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# CONSEQUENCES OF BANDING NITROGEN FERTILIZERS IN SOIL

## II. EFFECTS ON THE GROWTH OF WHEAT ROOTS

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SUMMARY

An account is given of the growth of wheat roots in the environment produced by banded urea and ammonium sulphate in both sterile ($\gamma$-irradiated) and non-sterile soil. In the non-sterile soil, (i) roots were absent from the fertilizer-affected zone (diameter about 10 cm) for both fertilizers at 2 weeks, presumably owing to unfavourable osmotic suctions there, (ii) roots proliferated enormously in the zone at both 4 and 8 weeks with ammonium sulphate, and (iii) roots were absent from the zone at both 4 and 8 weeks with urea (presumably owing to the large amounts of nitrite there), but they proliferated at the edge of the zone and completely encased it by eight weeks. In the sterile soil there was no marked proliferation of roots with ammonium sulphate, and with urea there was a region of intense proliferation surrounding a small zone (diameter 2 cm) which was devoid of roots. There were no universal correlations between the proliferations and the distributions of nitrate, nitrite, ammonium, pH, or (presumed) activity of nitrifiers. Nevertheless, ammonium seemed to be the main stimulus for the roots; it only failed to correlate with the root distributions if the concentration of nitrite was high or if the pH was below 4.

INTRODUCTION

When a solid nitrogen fertilizer is placed in a band in soil, the fertilizer dissolves and subsequently moves out to interact with the soil in various ways. Some aspects of this interaction, including effects on nitrification, have been discussed in Part I [3] of this series of two papers. In the present paper the growth of wheat roots is discussed in relation to the environment produced in the vicinity of banded urea and ammonium sulphate fertilizers. Because preliminary experiments had shown that the response of the roots to the fertilizers was great, the wheat was grown in both sterile ($\gamma$–irradiated) and nonsterile soil; it was hoped that the behaviour of the roots in the absence of nitrification would help explain their behaviour in its presence.

## MATERIALS AND METHODS

Cununurra clay was the soil [3], and Gabo the variety of wheat, used in the experiments reported here.

### (a) *Main experiment*

Wheat was grown in a growth chamber in the plexiglass root boxes described in Part I [3]. The growth chamber was run on a 12-hour day with a day temperature of 32°C and a night temperature of 24°C. The light intensity at the level of the plants was approximately 3000 ft-c. The boxes were filled to within 3 cm of the top with air-dry soil which had been ground to pass a 2-mm sieve. The soil was wetted from below so as to equilibrate, finally, with a water table at 60 cm. A hole was then made in the back of each box and small amounts of soil were scooped out and replaced with fertilizer. The holes were located 15 cm from the tops of the boxes and equidistant from the sides. Urea and ammonium sulphate (A.R.) were the fertilizers used. They were applied at the same rate as in Part I [3], *i.e.* 750 mg N per box. Three days later wheat was sown at about 1-cm intervals along the soil surface and covered with about 1 cm of soil. After emergence the plants in each box were thinned to ten. The water table at 60 cm was maintained throughout the growth of the plants. This was adequate to keep the water content in the soil at the initial value until four weeks, but thereafter water had to be added to the tops of the boxes at frequent intervals to keep them at their original weights. Boxes were harvested in duplicate at 2, 4, and 8 weeks after sowing. There were 18 boxes in all (urea, ammonium sulphate, no fertilizer, $\times$ 3 harvests $\times$ 2 replicates).

At harvesting the tops of the plants were cut off and oven-dried and the boxes were deep frozen to prevent any further movement or microbial degradation of the products of the fertilizers. The boxes were then dismantled and the frozen slabs of soil cut in two down the middle. One half of each slab was placed on a pin-board having a 1-cm grid and the soil was washed away to expose the roots, which were then dried and photographed. The other half of each slab was cut into small blocks ($1 \times 1 \times 1$ cm within 5 cm of where the fertilizer was placed, $2 \times 2 \times 1$ cm at greater distances). These samples were analysed for water content, pH, nitrate, nitrite, and ammonium, as described previously [3].

### (b) *Irradiation experiment*

Six root boxes were filled with soil, watered, and fertilizer added, as described above. Two boxes had ammonium sulphate, two had urea, and two were controls. All six boxes were then irradiated with $Co^{60}$ to give a dose greater than 2.5 megarad. Three days later one of each of the three pairs of boxes was sown with wheat as in the main experiment and all six were placed in the growth chamber with the boxes of the main experiment. The water regime was the same as for the main experiment. The boxes were harvested after eight weeks and analysed as for the main experiment.

## RESULTS

### (a) *Main experiment*

The root patterns produced in one replicate are shown in Plate 1. The patterns in the other replicate were similar. The main points to be noted are (i) the absence of roots from the fertilized zone for both fertilizers at two weeks, (ii) the proliferation of roots in the fertilized zone for ammonium sulphate at 4 and 8 weeks, (iii) the proliferation of roots at the periphery of the fertilized zone with urea, coupled with an absence from the centre of the zone, at both 4 and 8 weeks. Weights of roots per $cm^3$ of soil as a function of depth down a line going through the point of placement of fertilizer are shown in Figure 1 and reflect the patterns shown in Plate 1. The concentrations of ammonium–N, nitrite–N, and nitrate–N as functions of depth (through the band) are shown in Figures 2, 3, and 4, and the pH's are shown in Figure 5. Nitrate–N concentrations as functions of horizontal distance from the band are shown in Figure 6. The values shown are the means of the duplicates. Above ground yields of dry matter and nitrogen are shown in Table 1.

### (b) *Irradiation experiment*

Plate 1 shows the root patterns and Figure 1 shows the concentration of roots ($mg/cm^3$) as a function of depth. The patterns are

TABLE 1

Above-ground yields of dry matter (DM) and nitrogen. 8I refers to the irradiated soil.

| Week | Ammonium sulphate | | Urea | | No fertilizer | |
|---|---|---|---|---|---|---|
| | DM (g) | N (mg) | DM (g) | N (mg) | DM (g) | N (mg) |
| 2 | 0.30 | 18 | 0.22 | 13 | 0.30 | 18 |
| 4 | 0.63 | 74 | 0.85 | 40 | 0.58 | 19 |
| 8 | 6.22 | 200 | 4.5 | 144 | 1.40 | 24 |
| 8I | 14.5 | 335 | 15.2 | 380 | 3.50 | 69 |

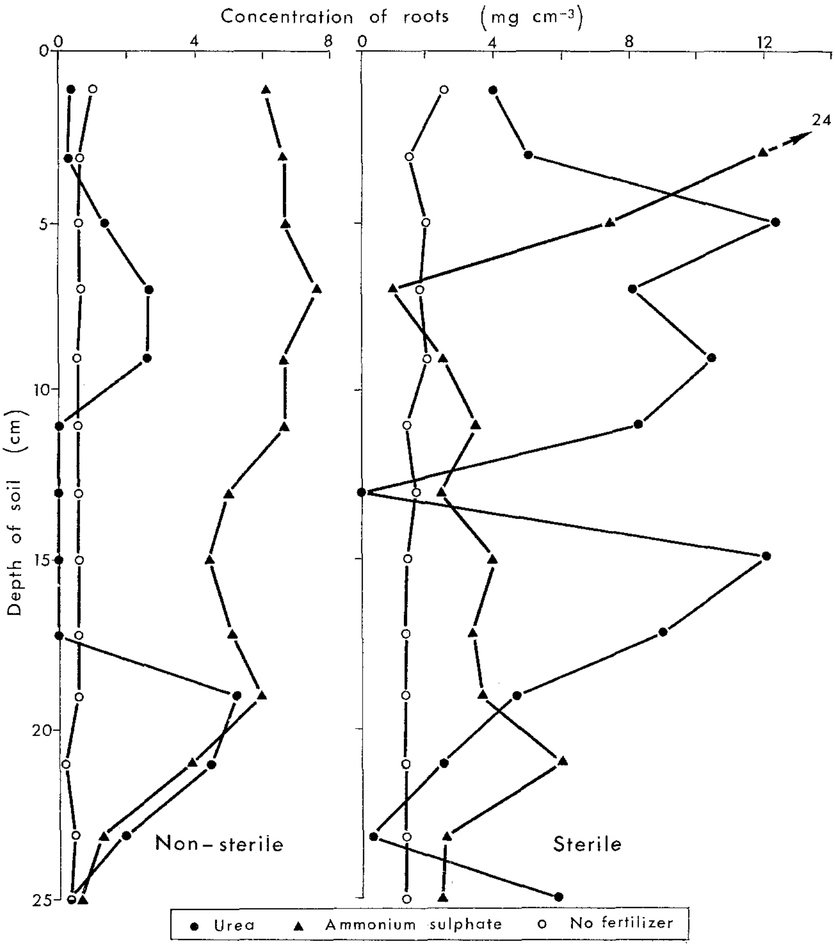


Fig. 1. Concentration of roots at 8 weeks as a function of depth (through the band) with no fertilizer, or with urea or ammonium sulphate banded at a depth of 15 cm in non-sterile and sterile soil.

strikingly different from those in the non-irradiated soil: with ammonium sulphate there is a suggestion of enhanced root growth near the fertilized zone, but it is slight; with urea there is a proliferation of roots in the fertilized zone but it is near the centre rather than at the periphery – there is a zone devoid of roots, but it is much smaller than in the non-irradiated case. The concentration of ammonium-N as a function of depth (through the placement) is shown in Figure 7 and the pH's are given in Figure 8. The concentrations of nitrate

TABLE 2

Average concentrations of $NO_3^-$–N at eight weeks in the irradiated soil (ppm)

| | Ammonium sulphate | Urea | No fertilizer |
|---|---|---|---|
| With plants | 8 | 3 | 0 |
| Without plants | 8 | 16 | 10 |

were small and are shown in Table 2. No nitrite was detected. The above ground yields of dry matter and nitrogen are shown in Table 1. The beneficial effect of irradiation on the yields is considerable, but the reason for this is obscure.

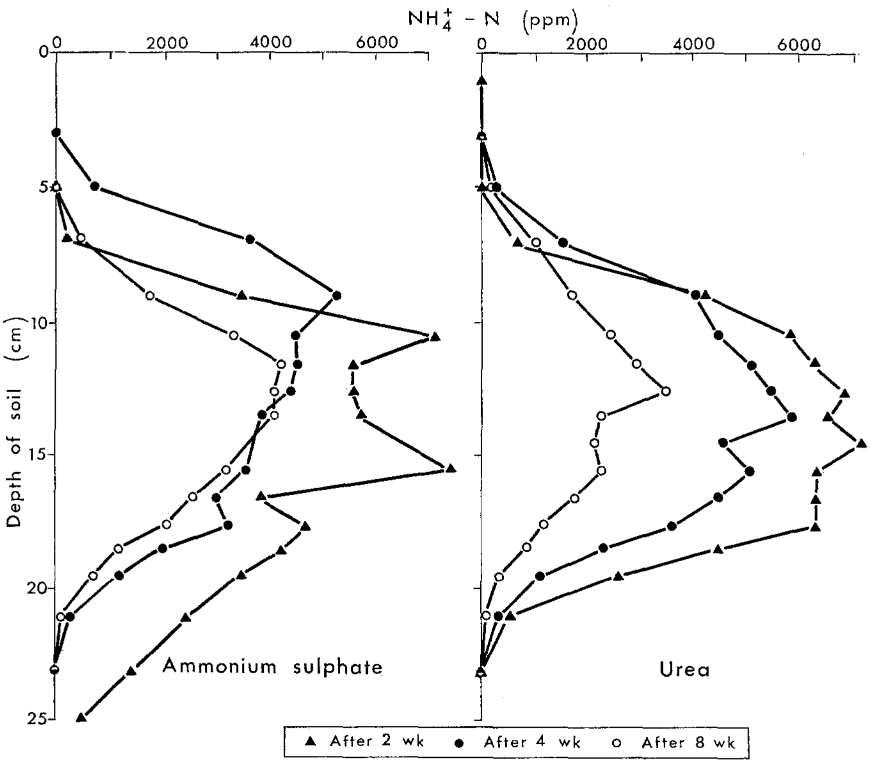


Fig. 2. Ammonium–N concentration as a function of depth (through the band) for ammonium sulphate and urea at 2, 4, and 8 weeks after placement at a depth of 15 cm in non-sterile soil.

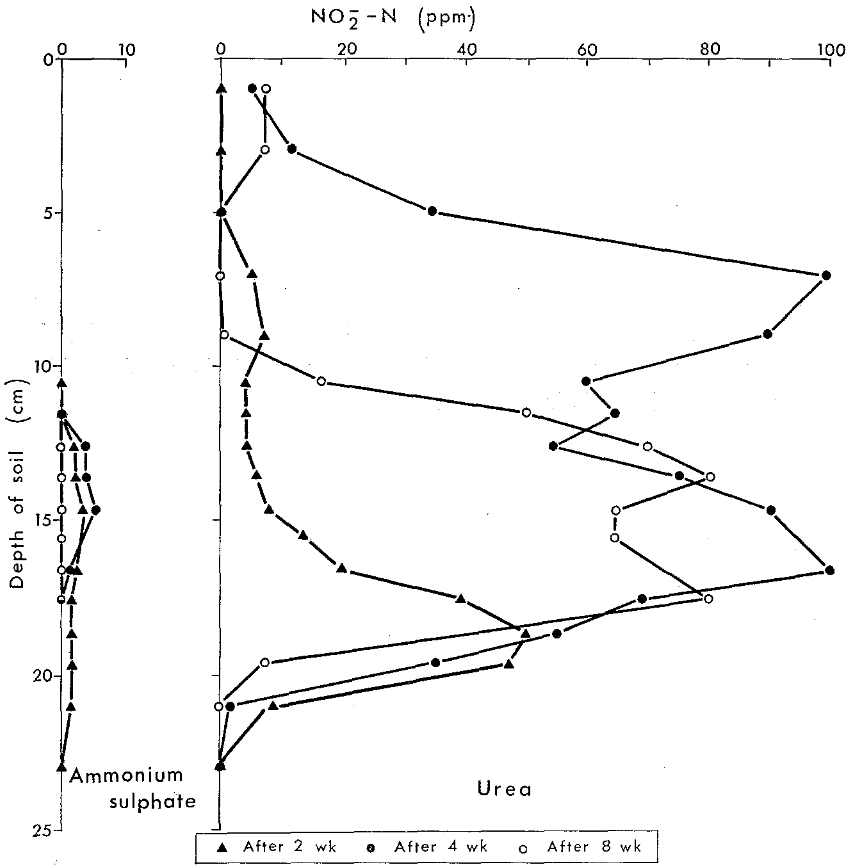


Fig. 3. Nitrite–N concentration as a function of depth (through the band) for ammonium sulphate and urea at 2, 4, and 8 weeks after placement at a depth of 15 cm in non-sterile soil.

## DISCUSSION

The effects of the fertilizers on the growth of the roots were great. Both toxicity and stimulation were evident. The toxicity at 2 weeks occurred with both fertilizers and was presumably due to high osmotic suctions in the fertilized zone (*cf* Table 2 of Part I[3]), although with urea high pH may have been partly responsible. By 4 weeks the toxicity due to the ammonium sulphate had disappeared. With urea on the other hand the toxicity was still present and (in the non-irradiated soil) was still strong at 8 weeks. This toxicity was

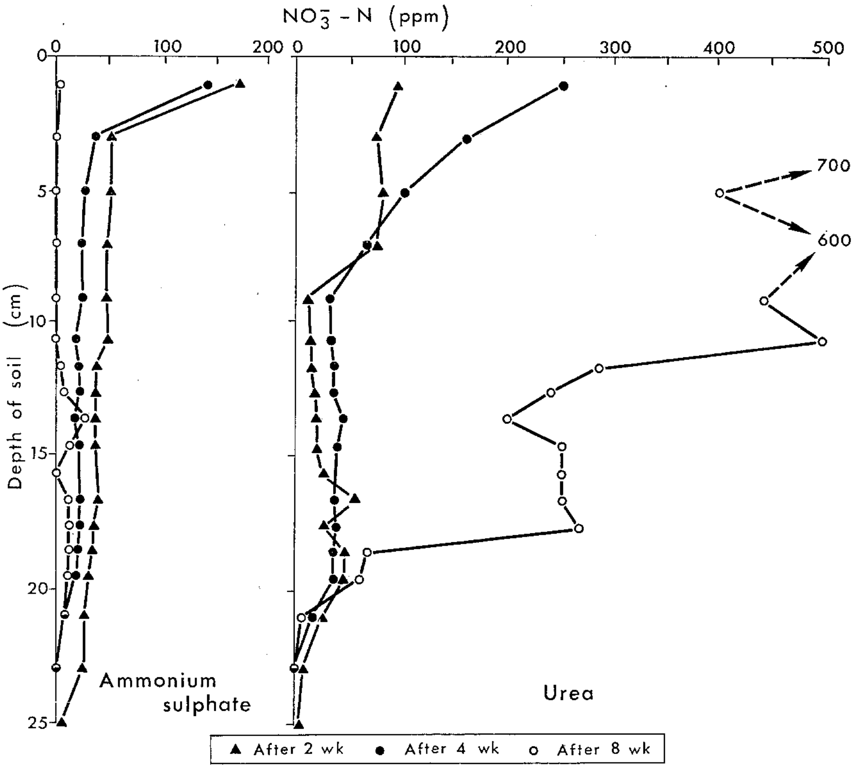


Fig. 4. Nitrate–N concentration as a function of depth (through the band) for ammonium sulphate and urea at 2, 4, and 8 weeks after placement at a depth of 15 cm in non-sterile soil.

probably due to the high concentrations of nitrite which occurred with urea in the non-irradiated soil (see Fig. 3), although there were no obvious symptoms in the tops of the plants such as those found by Court *et al.*[1] in corn, and the yields with urea were similar to those with ammonium sulphate (Table 1). In the irradiated soil, where no nitrite was detected, the small intense zone of toxicity with urea at a depth of 13 cm may have been due to high osmotic suction, for the concentration of ammonium was still surprisingly high there at 8 weeks (see Fig. 7). The toxic effects of the high concentrations at 2 weeks are similar to those described by Ishizuka *et al.*[2] for corn grown in Hokkaido soil. Ishizuka *et al.*[2] also found toxicity due to urea at about 4 weeks but attributed this to high osmotic suction rather than to nitrite.

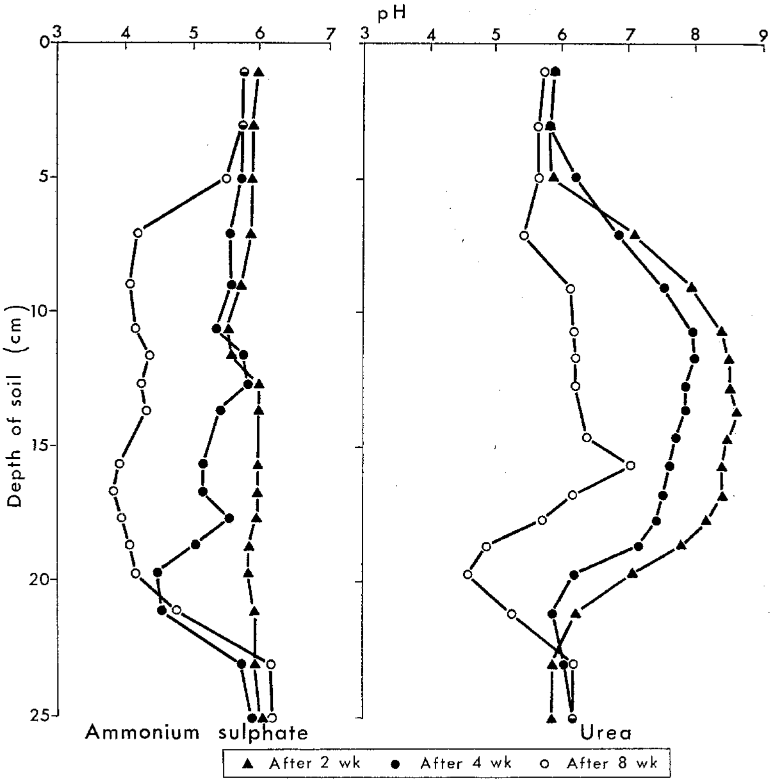


Fig. 5. Soil pH as a function of depth (through the band) for ammonium sulphate and urea at 2, 4, and 8 weeks after placement at a depth of 15 cm in non-sterile soil.

In apparent contrast with the results of Ishizuka *et al.*[2] is the proliferation of roots both throughout the fertilized zone in the case of ammonium sulphate and at the edge of it in the case of urea. The work of Wiersum [4] suggests that nitrate may have been the stimulus for the roots, but Plate 1 and Figures 1, 4, and 6, show no obvious similarities between the distributions of nitrate and of roots. Furthermore, there was stimulation of root growth in the irradiated soil near the placement of the urea fertilizer even though the nitrate concentration was low.

Since the proliferation of roots was symmetrical about the point of placement of fertilizer, it seems likely that the stimulus for this proliferation was similarly symmetrical. There were several sym-

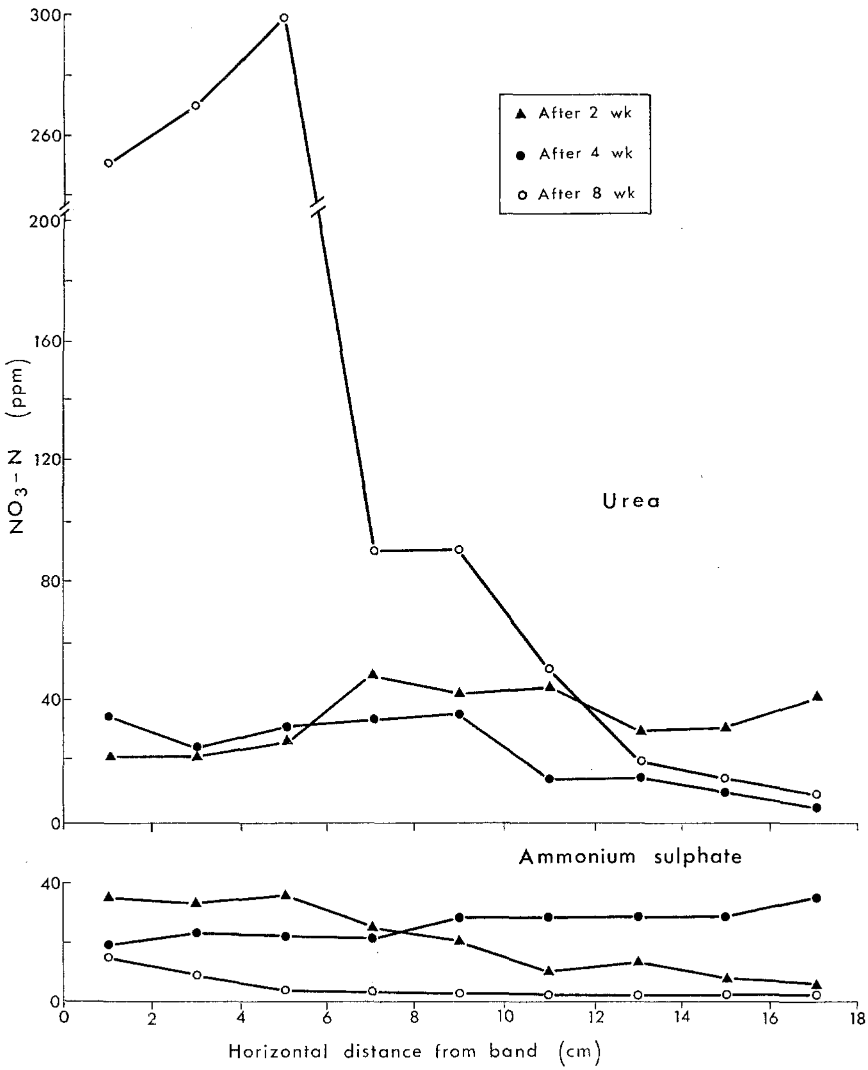


Fig. 6. Nitrate–N concentration as a function of horizontal distance from the band for ammonium sulphate and urea at 2, 4, and 8 weeks after placement in non-sterile soil.

metrically distributed variables which conceivably could have provided a stimulus for the roots. These were: concentrations of ammonium and of nitrite, osmotic suction, pH, and (presumably) activity of nitrifying and other micro-organisms. Of these, ammonium is the most likely; both osmotic suction and pH seem highly improbable, and against both nitrite and microbial activity there is the strong growth of roots near the banded urea in the irradiated soil. The main argument against ammonium is the unspectacular growth of roots in response to ammonium sulphate in the irradiated soil. But here, the low pH in the fertilized zone (an average of 3.7 between the depths of 10 and 20 cm in Fig. 8) may have inhibited the growth of the roots; the roots within the zone were dark brown and presumably necrotic, while just outside the zone they were white and had proliferated somewhat (Plate 1). Admittedly, the pH was also low at 8 weeks with ammonium sulphate in non-irradiated soil (Fig. 5), but here the average pH in the fertilized zone was 4.2, and the difference of 0.5 unit may have been sufficient to account for the difference in the performance of the roots. This evidence in favour of ammonium being the main stimulus for the roots is, however, circumstantial, and the root growth observed may have been due to different causes in different cases. Further work in this laboratory is in progress which aims at elucidating the problem.

The profound effects of the fertilizers on the roots were not matched by the effects of the roots on the fertilizers, at least in the non-irradiated soil. Comparisons between Figures 2, 3, and 4, and their counterparts in the absence of plants (Figs. 5, 6, and 7, in Part I[3]) show little differences in pattern: (i) the distributions of ammonium were similar ; (ii) the distributions of nitrite were also similar, although there was some upwards translation where plants were present, which was presumably associated with a greater upward movement of water from the water table; (iii) with urea, the distribution of nitrate at 8 weeks showed an upward translation similar to that with nitrite; (iv) the only major effect was on nitrate with ammonium sulphate, where the great concentration of roots in the fertilized zone substantially lowered the nitrate concentrations at 4 and 8 weeks. These meagre effects of the roots on the fertilizers in the non-irradiated soil largely stemmed from the fact that the plants took up only small proportions of the 750 mg N applied (Table 1); the disappearance of ammonium was apparently dominated by nitrification. In the irradiated soil, where the plants took up half of the applied N, the effects on the ammonium concentrations were great (Fig. 7); indeed, the roots consumed more ammonium than did nitrification in the non-sterile soil (*cf* Fig. 2 above, and Fig. 5 of Part

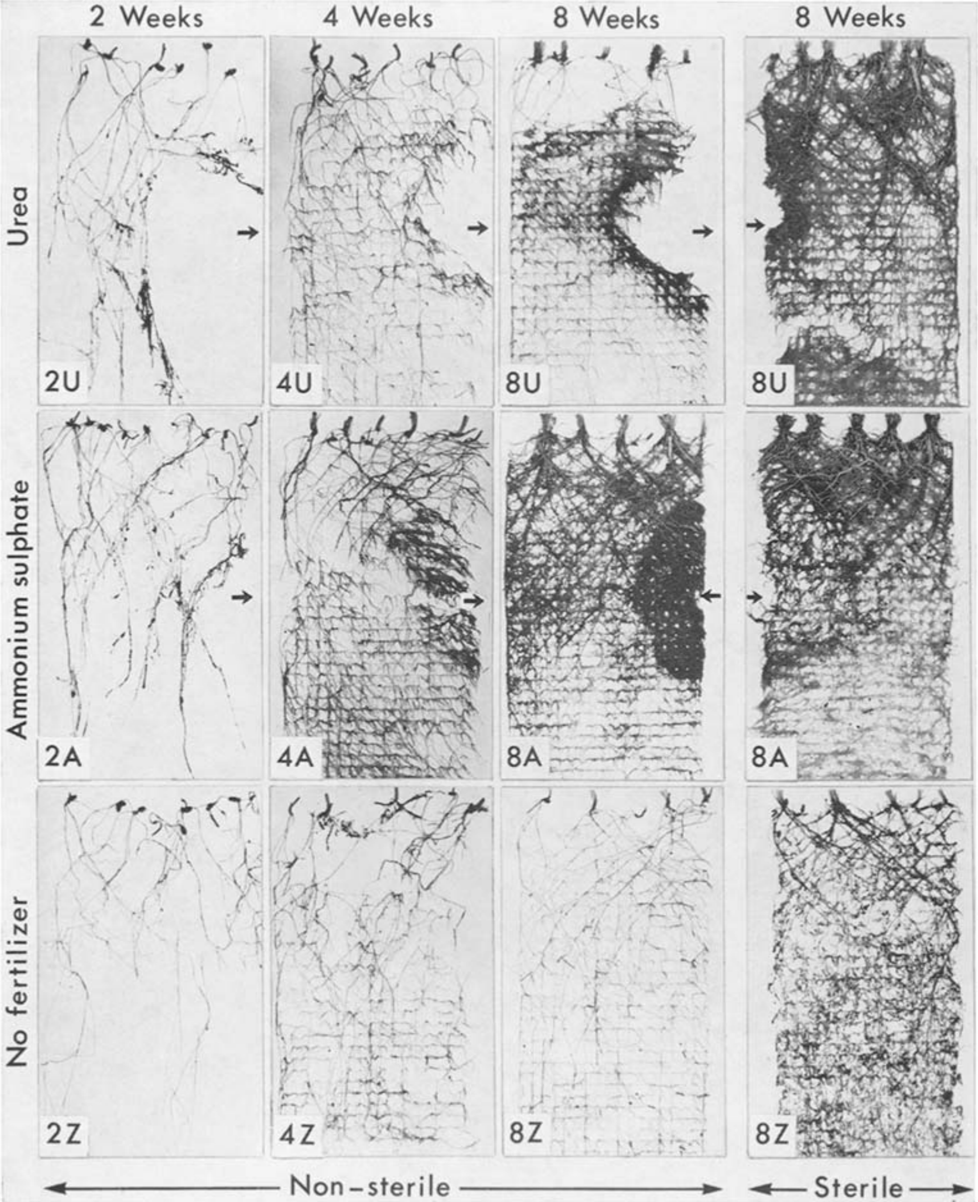


Plate 1. Root patterns formed in response to banded urea (U) or ammonium sulphate (A), or without fertilizer (Z) after 2, 4, or 8 weeks, in non-sterile or sterile soil. The arrows show the locations of the bands.

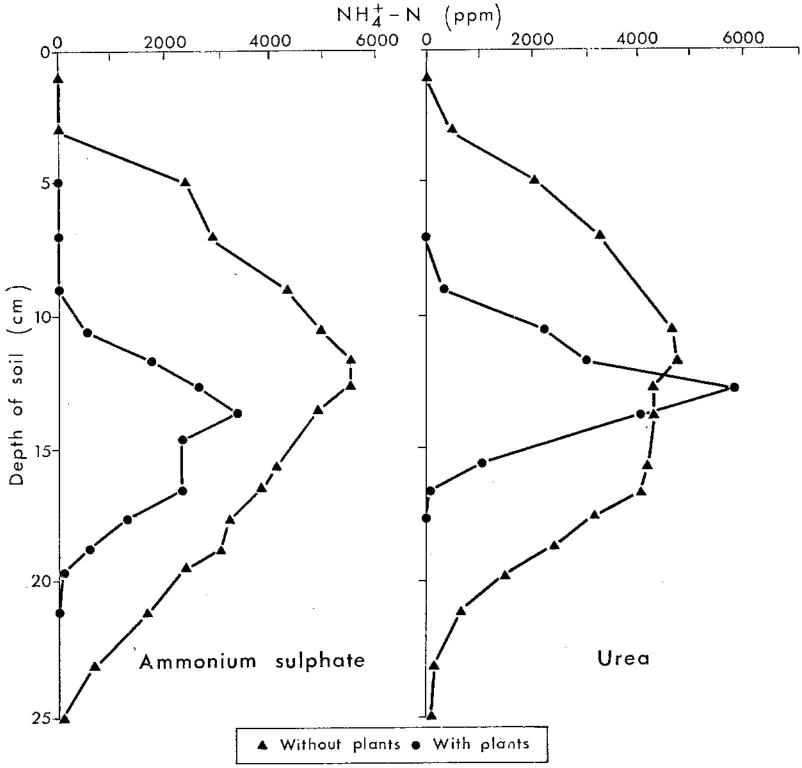


Fig. 7. Ammonium–N concentration as a function of depth (through the band) for ammonium sulphate and urea 8 weeks after placement at a depth of 15 cm in sterile soil, in the presence and absence of plants.

I[3]), and thus appeared to be less sensitive to the high ammonium concentrations than were the micro-organisms.

The most striking effect of both the roots and nitrification was on pH (Figs. 5 and 8), with the roots in the irradiated soil having the greatest effect. The tops alone accounted for 335 mg (24 me) of the N supplied as ammonium sulphate in the irradiated soil (Table 1), and if we add say another 6 me for the N in the roots we have 30 me of ammonium taken up by the roots and therefore 30 me of acid excreted. This excretion occurred predominantly in the soil contained within a radius of 6 cm of the point of placement of the fertilizer and thus represents about 25 me/100 g soil (the bulk density was 1.12). This is a large proportion of the cation exchange capacity

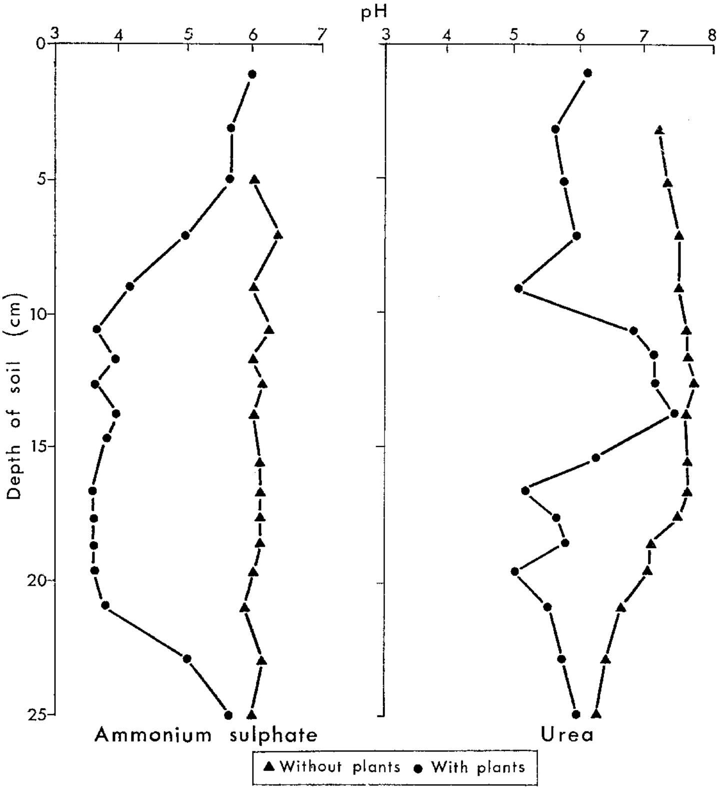


Fig. 8. Soil pH as a function of depth (through the band) for ammonium sulphate and urea 8 weeks after placement at a depth of 15 cm in sterile soil, in the presence of and absence of plants.

of the soil, namely, 34 me/100 g, and it is therefore not surprising that the pH dropped below 4.

That the roots encompassed the fertilized zone in the case of urea, and thoroughly invaded it in the case of ammonium sulphate, lends support to the suggestion made in Part I[3] that, by placing nitrogen fertilizers locally, the efficiency of their use should be increased. With a high concentration of roots in the region where nitrate is being formed, leaching of the nitrate should be minimized.

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