weights fall behind somewhat. The increase observed in the former case may be an instance of a local stimulation whereby increased growth is made to enable the organ concerned to cope with some special circumstance affecting the plant economy. This is quite different from stimulation in the ordinary sense, whereby the rate of growth of the whole plant is affected, giving corresponding increase in the dry weights of both root and shoot.

In this connexion it is interesting to make a comparison of the shoot-root ratios in relation to the actual weights. With high concentrations of the poisons (except when root growth was so inhibited that death occurred early, so vitiating the value of any figures) the development of the roots in comparison with the shoots is much above normal, so that the shoot-root ratio is very low. This is what might be expected, as the action of the poison probably prevents a sufficient supply of food from entering the plant, so that if the latter is able to make any growth at all it concentrates its efforts first on extending the root system as far as possible in order to enlarge the absorbing area, improvement of the shoot following later, if at all, i.e. if the increase of root area is really associated with increased absorption. In the case under consideration with a particular concentration of poison, $M/100 \times 1/5^3$, the shoot reached a normal size, but to enable this amount of growth to be made the roots had to develop to an abnormal extent, so that the shoot-root ratio is still low. Below this concentration, when the action of the poison is very weak and the resistance of the plant is almost nil, the ratio approximates closely to the normal.

Shoot-Root Ratio.

	<i>Ortho-cresol.</i>	<i>Meta-cresol.</i>	<i>Para-cresol.</i>
Control	2.744	2.974	2.638
$M/100 \times 1/5$	5.700	1.960	1.200
$M/100 \times 1/5^2$	1.955	1.988	1.681
$M/100 \times 1/5^3$	2.252	2.776	2.367
$M/100 \times 1/5^4$	3.156	3.133	3.013
$M/100 \times 1/5^5$	3.110	2.907	2.826
$M/100 \times 1/5^6$	2.983	2.939	2.748

Resorcinol.

The effect of very strong ($M/100$) resorcinol on peas (Fig. 12) was rather remarkable, on account of the great difference in the initial action of the poison on the roots and shoots. The roots were killed at once, as within two days they were white and flabby, and the parts above the solutions had begun to shrivel. In spite of this the shoots started into growth and made very fair development for several days, so that they were nearly as good as the controls, although by the end of the first week the roots were infested with a strong growth of mould. After ten days the shoots were much stronger than any others that had received the same concentration of

other phenols, as cresol, orcinol, pyrogallol, &c., the amount of shoot growth being most surprising considering the state of the root. Perhaps the effect of the resorcinol was in some way to give a stimulus to shoot production, or at least to allow it to go on unhindered, so that although no fresh nutrient was being absorbed on account of the death of the root, yet the shoot was able to make use of the stores in the seed and develop for some time wholly at their expense. This may indicate that this particular poison is primarily local in its action, and that though it kills the root, the lethal

FIG. 12. Average dry weights of ten series of pea plants grown in strong nutrient solutions in the presence of differing amounts of resorcinol. Sept. 26-Dec. 17, 1914.

or paralysing influence is not transmitted to the shoot at once, but only makes itself felt after some time has passed.

With a rather lower concentration, $M/100 \times \frac{1}{5}$, the resorcinol did not make itself felt for several days, and even then the roots were much more affected than the shoots. The roots gradually turned brown, then black; the laterals were weak and were usually formed above the solutions. At a still later date recovery set in, and long straight laterals were pushed into the solutions, so that at the end of the experiment most of the plants looked fairly healthy, and were not so very deficient in dry matter. Lower concentrations had little effect on

FIG. 13. Average dry weights of ten series of barley plants grown in strong nutrients in the presence of differing amounts of resorcinol. March 16-May 3, 1915.

the plants, except that in some cases the roots were rather discoloured. On the whole, to peas resorcinol is about as toxic as phenol itself, and much less toxic than most of the others of the phenol group.

Barley is, as usual, more sensitive than peas (Fig. 13). With strong concentrations, including $M/100 \times \frac{1}{5}$, the usual phenomena of intense poisoning were noticed—belated start into growth, bunching of roots owing to reluctance of laterals to enter the solutions, poor shoot development, with purple coloration. No recovery was noted in these cases, so the dry weight remained low. With rather lower concentrations, again as usual, an initial check was followed by recovery—recovery so complete that the dry weights were fully equal to controls. No stimulation nor toxic action was observed in the greater dilutions of poison.

Pyrocatechol.

The general course of events was the same as with other phenols

FIG. 14. Average dry weights of ten series of pea plants grown in strong nutrients in the presence of differing amounts of pyrocatechol. Sept. 29–Dec. 17, 1914.

$M/100 \times \frac{1}{5}$, was not on the border-line of indifference, since with only one-fifth the strength, $M/100 \times 1/5^2$, very little root recovery occurred in any case, and even when it did take place it was only to a slight degree.

The continuance of shoot growth after the death of the root was shown by the shoot-root ratio, which reached 10.5. As soon as root recovery set in the ratio rapidly fell towards that of the controls, which is about 4.2.

with which root recovery takes place at certain concentrations. Pyrocatechol is more toxic than many of the others, as with both peas and barley the harmful effects were noticed much farther down the scale. The behaviour of pea plants with $M/100 \times \frac{1}{5}$ poison was more noticeable (Fig. 14). The roots were killed beyond recovery at the very beginning and rapidly became grey, flabby, and mouldy. In spite of this the shoots continued to drag out an existence, and six weeks later actually came out into flower, though naturally the blooms were very small and poor. This is still more remarkable in that the concentration,

Pyrogallol.

Owing to shortage of the supply it was only possible to test the effect of pyrogallol and phloroglucin upon peas. Pyrogallol was very poisonous, the toxic effect being noticeable with comparatively low concentrations (Fig. 15). High strengths killed the plants outright, and rather lower strengths allowed of well-marked root recovery. The poisoned roots became intensely black in colour, so that when recovery set in the contrast between the black root and the fresh white laterals was very marked. Decomposition of the solution took place very rapidly. The stronger solutions became very yellow and developed much heavy black or dark brown precipitate. The discoloration of the roots was still noticeable in the presence of so little pyrogallol that the solutions themselves were not turned but retained their usual colour. The mould development was rather unusual, as fungus was evident in the precipitate as well as floating on the surface of the solution. That among the precipitate included a *Nectria*, possibly *N. cinnabarina*, Fr., and a mycelium which was producing myriads of budding conidia. The surface mould was a starved condition of *Penicillium glaucum*, Link.¹

$$I = \frac{M}{100} \times \frac{1}{5^6}$$

FIG. 15. Average dry weights of ten series of pea plants grown in strong nutrient solutions in the presence of differing amounts of pyrogallol. Oct. 9, 1914-Jan. 19, 1915.

Phloroglucin.

This proved to be somewhat less toxic to peas than the pyrogallol (Fig. 16). No change occurred in the colour of the solution and the roots that were killed turned yellowish, without darkening much. After the moribund shoots lost their green colour they took on a curious reddish-brown colour in their stems, and the leaves turned brownish. Plants with $M/100 \times \frac{1}{5}$ did not show the usual phenomena of arrested growth followed by later recovery. Instead the laterals were formed at the beginning, but made very poor growth above the solution, and very little in it. Later on, they grew out but were short, and became thick and yellow, and still later they became spindle-shaped, being stubby and thickened in the middle. The roots eventually blackened, and retained their abnormal character to the last, though they developed a few straight greyish-white laterals. With

¹ Moulds identified at Kew by the kindness of the Director.

a lower strength of poison the laterals showed an inclination to behave the same way at first, but before very long they pushed out well and the plants improved very greatly, approaching the controls. The shoot-root ratio remained fairly constant all through. The same mould as was obtained with pyrogallol (*Nectria cinnabarina*) was observed floating in the solution.

Orcinol.

Strong solutions of orcinol, $M/100$, acted unfavourably on the roots of peas from the outset; as the tips became flabby within twenty-four hours of insertion in the solution, and within three days the whole root was involved. Within a week all the roots were flabby and constricted and

FIG. 16. Average dry weights of ten series of pea plants grown in strong nutrient solutions in the presence of differing amounts of phloroglucin. Oct. 10, 1914-Jan. 19, 1915.

FIG. 17. Average dry weights of ten series of pea plants grown in strong nutrient solutions in the presence of differing amounts of orcinol. Oct. 15, 1914-Jan. 21, 1915.
N.B. 5^5 Upper curve = mean dry weight of plants which made fair recovery. Lower curve = plants which made poor recovery.

moulds had appeared. Curiously, though, the shoots were not checked at the beginning and for the first week their growth almost equalled that of the controls, but this initial spurt was not maintained, as after a fortnight no further progress was made. Nevertheless the shoots did not wilt or die at all easily, as nearly a month passed before they began to get flabby. Meanwhile the moulds on the roots made rapid progress, and ultimately no signs of life remained in the plants.

With rather lower concentrations, $M/100 \times \frac{1}{5}$, the roots were injured from the first, though they were not killed. They were discoloured and made poor laterals, which remained short and stubby for some time. Growth was at a standstill for a period, but after the lapse of two months new laterals appeared, which remained short in some cases and elongated into normal rootlets in others. This continued to the end, and the ultimate effect on growth is shown by the two parts of the curve in Fig. 17, which

shows the mean dry weight of those plants which made a good recovery, and also of those which hung back to the last. Although the roots were injured directly they entered the solutions, the shoots were not affected at first and were as good as those of the control plants. After a time the shoots began to feel the defection of the roots, and as insufficient nutriment was supplied to them their growth suffered, though they remained green and healthy all along. The improvement in root growth was strongly reflected by that in the shoots, and the plants made rapid headway when once root recovery had set in. Some mould appeared on the roots at an early stage, but did not seem to interfere with recovery.

With the next lower concentration, $M/100 \times 1/5^2$, the toxic action was much less marked. For a little time the root laterals were rather short and somewhat discoloured, and before very long some degree of distortion appeared, but later on growth became more normal and the plants approximated in appearance to the controls.

All the lower strengths of orcinol had little or no effect upon growth, as the plants compared very favourably with the controls.

Barley.

A comparison of the curves for barley and peas shows that barley is more sensitive to the action of orcinol, as so often happens with these poisons. The highest concentration, $M/100$, probably

FIG. 18. Average dry weights of ten series of barley plants grown in strong nutrient solutions in the presence of differing amounts of orcinol. Mar. 27-May 17, 1915.

killed the plants immediately, although the shoots grew just a very little during the first three days. The leaves soon began to die down from the tips and the plants quite shrivelled up within three or four weeks. No mould appeared in their case, though with peas such a strong growth was observed.

With $M/100 \times \frac{1}{5}$ growth was checked at once and for about a fortnight little progress of any kind was made. The leaves kept their healthy green colour, but the stems became purplish. After the plants had marked time for about four weeks the roots began to make slight attempts to put out laterals, but the shoots did not respond at once. Lateral formation proceeded apace and the roots became very full and bunchy, but very few of the laterals ever entered the solutions. Only in three plants was the reluctance overcome, and in these cases the roots were rather long and thick. As a result of this reluctance on the part of the roots the shoots were unable to make as much improvement in growth as might have been expected, and the ultimate result was that the plants were very variable, so that the average dry weight does not in this case convey a true idea of what actually happened.

The toxic effect was still marked with the next strength, $M/100 \times 1/5^2$, as for nearly three weeks the root growth was not much better than it was with stronger orcinol. When once lateral formation did make a start, however, progress was rapid. Thick rootlets were pushed out into the solutions, and these were eventually accompanied by more normal thinner roots bearing fine laterals. In spite of all the progress the initial check was never fully overcome and the average dry weight of the plants was considerably behind that of the controls.

Even with a lower strength of orcinol, $M/100 \times 1/5^3$, the roots were rather adversely affected at first. For a few days this was not evident, but then the growth of both roots and shoots fell behind that of the controls, although later on most of the leeway was made up.

An interesting feature of the action of orcinol on barley is that at the time of cutting it appeared that there was a decided stimulation with some of the concentrations below those discussed above. This appearance, however, was not borne out by the dry weights, the balance being in favour of the control plants. This apparent stimulation was not observed in the case of peas.

SUMMARY OF RESULTS.

1. The general action of the various phenols upon barley and pea plants grown in water cultures is very similar, though the individual substances exercise their specific action at somewhat varying concentrations. In every case a solution containing one per cent. of the molecular weight ($M/100$) of the phenol proves to be fatal, and usually death occurs within

a very short time after the plant comes in contact with the solutions. Occasionally, as with resorcinol and orcinol on peas, the shoots continue to make a certain amount of growth for a few days, even though the roots are killed. Apparently the toxic principle in these cases is not conveyed to the leaves at once, so that they are able to grow for a time at the expense of the food stored up in the seeds. More usually, however, the growth of the shoots is checked simultaneously with that of the roots, though the leaves retain their green colour for quite a long time before they wilt.

The difference in the relative toxicity of the phenols is well shown by the action of solutions one-fifth as strong as the above ($M/100 \times \frac{1}{5}$). Marked toxic action is evident at the first in every case, and the roots are often killed and discoloured. *o*-Cresol, pyrocatechol, and pyrogallol kill peas outright at this strength, but with the other substances the roots make an attempt to right themselves after some time has elapsed. New laterals are pushed out, which frequently refuse to enter the solutions, so that the recovery is only partial. *m*-Cresol admits of only very slight recovery with peas; *p*-cresol, phenol, and phloroglucin permit rather more; while with resorcinol and orcinol quite good root development is able to take place ultimately, with which a corresponding improvement in the shoot growth is associated. Barley is more sensitive than peas, as recovery seldom takes place, and even with resorcinol and orcinol the roots make very little improvement.

The lower strength, $M/100 \times 1/5^2$, also shows clearly the difference in the action of the phenols, the range of variation being considerable. In nearly every case an initial check is evident, but the degree of injury varies very much. Resorcinol at this strength has very little effect on peas, as growth is fairly good from the beginning; and with orcinol, too, strong growth is made. Phenol makes the roots bunchy when they put out laterals, but the recovery is so complete that the plants make nearly as much dry weight as the controls. Recovery is variable in amount with most of the other substances, but pyrocatechol is so poisonous that very little growth is made up to the end. Barley behaves in much the same way as peas, though owing to its sensitiveness the recovery is not always so complete as in peas.

Lower concentrations of all the poisons do not seem to exercise injurious action on growth.

2. The root recovery observed in strong solutions suggests that in these cases the poison acts largely by suspending the activities of the plants, paralysing it without killing it outright. Consequently, when the paralysing effect wears off or when the concentration of the solution is somewhat reduced by oxidation (in cases where this occurs), then the plant reasserts its vitality, struggles to put out lateral roots, and frequently succeeds so well that fairly good growth is eventually made.

3. No signs of stimulation have been observed with any of the phenols

tested, except that in the presence of dilute solutions of orcinol barley plants appeared better than the controls before they were cut. This appearance was not corroborated by the dry weights.

4. When the plants were killed by high concentrations of the phenols, moulds usually appeared very rapidly on the dead roots and on the solutions. Phenol itself, however, exerted an antiseptic action for a long time and no mould appeared until towards the end of the experiment, while the three cresols were still more antiseptic and did not allow of any mould formation at any time. This only held good with very strong concentrations, as moulds did appear in rather weaker strengths in which the roots were injured. Where no root injury occurred no moulds grew in any case.

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