eutrophication of lakes in the United States (Sharpley and Rekolainen, 1997).

Management practices such as conservation tillage used to improve water quality by reducing sediment and sediment-bound nutrient export from agricultural fields and watersheds in warm, humid regions may be effective for reducing sediment and N losses, but less effective for reducing P losses in cold, dry regions where the nutrient export is snowmelt driven and primarily in the dissolved form. In these situations, it may be more practical to implement management practices that reduce the accumulation of nutrients in crop residues and surface soils. One possible management option raised in the study by Tiessen et al. (2010) is that there may be potential benefits from some tillage operations in the fall prior to freeze-up and snow events. These tillage operations would incorporate a portion of crop and weed residues, as well as any manure applications, so that less soluble P will be at the soil surface and available to be exported from fields during snowmelt runoff. However, further research is required to test this theory.

From a practical viewpoint, all of the studies mentioned above show that STP is a very important factor in the amount of P lost from fields in the NGP, suggesting that P in runoff can be minimized if STP levels are not excessive. The same principles can be applied to N management, in that N additions from manure and inorganic fertilizer sources should be sufficient to supply crop needs, but not excessive to result in unnecessarily high levels of residual inorganic N (NO_3^- and NH_4^+) in topsoil. There needs to be further research determining what STP level guidelines should be, and what management practices can be used to control P losses from fields in cold climate regions of North America.

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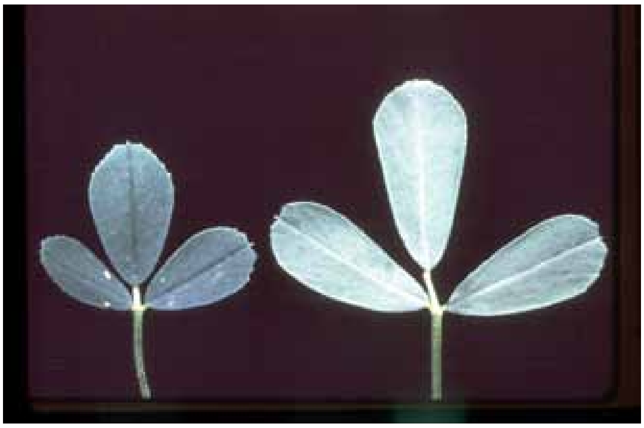
Visual Indicators of Phosphorus Deficiency: Selected Crops

Phosphorus deficiency in canola

Phosphorus deficiency in canola



Phosphorus deficiency in alfalfa

Small deficient leaflet compared with healthy leaflet (right).

Phosphorus deficiency in winter wheat

Wheat crop followed long-term alfalfa with little fertilizer application. Problems with starter fertilizer application are apparent from the poor growth. The P soil test in the effected rows was 3 ppm, while in rows growing normally it was 13 ppm

Phosphorus deficiency in cabernet sauvignon grape.

Phosphorus deficiency in potato (var. Russet Burbank).

Phosphorus deficiency in sorghum

Phosphorus deficient sorghum plant that has developed a dark purple colour on its older leaves.

Phosphorus deficiency in barley

Affected purple leaves turn dark yellow to orange red.

Phosphorus deficiency in corn

Younger leaves turn purple resulting in no, or rudimentary, cob formation. The crop grown on NPK omission plot. The soil test P was 8 mg/kg. The plot received continuous rains for past 45 days. The surface soil partially removed during levelling resulting in poor organic matter status.

Phosphorus deficiency in canola

Direct seeded into alfalfa stubble. The previous alfalfa crop depleted soil P and, in this case, the farmer ran out of seed-row P fertilizer on the last pass during seeding, causing slow and stunted growth.

Phosphorus deficiency in corn

Corn planted April 12; photo date June 16. Growth stage V-9. Tissue analysis May 22 indicated P at 0.12%.

Phosphorus deficiency in cabbage

Grown on an acid soil site with low soil test P.