

Managing Phosphorus

C. Grant Kowalenko

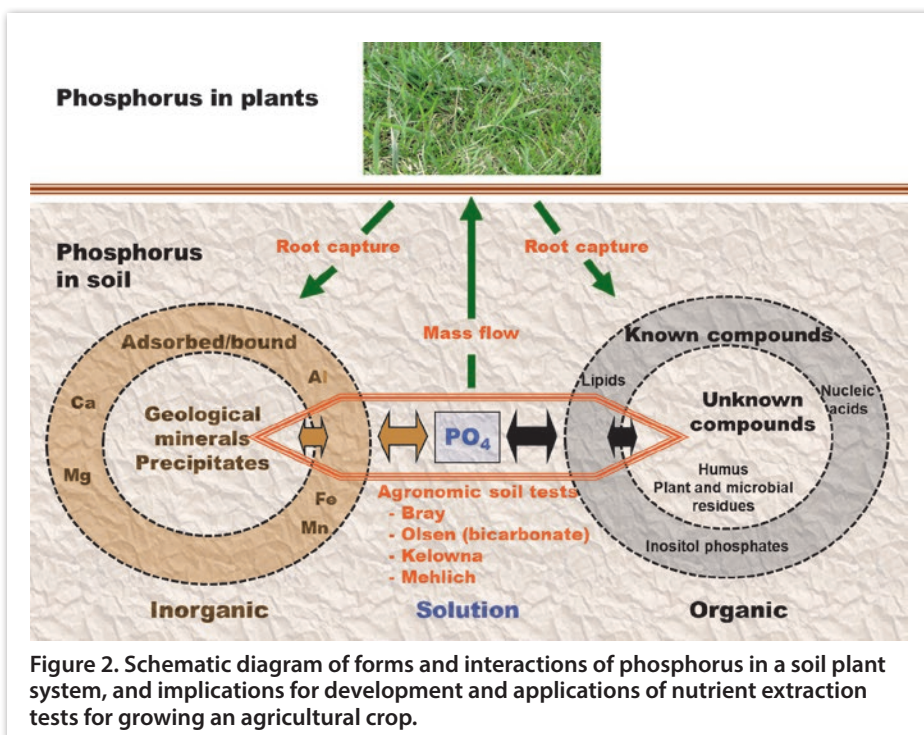
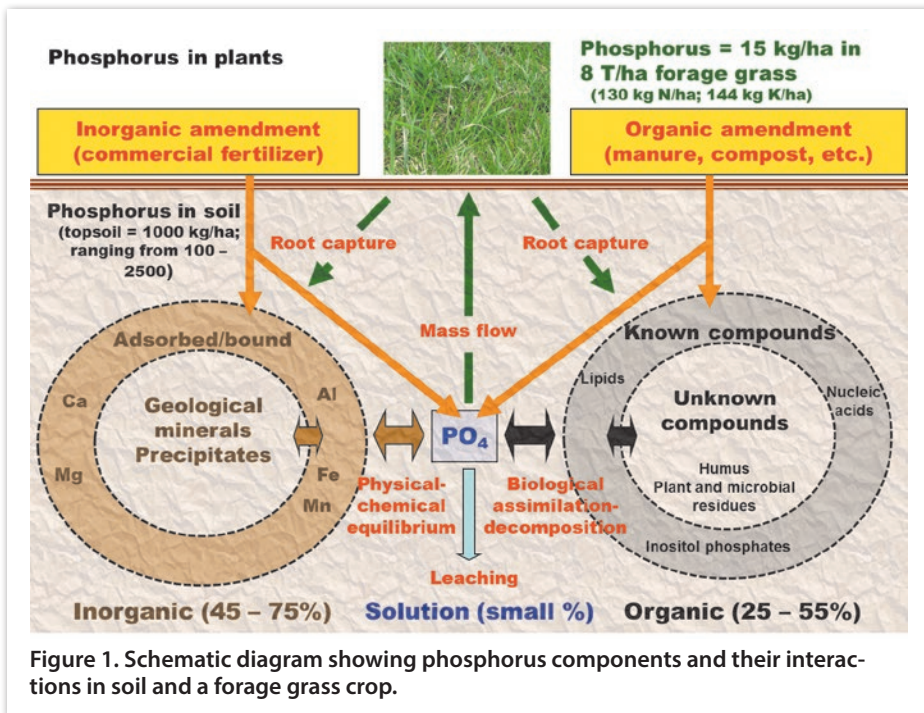


Phosphorus (P) is an essential plant nutrient. Although most temperate soils contain significant quantities of P, it is frequently added as fertilizer, manure, compost etc. to improve crop yields. Conversely, P is a potential pollutant if even very small amounts are transported into fresh water bodies, because P in these water bodies will stimulate algae growth which over time results in oxygen depletion and harm to aquatic life. Therefore P management on farms must balance economic and environmental interests. Knowledge about the forms of P in soil and how they relate to both plant growth and pollution risk helps in devising appropriate management practices.

Typical agricultural topsoils contain about 1,000 kg/ha (900 lb/ac) of P, but range from 100–2,500 kg/ha (90–2250 lb/ac) (Fig. 1) (Negessa and Leinweber 2009; Tisdale et al. 1985). Most soil P is bound in inorganic or organic forms and only a small portion is in soil solution as the plant available phosphate anion. Neither the inorganic nor the organic fraction is composed of a single homogeneous form, rather a series of forms of varying size and solubility. The small fraction of P which is dissolved in the soil solution is in equilibrium with the inorganic and organic fractions through physical-chemical reactions

or biological processes. Since most soil P is insoluble, it is quite immobile and not readily leached. Identification and quantification of specific P fractions is imprecise with current analytical methods; compounds in the soil are transient and chemical analyses are subject to interferences. Only small proportions of specific organic P compounds have been quantified by direct measurement (i.e. extraction and purification). Hence P fractions are functionally defined by their relative solubility in a continuum of chemical solutions: labile, available, reactive, sparingly soluble, etc.

The essential functions of P in plants are energy transfers (ATP) and genetic coding (DNA). As there is no structural role for P, only small amounts are needed, although larger amounts are needed by animals for bone formation (Fig. 1). For example, 8 T/ha of grass (~4 t/ac) takes up about 15 kg of P (~33 lb) from the soil in a year, a tiny fraction of what is present (Fig. 1). That crops often benefit from application of P shows that most soil P is not readily available to plants. As plants absorb P from the soil solution, P adsorbed by soil particles replenishes the soil solution by equilibration processes. Juvenile plants require high concentrations of P during rapid growth, thus young plants with insufficient P tend to show signs of deficiency (purpling), which later results in reduced growth and delayed maturity. Plants



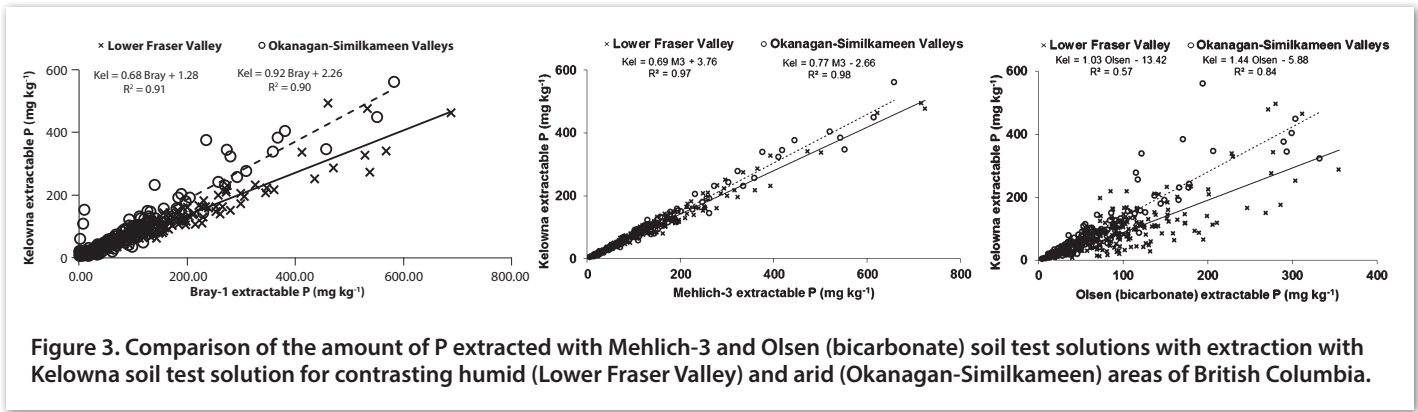
obtain P from the soil solution when they absorb water (i.e. mass flow), and by extending their root system to ‘capture’ P bound by soil particles. Root exploration is enhanced by symbiotic fungi called arbuscular mycorrhizae (AM) that associate with roots of most crops (except the Cruciferaeae and some other crops) (Bittman et al. 2006). Small amounts of P placed near roots often have noticeable effects (referred to as pop-up effect) on juvenile plants and early season P application is more effective than late application once the root system has expanded. Management factors

such as previous crop and tillage practices affect the amount of P that should be applied to the crop.

Phosphorus added to soils varies in solubility depending on the type of inorganic and organic amendment, but it eventually becomes incorporated into soil constituents (Fig. 1). Soluble inorganic P (phosphate) is subject to extraction by plants and rapid physical-chemical binding in soils. Organic P is gradually released from amendments through biological decomposition. Most organic amendments such as manure, compost and biosolids have a high ratio of P to nitrogen (N). This is because N is more easily lost, usually as a gas (especially by volatilization of ammonia and denitrification of nitrate), whereas P does not get lost to the air. Plant N:P ratio is between 5:1 and 10:1. Amendments are often less than 5:1, so where amendments such as manure or biosolids are added to soil at agronomic N rates, P will likely accumulate in the soil. The build-up of P in soil will eventually cause a nutrient imbalance that will reduce plant growth and will increase the risk of polluting water.

Soil tests have been developed to determine the P supplying power of soils. Simply measuring the amount of phosphate in a water extract will not predict how much of the bound P will be taken up by the plant. Current soil tests employ various solutions that will extract some of the bound P in proportion to what the plant will utilize in a growing season (Fig. 2). These extracting solutions were selected with a focus on the inorganic fraction of the soil, assuming that it is the predominant

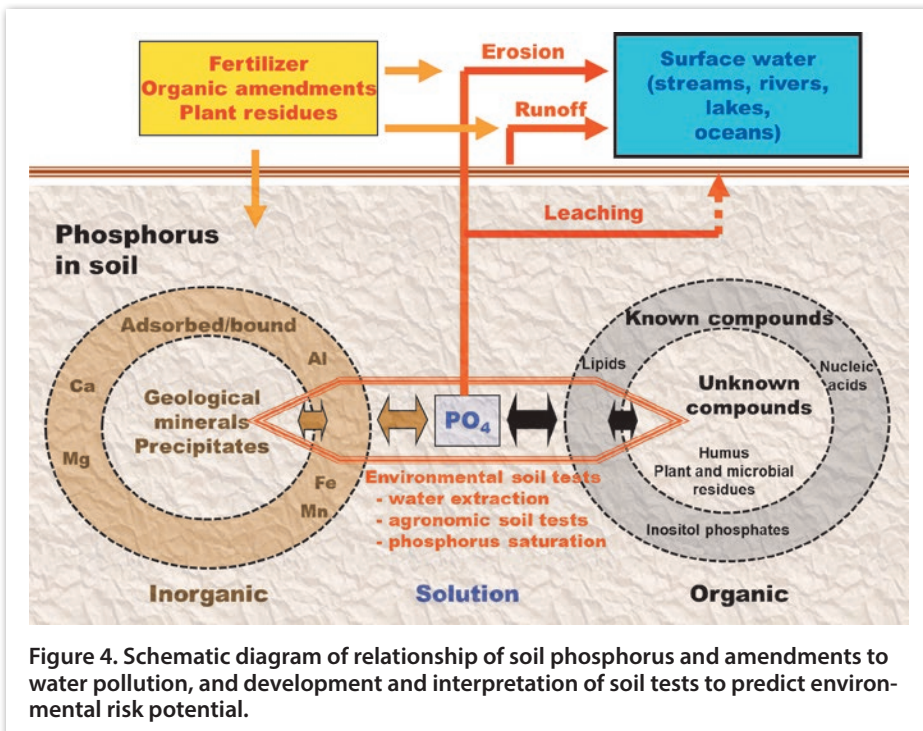
source of plant available P. The extractants function differently across soils, particularly acidic vs. alkaline (Kowalenko and Poon 2010). The Bray extractant is acidic and appears to work best in acidic soils; the Olsen extractant is alkaline and appears to be more suitable for alkaline soils. While these extraction solutions were developed specifically for P, more recent extracting solutions e.g. Kelowna and Mehlich contain a complex mixture of chemicals for extracting multiple nutrients simultaneously for greater versatility and efficiency. While these methods are fairly well correlated,



the amount of P extracted varies with soil (Fig. 3). For example, the regression coefficients (R²) between Kelowna and Bray-1 P extractions are high (0.9), but Bray-1 extracts significantly more P than Kelowna from Lower Fraser Valley soils (humid area of British Columbia) than from Okanagan-Similkameen soils (arid area of British Columbia). Mehlich-3 extracts more P than Kelowna regardless of region. Kelowna extraction (which is acidic) is more closely correlated with other acidic extracts (e.g. Bray-1 and Mehlich-3) than with Olsen extraction (which is alkaline). Unlike older analysis methods (e.g. colorimetry) which measured only inorganic P, newer analytical instruments (e.g. inductively coupled atomic emission spectrophotometry) quantify both organic and inorganic P. Hence in the past, less attention was focused on the potential availability of organic forms of P (Kowalenko 2005). We have recently discovered that colorimetry, a common analysis method that was thought to measure only inorganic P, includes some organic forms and, further, is subject to interferences by other elements (Kowalenko and Babuin 2007). Clearly,

more work is needed to improve the predictive ability of soil tests for P.

The environmental impact of P has been increasing, especially in locations with intensive crop and livestock production. The predominant concern is transport of P into surface water, where it leads to oxygen depletion through a process called eutrophication. Phosphorus is transported to surface water by runoff, leaching and soil erosion. As P bound to soil or organic material cannot leach, P leaching can be a factor only in soils that bind P less readily and/or are artificially drained with tiles. Runoff transports soluble P while particulate P is transported by erosion. Management factors that minimize runoff and erosion such as conservation tillage, perennial crops, buffer/riparian strips, grassed runways, and distance from surface water bodies, will minimize risk of P transport to surface water. But most importantly, P pollution risk can be reduced by minimizing the quantity of P in the soil; the risk of P pollution by runoff and erosion is greatest for soils that have high concentrations of P, especially labile and soluble forms. Soil



tests and field assessments are being developed (Pellerin et al. 2006; Sharpley et al. 2008; Sims et al. 2002) to determine the potential for agricultural soils to be a source of P pollution (Fig. 4). Soils with high concentrations of P (especially phosphate) in solution are at high risk during runoff events, and this is well predicted by simple water extraction. While soils vary in their ability to bind P, the proportion that is bound decreases as more P is added to the soil (Fig. 5). Measurements that estimate the relative degree of saturation of P binding mechanisms provide an indication of future potential for pollution as amendments result in accumulations (Giroux and Tran 1996). Agronomic soil tests used to estimate P available to plants over a growing season can be useful to determine P

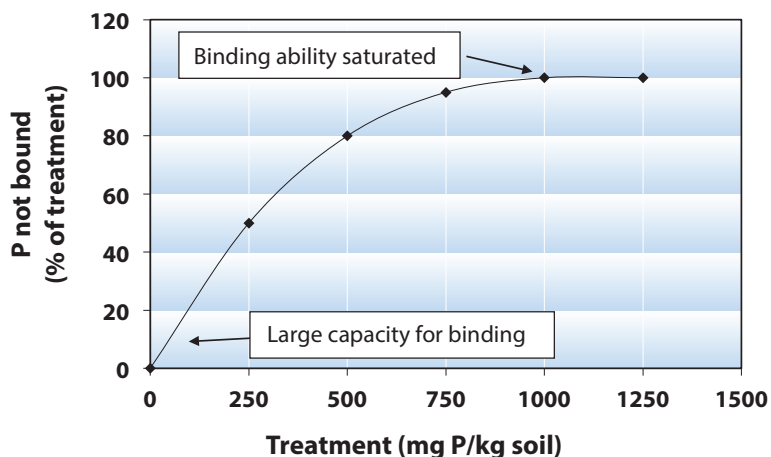


Figure 5. Example of the proportion of unbound P in a soil supplied with increasing doses of P (indicated as soil P concentrations).

pollution risks once appropriate relationships are derived.

Agricultural land in proximity to urban centers in British Columbia is intensively managed because of its limited supply and high cost, and we are currently studying risk of pollution from P accumulations in these soils (Kowalenko et al. 2007, 2009). With the help of previously published reports, we have proposed risk categories based on amounts of water-extracted P (Table 1). Water extractable P is the most direct indicator of immediate pollution risk. We compared water extraction with the Kelowna extraction routinely used for agronomic soil testing in British Columbia and elsewhere. Where the ratio of water to Kelowna extractable P is low, the environmental and agronomic categories (low, medium, high) for a given P concentration are similar (Table 1). The ratio of water extractable inorganic P (phosphate) to Kelowna extractable P is very low (~7%) in Lower Fraser Valley soils but much larger (~15%) for Okanagan-Similkameen soils (Fig. 6). For example, when 10 mg/kg (10 ppm) is extracted with Kelowna solution from Lower Fraser Valley soils, only ~0.7 mg/kg (0.7 ppm) is water extractable, thus a low environmental risk. However, the proportion of water to Kelowna extractable P is higher in Okanagan-Similkameen soils, hence values for environmental categories would be lower than for agronomic categories for a given P concentration. In these soils, restricting P amendments to reduce environmental risk would probably reduce crop yields. Thus, adding P to satisfy crop requirements on these low phosphate binding soils calls for greater attention to reducing the potential for P transport. Fortunately, the Okanagan-Similkameen area has low rainfall which naturally minimizes the risk of P transport.

We developed a low cost method for determining the degree to which a soil is saturated with P to determine the potential for pollution. The method is based on equilibrating a soil with a fixed concentration of phosphate (50 mg P/kg). Another P saturation index used in some regions is the ratio of P to aluminum (Al) extracted within a Mehlich-3 solution (Pellerin et al. 2006). This index is based on the theory that most of the binding of P is associated with Al, which is most appropriate for acidic soils. A ratio of P to Ca or Mg, rather than to Al is used for neutral to alkaline Manitoba soils since these elements dominate the binding of P (Ige et al. 2005).

We have proposed environmental risk categories (Table 1) based on the effect of the P amendment on water extractable phosphate. Applying these environmental risk criteria to surveys of British Columbia commercial fields showed that about 80% of fields in the Lower Fraser Valley are at high to very high P risk according to water and Kelowna extractions, but the percentages are only 39–53% when based on P/Al extractions (Table 2). This difference between the indices reflects the large P binding capacity of the soils in this area. A large proportion of Okanagan-Similkameen fields (54–89%) were also high and very high risk according to Kelowna and water measurements, respectively. Based on the ratio of 15% between water and Kelowna extractable P, 91% of fields in this region are in the high to very high categories. All Okanagan-Similkameen fields tested were classified as very high risk according to the equilibration measurement method

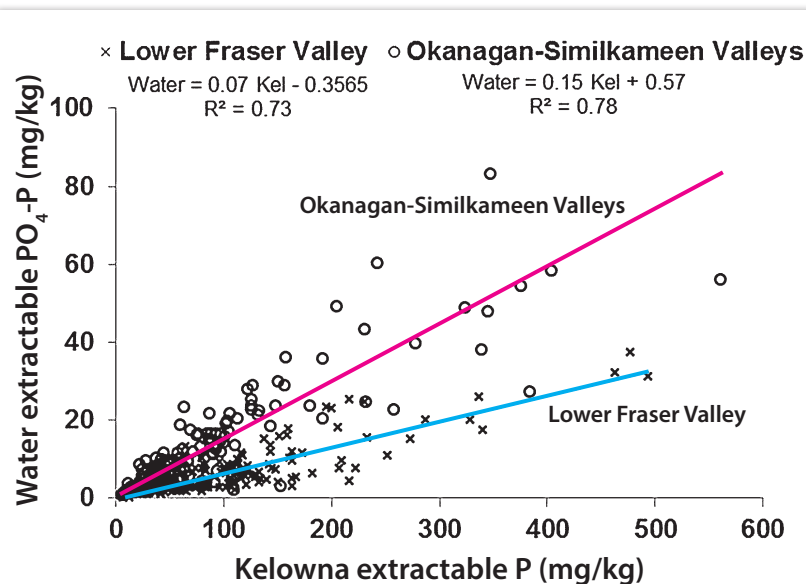


Figure 6. Comparison of the amount of phosphate-P (PO_4 -P) extracted with water with amount of P extracted with Kelowna soil test solution in contrasting humid (Lower Fraser Valley) and arid (Okanagan-Similkameen) areas of British Columbia.

Table 1. Proposed measurement values for environmental risk categories for British Columbia soils.

Environmental risk rating	Water extraction	Kelowna extraction based on agronomic status*	Kelowna extraction if 15% is water extractable	Unbound when equilibrated with 50 mg P/kg	P saturation as Mehlich-3 P/Al
	<i>mg PO₄-P/kg</i>		<i>mg P/kg</i>	<i>%</i>	<i>ratio</i>
Low risk	<1.1	<20	<16.6	<5	<5.0
Medium risk	1.1 – 2.5	20 – 50	16.6 – 41.5	5 – 10	5.0 – 9.8
High risk	2.6 – 6.0	51 – 100	41.6 – 40.0	11 – 20	9.9 – 19.6
Very high risk	>6.0	>100	>40.0	>20	>19.6

* Environmental risk is approximately equivalent to the agronomic fertility status of the soil when water extractable PO₄-P is about 5% of Kelowna extractable P.

Table 2. Distribution of the number of commercial fields in two areas of British Columbia classified in environmental risk categories using different measurement criteria and maximum values for each of the measurements.

Area (no. of fields in brackets)	Environmental risk/ measurement value	Water extraction	Kelowna extraction*	Unbound when equilibrated with 50 mg P/kg	P saturation as Mehlich-3 P/Al
Lower Fraser Valley (54)		----- % of fields sampled -----			
	Low risk	2	4	11	17
	Medium risk	20	16	35	30
	High risk	41	41	22	33
	Very high risk	37	39	32	20
	Maximum value	mg PO₄-P/kg	mg P/kg	%	ratio
	31	436	66	63	
Okanagan-Similkameen (56)		----- % of fields sampled -----			
	Low risk	2	14 (0)	0	5
	Medium risk	9	32 (9)	0	20
	High risk	23	27 (27)	0	39
	Very high risk	66	27 (64)	100	36
	Maximum value	mg PO₄-P/kg	mg P/kg	%	ratio
	112	561	91	395	

* Assuming environmental risk is approximately equivalent to the agronomic fertility status of the soil and water extractable PO₄-P is about 5% of Kelowna extractable P; values in brackets for Okanagan-Similkameen area are percentages when environmental risk is based on water extractable PO₄-P being 15% of Kelowna extractable P.

and 75% according to P/Al ratio method. The large proportion of high risk fields in Okanagan-Similkameen reflects their low ability to bind P.

Knowledge of the forms and dynamics of P in soils provides a basis for determining a balance between P management for economic crop production and risk of water pollution. While still imprecise, soil testing is a valuable tool to

guide management decisions such as rate, time, form and placement of P amendments. 

References available online at www.farmwest.com

C. Grant Kowalenko Agriculture and Agri-Food Canada, Agassiz, BC, Canada | grant.kowalenko@agr.gc.ca