SOME EFFECTS OF SOIL COMPACTION ON ROOT GROWTH, NUTRIENT UPTAKE, AND YIELD

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Root growth and nutrient uptake are obviously related, and yet not well understood under field conditions. An oversimplified premise is that plant roots must grow to the site in the soil where the nutrients are retained, or that the nutrient must move to the absorbing root surface (or both). Relationships developed under well controlled uniform laboratory conditions often do not extrapolate to field conditions. In this respect, progress is often hindered by the fact that root growth measurements are difficult at best and generally destructive. Nevertheless, there are some field studies that can provide some insights on how root growth and nutrient uptake are affected by soil environment. The objective of this paper is to briefly review and discuss some observations from field studies over the last 10 years in Minnesota concerning the effect of wheel-induced soil compaction on root growth, nutrient uptake, and crop yield. These field studies are being conducted at the Southwest Experiment Station at Lamberton, and the Southern Experiment Station at Waseca. The soils are Nicollet and Webster clay loams, typical of the corn-soybean regions of southern Minnesota and northern Iowa. Cultural practices on these experiments are typical of surrounding farms, including the use of large field machinery. One obvious exception is that all wheel traffic from all field operations is controlled to occur only between the rows and in the same place every year. Root growth data was obtained using the modified monolith method (Nelson and Allmaras, 1969) whereby roots were extracted from a volume of soil 1.5 m wide (2-30 inch rows) 90 cm deep and 38 cm front to back. Root length was determined by the method developed by Voorhees et al. (1980).

Based on 60 monoliths of corn and soybeans sampled about 60 days after planting over a 3-year period (1973-1975) from experiments conducted at Lamberton, about 50% of the total root length and about 80% of the total root weight is located within the surface 30 cm of soil. This surface 30 cm is also most easily altered by various management practices. For example, wheel traffic of normal farming operations can decrease total porosity by 10 to 15% and increase penetration resistance by a factor of 4 (Voorhees et al., 1978). Root growth is affected by both of these factors. Since most of the applied fertilizer is incorporated within this surface 30 cm, it becomes important to consider how wheel traffic affects root distribution and nutrient uptake.

Figures 1 and 2 show the root length density (cm of root/cm^3 soil) for soybeans and corn, respectively. Within the surface 30-cm layer, root distribution is delineated into the row zone (a 30-cm wide nontrafficked volume of soil) and the 23-cm wide interrow zone on either side.

The layer of soil at the 30-to 45-cm depth is a transition between the tilled layer and the subsoil. Depending on the year, this transition layer is generally not compacted by wheel traffic from vehicles with axle loads < 5 tons. The soil deeper than 45 cm is termed "subsoil" and was not compacted in these particular studies. The average total root length of soybeans was not affected by wheel traffic compaction (148 meters per monolith vs. 147 meters). However, the distribution was. Interrow wheel reduced the root length density from 0.05 to 0.04 cm/cm^3, and increased the root length density in the row from 0.10 to 0.13. There was no difference below a depth of 30 cm.

Total root length for corn was decreased from 266 meters to 228 meters by interrow wheel traffic (see fig. 2). Distribution of the root system was also affected. The root length density was decreased throughout the surface 45 cm but increased in the subsoil.

Two apparent differences between corn and beans with respect to interrow wheel traffic: (1) with corn, total root length was decreased, but the quantity of roots in the subsoil was increased by wheel traffic compaction, i.e., surface layer compaction forced a higher proportion of the corn root system to grow deeper; (2) with soybeans, the total length was unaffected but surface compaction caused more of the roots in the upper 30 cm to concentrate in the row zone.

Phosphorus concentration in soybean in 1975 is shown in figure 3. The "low P" plots had received no phosphorus fertilizer for a number of years (soil test was "low"), whereas, the "high P" plots received 132 kg/ha of P_2O_5 broadcast every year since 1973. Soybeans were grown in rotation with corn, and the corn plots were fall plowed. The solid curve represents the % P in soybean plants in rows that had wheel traffic on both sides of the row (right-hand side of fig. 1), while the broken curve represents plants from rows with no wheel traffic (left-hand side of fig. 1). The higher concentration of phosphorus in plants from the wheel-tracked row may be associated with a higher root length density in the row zone or better root-soil contact in the surface 30 cm of soil. The total uptake and accumulation of phosphorus by soybean expressed as kg P/ha also shows interrow wheel traffic compaction to be beneficial (fig. 4).

The growing season precipitation for 1975 was about 60% of average. Under relatively dry conditions, phosphorus uptake should be potentially increased by higher root concentration and higher volumetric water content as a result of wheel traffic compaction. This resulted in increased yield as shown in Table 1. Under both "low" and "high P" interrow wheel traffic increased soybean yields by about 300 kg/ha. This beneficial effect of interrow wheel traffic is highly dependent on growing season precipitation. The change in soybean yield due to wheel traffic compaction over a 10-year period is plotted against growing season precipitation in figure 5. When May-August precipitation exceeds 400 mm ($\sim$ 16 inches), soybean yields may be decreased by 5-10% due to interrow wheel traffic compaction. During relatively dry years, however, (< 400 mm) yields were increased substantially, presumably because of the change in surface layer rooting patterns and phosphorus uptake.

Corn response to interrow wheel traffic was similar to that of soybeans in some respects and dissimilar in others. The percent phosphorus in the whole plant was higher in rows having wheel traffic on both sides (similar to soybeans in fig. 3), but only for the "low P" treatment. When phosphorus fertilizer was added, wheel traffic had no effect on P uptake by corn. Total accumulation of P by the whole corn plant was increased by 40% due to wheel traffic as a combined result of increased concentration in the plant and increased dry matter, but only for the "low P" treatment.

The influence of interrow wheel traffic and growing season precipitation on corn yield was not as well defined as it was for soybeans. Long term corn yields tended to show the opposite response, with yields being decreased by compaction during relatively dry weather. The three years in which the root data in figures 1 and 2 were collected can be characterized as being drier than average. Under "dry" conditions, interrow wheel traffic reduced total root length of corn which could limit the amount of water taken up by the plant and thus reduce yield in spite of increased P uptake.

Two important constraints in the discussion thus far need to be emphasized. The root data shown in figures 1 and 2 are from relatively dry years. Under wetter soil conditions, the compaction patterns, and root response to it, may be quite different. Secondly, the discussion thus far has been limited to surface soil compaction (< 30 cm deep).

The extent to which a soil will compact at deeper depths is a function not only of applied surface pressure but also total load. Practically, this means that axle loads greater than 5 tons may cause compaction deeper than normal tillage depths. The primary source of such axle loads are the harvest and associated transport equipment. Such equipment is not only heavy, but is often used when soils are wet and easily compacted. A series of field studies are currently being conducted across the northern United States and northern Europe to evaluate the effect of heavy axle loads on plant growth over a range of soil and climatic conditions. In Minnesota, experiments are being done at Waseca and Lamberton. The heavy axle load treatments were applied in the fall of 1981 only, with all subsequent traffic limited to ≤ 5 tons per axle. The treatments consist of 10 tons/axle (typical unloaded combine with 6-row corn head) and 20 tons/axle (typical for larger loaded combines and large grain wagons). Whereas, axle loads < 5 tons typically compact only in the surface 30 cm, compaction was measured to a depth of 60 cm under the 20 ton axle load (Voorhees et al., 1985). Direct measurements of root growth are not being made but indirect evidence of rooting depth are being ascertained from periodic soil water content measurements.

One of the more obvious results of the subsoil compaction is a wetter soil profile early in the season. This often results in near-anaerobic conditions in the surface soil, accompanied by higher rates of denitrification (Caskey et al., 1985). This, coupled with possible rooting depth restrictions, can result in decreased nitrogen uptake by corn as shown in figure 6. About 60 days after planting, corn growing on 20 ton/axle compaction plots at Waseca shows a drastic reduction in nitrogen accumulation compared to corn on the check plot. Corresponding soil water extraction data suggests reduced root growth activity in the 30-60 cm layer at this time. Final grain yield was reduced by 27% due to subsoil compaction. Rainfall was slightly below average in 1982. Qualitatively similar yield results have been obtained in subsequent years.

Summary

Wheel traffic from normal field operations can drastically affect root growth and nutrient uptake. This may be a result of reduced root growth, decreased rooting depth, or spatial redistribution of the root system. Soybeans generally have less total root length than corn and thus may be more sensitive to placement of phosphorus fertilizer relative to where the roots are concentrated in the surface 30 cm of soil. Wheel traffic can concentrate the roots in the row zone (when there's a track on both sides) or cause the roots to concentrate on one side of the plant if there's wheel traffic on only one side of the row. Thus, the need to consider relative placing of banded fertilizer with respect to location of interrow wheel traffic.

Ridge-till planting is increasing in the Corn Belt. There appears to also be an increase in the number of farmers using duals on the tractor during planting, and more recently, duals on the combine to facilitate harvest during wet weather. Since freezing and thawing are not very effective in removing wheel traffic compaction (Voorhees 1983), we can probably anticipate some root growth-nutrient uptake problems in some rows.

Perhaps one of the most important things to realize is that in spite of all the good things about conservation tillage, we do not let ourselves be lulled into thinking that compaction will not occur under such a system. We need to realize the potential for subsoil compaction from the heavy axle loads of harvest and transport equipment. These machines are used on our fields regardless of the kind of tillage we use -- or don't use. Subsoil compaction can affect rooting depth and activity because of high mechanical resistance and by creating anaerobic conditions, both of which may result in decreased nutrient uptake and yield reduction.

Literature Cited

1. Caskey, W. H., W. B. Voorhees, and J. F. Johnson. 1985. Effect of compaction on nitrifying and denitrifying activity in soil. Soil Sci. Soc. Amer. J. (submitted).

2. Nelson, W. W., and R. R. Allmaras. 1969. An improved monolith method for excavating and describing roots. Agron. J. 61:751-754.

3. Voorhees, W. B. 1983. Relative effectiveness of tillage and natural forces in alleviating wheel-induced soil compaction. Soil Sci. Soc. Amer. J. 47:129-133.

4. Voorhees, W. B., V. A. Carlson, and E. A. Hallauer. 1980. Root length measurement with a computer-controlled digital scanning

microdensitometer. Agron. J. 72:847-851.

5. Voorhees, W. B., W. W. Nelson, and G. W. Randall. 1985. Extent and persistence of subsoil compaction caused by heavy axle loads. Soil Sci. Soc. Amer. J. (submitted).

6. Voorhees, W. B., C. G. Senst, and W. W. Nelson. 1978. Compaction and soil structure modification by wheel traffic in the northern Corn Belt. Soil Sci. Soc. Amer. J. 42:344-349.

Table 1. Soybean yield as affected by interrow wheel traffic compaction at two levels of phosphorus fertility. Lamberton, MN 1975.

	Low P		High P	
	No wheel traffic	Wheel traffic	No wheel traffic	Wheel traffic
Kg/ha	1680	1956	1962	2332
Bu/a	25.0	29.1	29.2	34.7

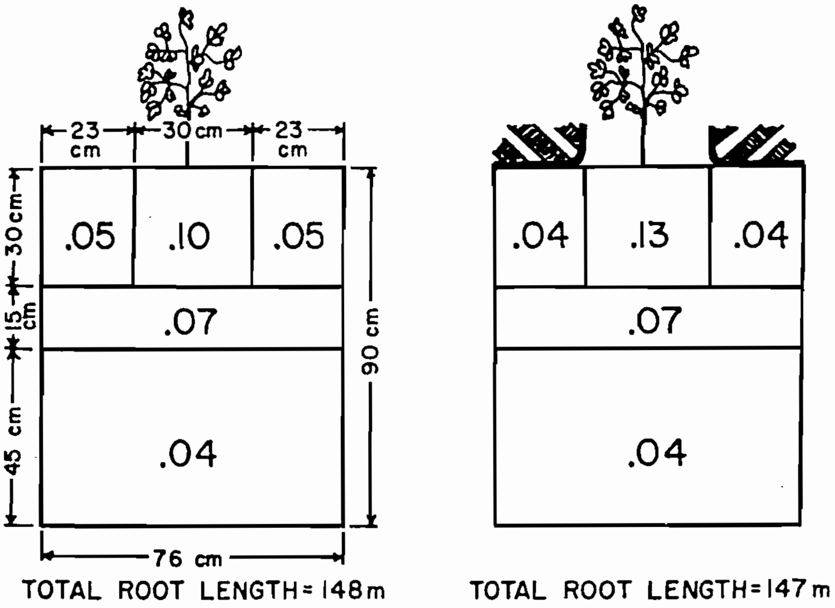

Figure 1. Soybean root length density (cm root/cm^3 soil). Lamberton, MN, 1973-1975.

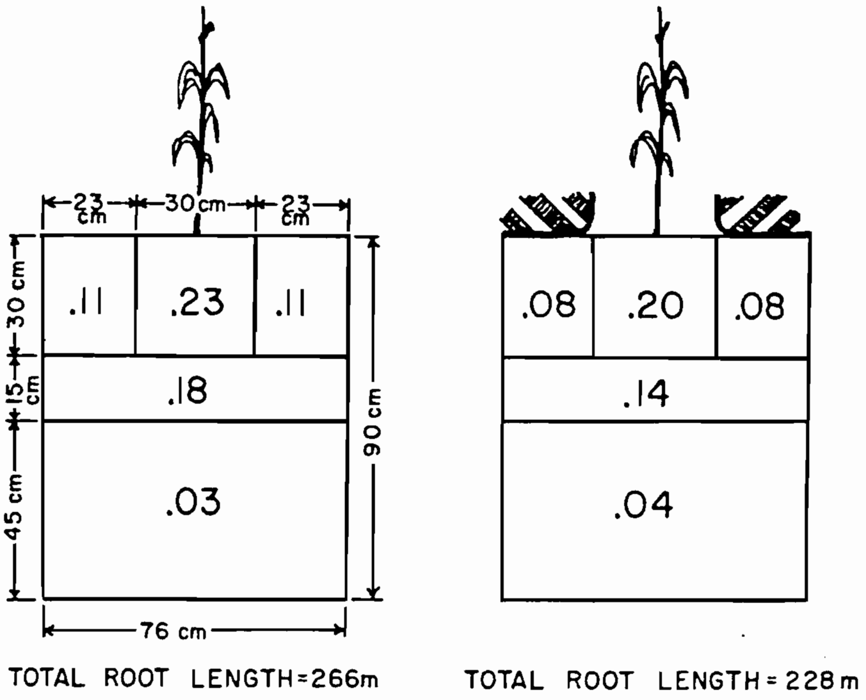

Figure 2. Corn root length density (cm root/cm^3 soil). Lamberton, MN, 1973-1975.

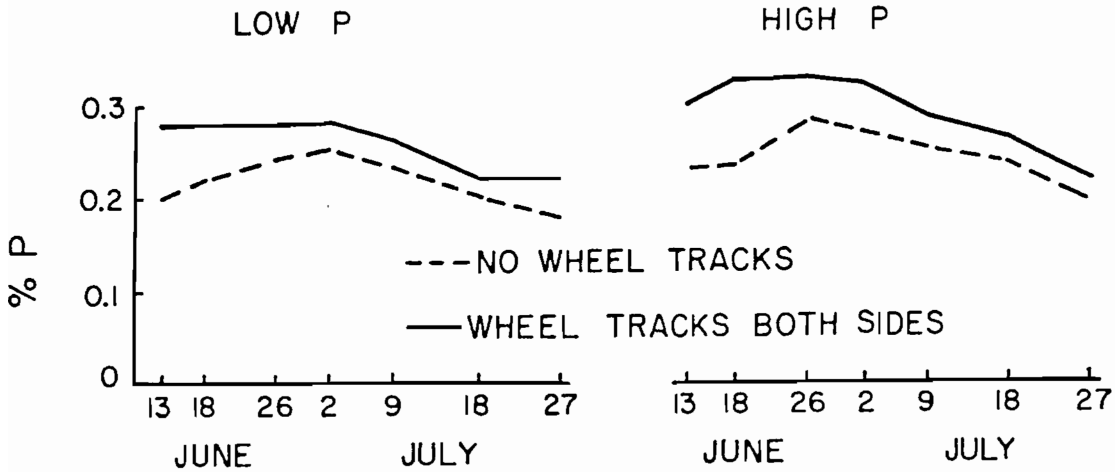

Figure 3. Concentration of phosphorus in soybean as affected by by interrow wheel traffic at two levels of soil P. Lamberton, MN, 1975.

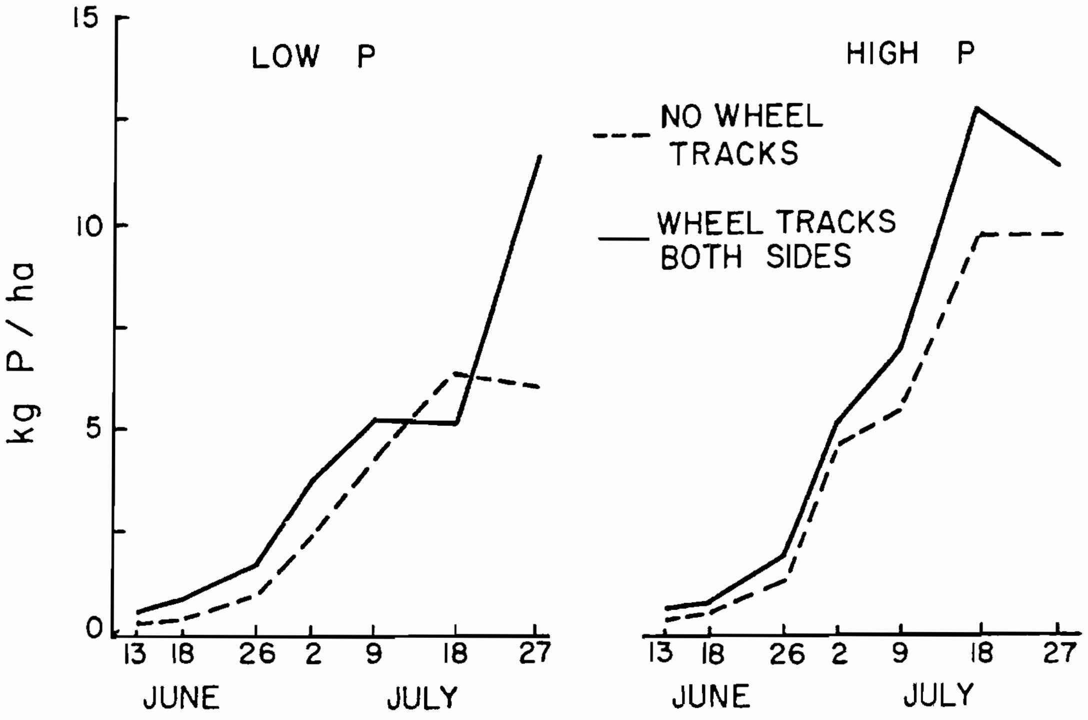

Figure 4. Accumulation of phosphorus in soybean as affected by interrow wheel traffic at two levels of soil P. Lamberton, MN 1975.

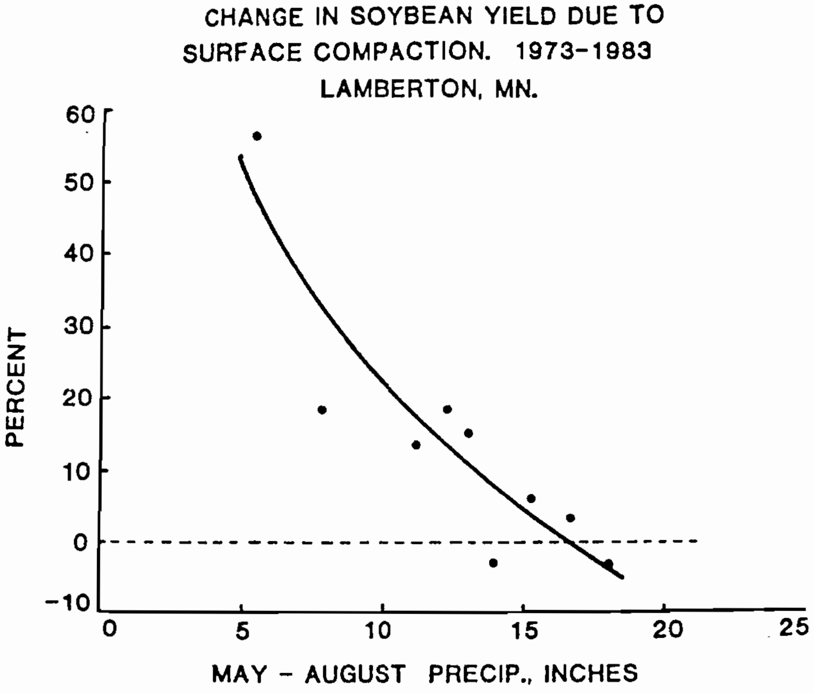

Figure 5. Change in soybean yield due to interrow wheel traffic as a function of growing season precipitation. Lamberton, MN, 1973-1983.

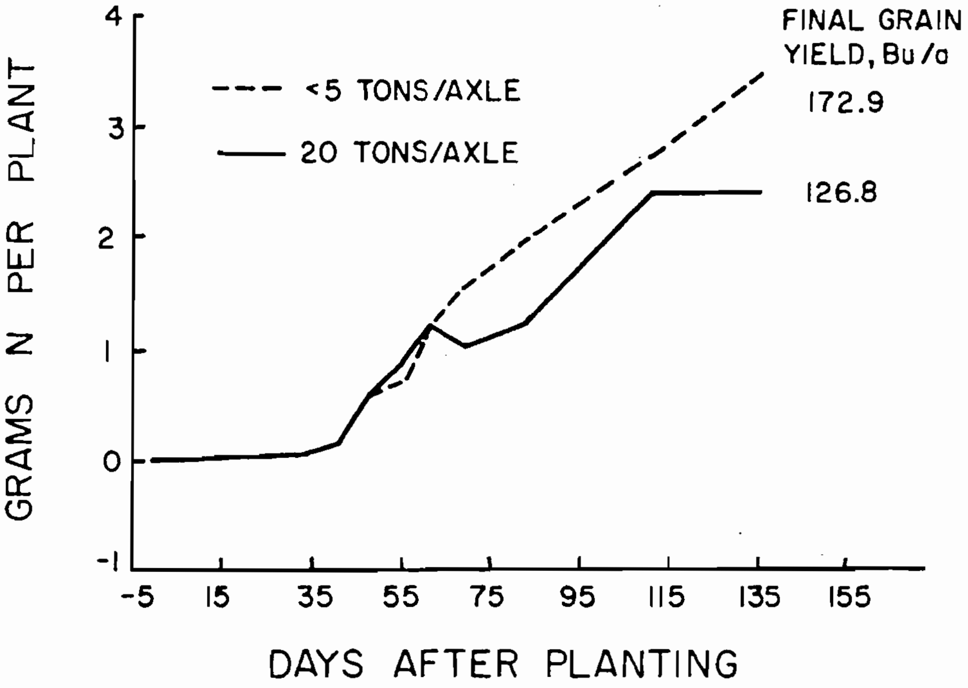

Figure 6. Uptake of nitrogen by corn as affected by subsoil compaction. Waseca, MN, 1982.

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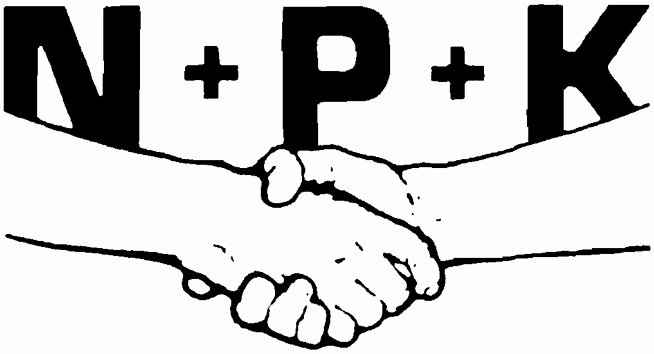

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