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INFLUENCE OF SOIL BULK DENSITY ON NUTRITION AND GROWTH IN THE TOMATO

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SUMMARY

Tomato seedlings grown in an acid krasnozem at bulk densities greater than 1·3 exhibited symptoms of stunting and purpling of stems, petioles and lower surfaces of leaves. Nutritional data presented demonstrate that uptake of mobile elements such as calcium and sodium is not affected by soil density. Phosphorus content and uptake in shoots decreased as soil bulk density increased. Although plants were phosphorus-deficient at soil bulk densities above 1·3, further additions of phosphorus caused luxury consumption of this element and no increase in dry weight. The decrease in phosphorus concentration and uptake as density increased was probably a result of restricted root distribution. This restricted root growth, together with changes in root anatomy and loosening of the soil surface at bulk densities above 1·3, support the hypothesis that inadequate pore size prevents normal root development.

I. INTRODUCTION

High soil bulk densities will influence root growth (Zimmerman and Kardos 1961), nutrient absorption (Flocker and Nielsen 1962), water relations (Flocker and Nielsen 1960), and oxygen diffusion (Gill and Miller 1956). These factors acting separately or in combination are responsible for part, if not all, of the growth peculiarities observed on plants grown in soils at high bulk densities.

On red loam soils in south-eastern Queensland, where intensive horticulture is practised, traffic-induced compaction is common, as many cultural operations are carried out by wheeled equipment when soil moisture content is high. Bulk densities as high as 1·4 are common in surface soils. Although the effects of high bulk density on plant growth have not been assessed under field conditions, its influence on water penetration, root extension, germination and clod formation is well known. Cultural operations are adjusted to eliminate these problems as much as possible.

The trials reported here were carried out under glasshouse conditions to investigate growth responses and nutrient levels in tomato plants grown in a red loam with three levels of nutrition and bulk densities ranging from 1·0 to 1·5.

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II. MATERIALS AND METHODS

Soil preparation.—The soil used in this experiment was a typical krasnozem as described by Stephens (1962), and was taken from Redlands Horticultural Research Station in southern Queensland. Chemical and mechanical analyses are as under:

pH	5·7
Ca^{++}	11·2 m-equiv. %
Mg^{++}	4·8 m-equiv. %
Na^{+}	0·17 m-equiv. %
K^{+}	0·47 m-equiv. %
Total N	0·14%
P_2O_5	0·073%
Coarse sand	5·10%
Fine sand	19·46%
Silt	28·12%
Clay	41·25%

Soil was air-dried and passed through a $\frac{1}{8}$-in. diam. screen, wet to field capacity and stored in polythene bags for 14 days.

The weight of the soil required for each density was calculated from the volume of the pot, the moisture content and the density required. The densities used ranged from 1·0 to 1·5, with increments of 0·1 between treatments. To ensure an even density throughout the pot, the amount of wet soil required for each pot was divided into four equal parts and packed with a hydraulic press in successive layers to the desired volume. As each portion was added, the surface of the previously packed layer was scarified to eliminate interfaces between layers. The final volume of soil was 2,800 c.c. The evenness of packing was tested with a bulk density sampler (Fox and Page-Hanify 1959) and found to be constant throughout the pot.

Nutrients.—Potassium, nitrogen and phosphorus were added as potassium nitrate and monocalcium phosphate at the levels indicated in Table 1. A high level of nutrition was used at one density only, namely 1·3. Boron and molybdenum were applied as foliar sprays.

TABLE 1

NITROGEN, PHOSPHORUS AND POTASSIUM (p.p.m. grav.) ADDED TO SOIL BEFORE COMPACTION

Level of Nutrition	N	P	K
Low	200	364	252
Medium	400	728	1,104
High	800	1,456	2,208

Planting, germination and harvesting.—Ten holes $\frac{1}{4}$ in. deep were made in a circle approximately 1 in. from the edge of each pot. Two seeds were placed in each hole and the soil repacked to its original volume in the hydraulic press. Emergence (hereafter referred to as germination) counts were made daily for a period of 30 days from the time seedlings began to emerge. Average rate of seed germination was calculated after the method of Harrington and Minges (1954) by summing for each day the product of the number germinated and the number of days from planting, and dividing by the total number germinated.

Soil moisture was maintained at field capacity by weighing pots and watering twice daily to replace water lost by evapotranspiration. After 7 weeks the plants were harvested and washed in distilled water. The cans were cut open and soil blocks divided into 1-in. layers. Roots were removed by sieving and washing. The samples were dried at 65°C and weighed.

Chemical analyses.—Plant samples were ashed at 550°C and analysed for phosphorus (Cavell 1955), potassium, calcium and sodium (Williams and Twine 1960), manganese, iron and aluminium (Chapman and Pratt 1961).

Physical measurments.—Soil moisture desorption curves and specific gravity were determined according to the method described by Richards (1954). Shrinkage and swelling experiments on this soil type have shown that there are no bulk density changes associated with moisture loss in the range 20-30% (grav.) (Cull 1963).

III. RESULTS

(a) Plant Growth

Germination.—The effect of soil bulk density on the rate of seed germination is shown in Figure 1. A significant linear increase in rate of germination is shown by low and medium levels of nutrition as soil bulk density increased. At these levels of nutrition, the rate of germination increased by approximately one half day for each 0·1 g/cm³ increase in bulk density. Seeds planted at the medium level of nutrition took approximately 1·5 days longer to emerge than

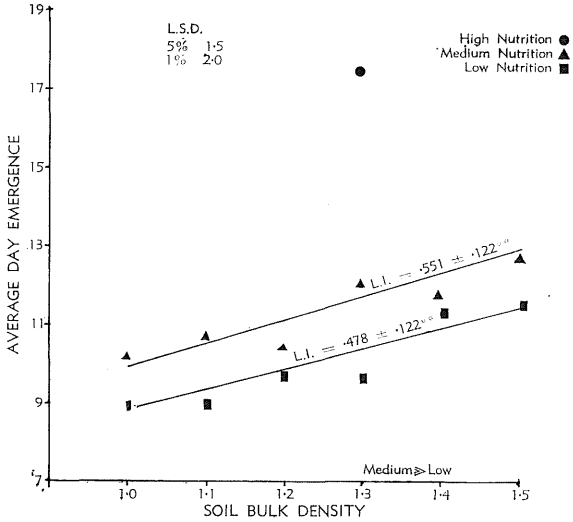

Fig. 1.—Rate of emergence. L.I. = Linear increase per $0 \cdot 1D_B$.

$$\Sigma \frac{\text{No. germinating daily x No. of days from sowing}}{\text{Total no. germinated}}$$

those at the low level. At soil density 1·3, the periods to emergence at the low, medium and high levels of nutrition were 9·7, 12·0 and 17·4 days respectively.

Oven-dry weight of tops and roots.—Oven-dry weight of tops was significantly reduced by increasing either soil density or level of nutrition (Figure 2). By increasing soil density, a highly significant linear decrease in top weight at the low and medium levels of nutrition occurred. At soil density 1·3, the weights of tops produced at the three levels of nutrition—viz. low, medium and high—were 8·5, 7·0 and 0·1 g respectively.

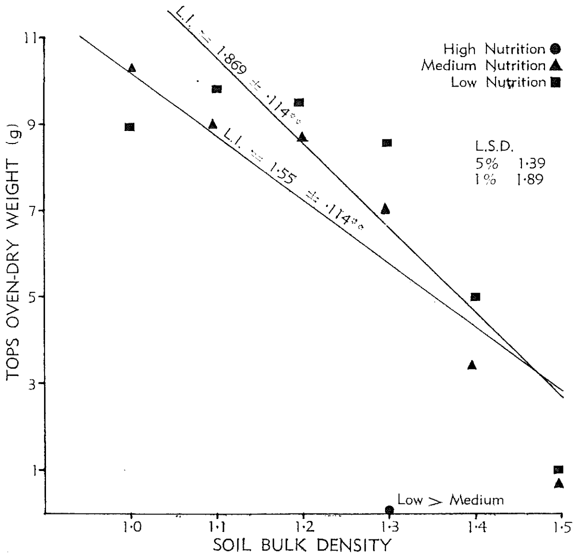

Fig. 2.—Mean oven-dry weight of tops.

The oven-dry weights of roots (Figure 3) showed similar decreases as soil density increased, with the largest root system apparent at the lowest level of nutrition.

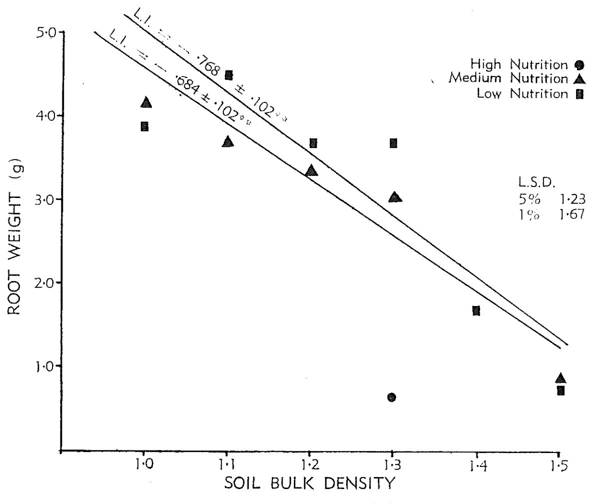

Fig. 3.—Mean oven-dry weight of roots.

Root distribution.—Root distribution data have not been statistically analysed, but the effects of density and nutrition are presented in Figure 4. In all treatments, the greatest proportion of roots was in the surface inch of soil. The effect is emphasized at soil densities in excess of 1·2, where 80% or more of the roots do not penetrate below a depth of 1 in. Level of nutrition appeared to have no effect on root distribution.

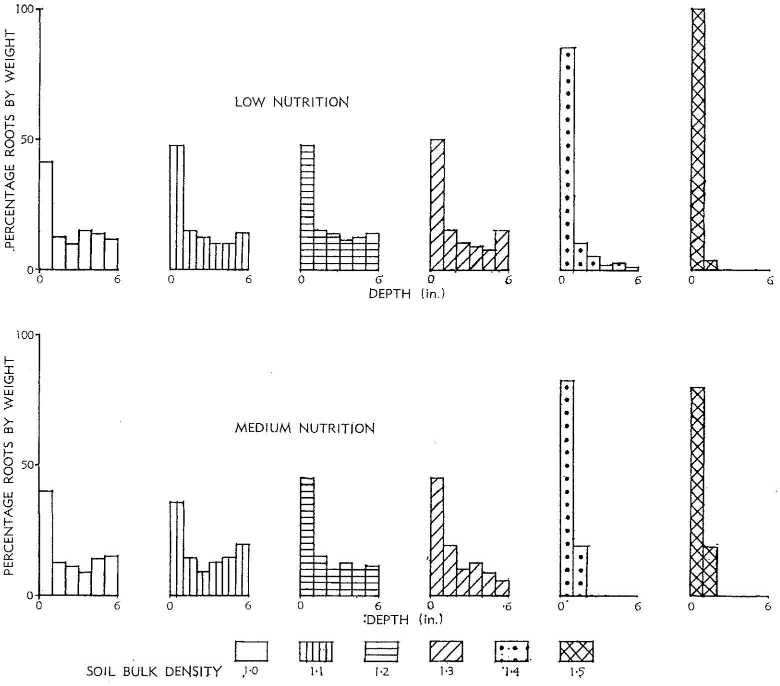

Fig. 4.—Root distribution in relation to bulk density.

Root anatomy.—Root samples were collected from soils at bulk densities 1·0 and 1·5. Macroscopic examination had shown that roots grown at soil densities above 1·3 were flattened or strap-shaped, while those from lower soil densities had the typical cylindrical form.

When roots grown at soil density 1·0 were sectioned,, they had a typical dicotyledonous structure. The flattened roots grown at density 1·5 had an atypical vascular arrangement. The xylem elements, instead of forming a normal stele, were flattened and in the most severe cases the central stele was replaced by five separate strands of vascular tissues separated by parenchyma.

(b) Nutrition

Calcium and sodium.—The calcium and sodium contents of shoot tissue showed significant linear increases as soil density increased; these results are given in Figures 5 and 6 respectively. The high level of nutrition resulted in significant increases in the concentration of both calcium and sodium in shoots. The uptake of these elements was similar at each level of nutrition irrespective of density and the increased concentration could be explained in terms of accumulation through lack of dilution from dry-weight increases.

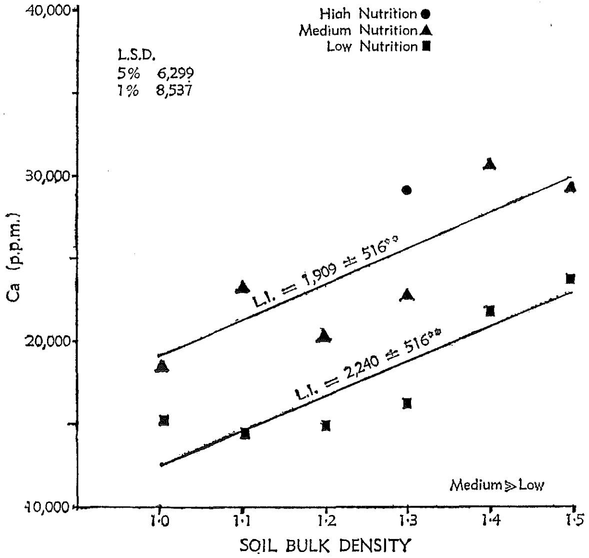

Fig. 5.—Mean calcium content of tomato tops.

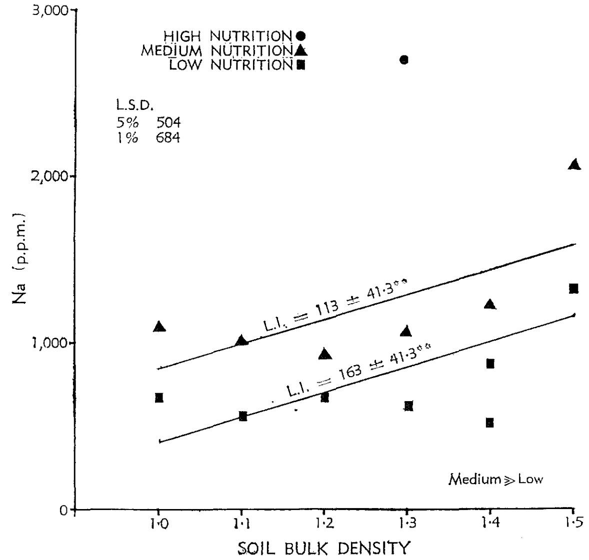

Fig. 6.—Mean sodium content of tomato tops.

Potassium.—There was no significant linear increase or decrease in potassium concentration of shoots as soil density increased. The potassium concentration increased significantly from 1·8% at the low level of nutrition to 2·4% at the medium level of nutrition.

Phosphorus.—The phosphorus contents of shoot tissue showed a highly significant linear decrease as density increased (Figure 7). An increase in the level of nutrition produced a significant increase in the phosphorus content of the tissue at all densities.

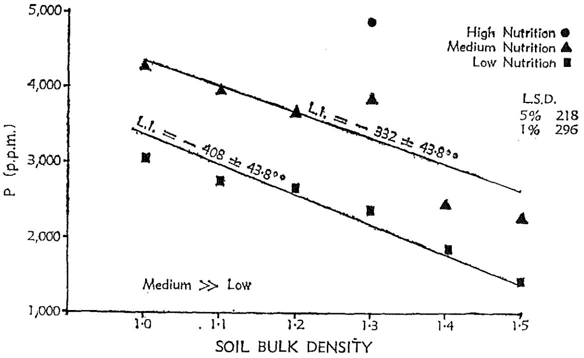

Fig. 7.—Mean phosphorus content of tomato tops.

(c) Soil Moisture and Porosity

Moisture tension curves for soil densities 1·0 to 1·5 are presented on a gravimetric basic in Figure 8. These curves indicate that changes in density had little effect on soil moisture retention.

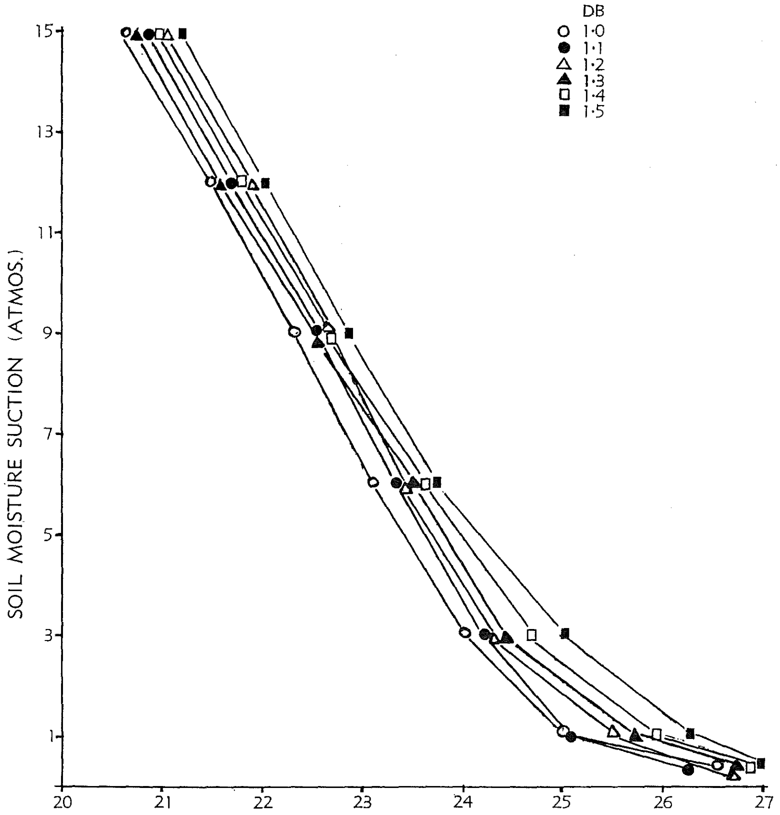

Fig. 8.—Soil moisture desorption curves for red loam.

When the soil bulk density was increased from 1·0 to 1·5, non-capillary porosity was reduced from 37% to 5% (Figure 9).

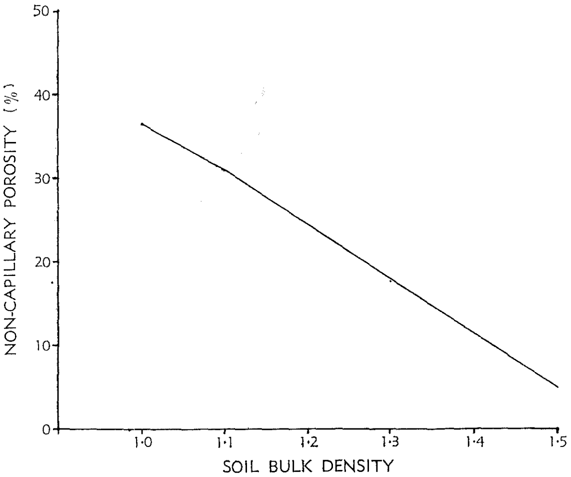

Fig. 9.—Non-capillary porosity.

IV. DISCUSSION

(a) General

At bulk densities above 1·3, plants exhibited symptoms of stunting and purpling of stems, petioles and lower surfaces of leaves. High levels of nutrients only increased the severity of the symptoms. Although these symptoms were typical of phosphorus deficiency, other contributing factors may have included poor aeration, nutritional disbalance and restricted root development.

(b) Soil Moisture

Although the induced compaction has had little effect on the soil moisture retention properties (Figure 8), it has had marked effect on root distribution (Figure 4). At soil densities in excess of 1·2, a major proportion of roots was in the top inch of soil. This restricted distribution would make a large portion of the soil moisture positionally unavailable. The increase in soil moisture by volume as density increased would not compensate for this effect. However, under the conditions of this experiment, limited root exploitation would have little influence on moisture availability as the soil was kept at field capacity by twice-daily waterings.

The increase in time to seedling emergence at higher bulk densities (Figure 1) does not appear to be related to soil moisture conditions. This is supported by the fact that at higher densities there is an increase in soil moisture (volumetric basis) and better contact between seed and soil.

(c) Pore Size Distribution

Non-capillary porosity is regarded by Vomocil and Flocker (1961) and Meredith and Patrick (1961) as a most useful estimate of soil compaction. In the experiments reported here, maximum growth was recorded at non-capillary porosities of 24–37% (Figures 2, 3 and 4). Very rapid decreases in growth and root extension were associated with a non-capillary porosity less than 24%. These data agree with those of Flocker, Vomocil, and Howard (1959), who found that a minimum of 30% air voids is required by tomatoes.

Gill and Miller (1956) demonstrated that root growth was related to the concentration of oxygen and degree of physical restraint imposed by soil pore dimensions. They found a positive interaction between root growth and oxygen in the root zone. Barley (1962) found that the combined effect of oxygen shortage and mechanical stress was more adverse than the effects produced by these factors acting singly. Although oxygen diffusion rates have not been measured, the work of Wiersum (1964) would indicate that oxygen levels could severely limit root growth at the high densities used in this experiment.

In this experiment, non-capillary porosity was reduced from 37% at bulk density 1·0 to 5% at bulk density 1·5. The effect of decreased pore size on root development at density 1·5 was shown by the restricted penetration and severe flattening or distortion of roots. As no swelling and contracting was recorded in this soil over the moisture range used (Cull 1963), the loosening of the top ¼ in. of soil at bulk densities above 1·3 was due to forces exerted by developing roots. This further supports the hypothesis that inadequate pore size at high densities restricts normal root development.

(d) Nutrition

Although sodium was not added to the soil, the concentration of sodium in tomato tops was increased by either fertilizer or increased bulk density. The concentration of calcium corresponded to the level applied as fertilizer and the increased concentration per unit of soil volume induced by compaction. When the concentration of each element is considered in relation to dry-matter yield, the uptake was similar irrespective of level of nutrition and density. The increased concentration of elements could therefore be explained in terms of accumulation through lack of dilution from growth.

The absence of an increase in potassium concentration in plant tissue as density increased may be due to the competitive effect of other cations or the lack of movement of potassium in the soil.

Manganese determinations were carried out on plants grown at bulk densities 1·0 and 1·5 and medium level of nutrition. The concentration of this element in tops of the plants at the two densities was 100 p.p.m. and 300 p.p.m. respectively.

A trial was designed to investigate the effect of manganese on plant growth (Appendix 1). The results (Figure 10) demonstrated that a manganese concentration of 300 p.p.m. will reduce plant weight. The magnitude of this effect is not sufficient to account for the growth differences recorded at the high soil densities.

Since the rate of diffusion of phosphorus through red loam is very slow, uptake will depend largely on root extension. The decrease in phosphorus concentration and uptake as soil density increased was probably due to restricted root distribution at the higher densities.

Tomato seedlings which were similar in physiological age to those grown at the higher densities responded to phosphorus as fertilizer when tissue concentration fell below 4,300 p.p.m. (Figure 11, Appendix 2). As concentrations as low as 1,400 p.p.m. were recorded in the trial, phosphorus deficiency would have been responsible for a decrease in dry matter produced (Figures 2 and 7). At the high level of nutrition and bulk density 1·3, the phosphorus concentration in tops was 4,800 p.p.m. Even though the concentration of phosphorus in tops was increased by increasing the level of nutrition, this did not lead to an increase in dry weight (Figures 2 and 7). In fact, the dry weight was significantly reduced by the increased level of nutrition, the effect being very marked at the high level of nutrition. It appears that adequate phosphorus nutrition will not produce normal growth in compacted soils. A further increase in fertilizer level aggravates the adverse growth effects due to soil compaction.

Iron and aluminium determinations were made on plants grown at the medium level of nutrition and soil densities 1·0 and 1·5. The concentration of these elements was doubled by increasing soil density from 1·0 to 1·5. The possibility existed that iron and aluminium phosphates were precipitated in the plant, thus inducing phosphorus deficiency even though total phosphorus determinations exceeded critical levels.

From the nutritional data presented, it appears that the uptake of elements such as calcium and sodium, which move readily through the soil, is similar irrespective of soil density. As dry weight per plant decreased with the increasing density, the ratios of elements in plant tissue at the different densities must vary. It may be postulated that nutritional disbalance contributed in part to the poor growth at high densities.

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APPENDIX 1

Tomato Responses to Manganese

A trial was designed to investigate the effect of high levels of manganese on plant growth. Manganese sulphate was added to a red loam seeded with Grosse Lisse tomatoes, and after 6 weeks seedlings were weighed and analysed for manganese. Dry weight (tops) decreased with increasing manganese concentration (Figure 10).

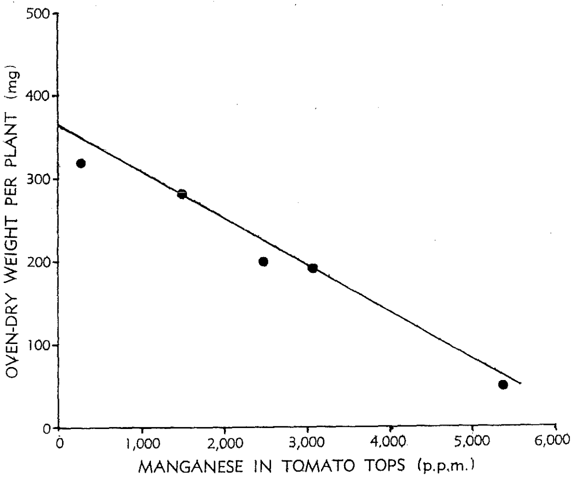

Fig. 10.—Seedling growth in relation to Mn content.

APPENDIX 2

Tomato Seedling Response to Phosphorus

Tomato seedlings were grown in a red loam to which luxury levels of nitrogen and potassium were added together with several levels of monocalcium phosphate. The plants were harvested for analysis at the same physiological age as seedlings which were showing suspected phosphorus deficiency symptoms in the bulk density trial. Oven-dry weight of the tops is plotted against phosphorus concentration in Figure 11. Dry weight increased with phosphorus content up to 4,300 p.p.m. and thereafter there was no change in dry weight as phosphorus content increased.

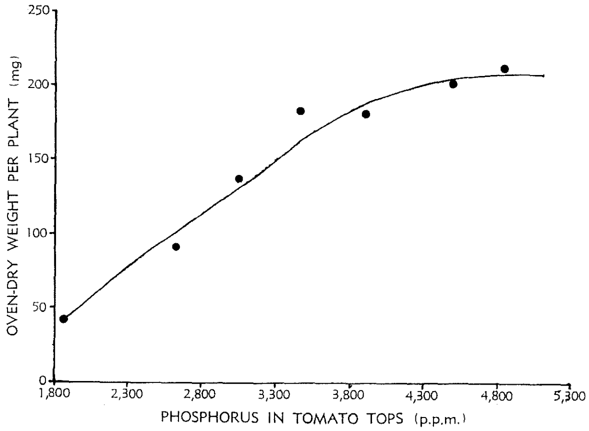

Fig. 11.—Dry-matter yield and phosphorus content of tomatoes.

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