

Residual Phosphorus Distribution and Sorption in Starter Fertilizer Bands Applied in No-Till Culture

John A. Stecker,* James R. Brown, and Newell R. Kitchen

ABSTRACT

Banding fertilizer P in no-till culture results in a heterogeneous soil P distribution for months to years. This study's objective was to quantify the spatial distribution and temporal dynamics of banded P to improve assessment of soil P availability. In three trials for no-till corn (*Zea mays* L.) and from four replicated plots each, we collected a grid of 1.3 by 1.3 cm samples around 10 and 20 kg P ha⁻¹ starter fertilizer bands at ~6, 12, and 18 mo after application. Soils were Mexico silty clay loam (Mollic Epiaqualf), Putnam silty clay loam (Vertic Albaqualf), and Dockery silt loam (Aquic Udifluent). Band affected soil was defined as having a Bray-1 P concentration of at least 1.5 times that of adjacent soil. Band dimensions varied from 5 to 8 cm (horizontal) and 5 to 12 cm (vertical), and tended to be largest at the 12-mo sampling. Cross-sectional area of bands ranged from 18 to 63 cm². Band P concentrations decreased logarithmically from the band center, and were largest at either 6 or 12 mo, and varied substantially along the direction of band application. Band P concentrations ranged from 100 to 313 mg P kg⁻¹ at 6 mo, 56 to 415 mg P kg⁻¹ at 12 mo, and 63 to 237 mg P kg⁻¹ at 18 mo (avg. of the six most concentrated samples of the 20 kg P ha⁻¹ bands). Soil in the band center was weakly buffered and appeared to be more easily extracted by the Bray-1 extractant than nonband affected soil. Inclusion of bands in soil samples would increase the risk to overestimate available P to a crop.

STARTER P FERTILIZER BANDS applied to no-till corn remain as zones of large P concentrations beyond the growing season in which they were applied (Kitchen et al., 1990; Sander et al., 1990; Selles, 1993). Without tillage to disturb P bands, their longevity has been estimated to be several years (Eghball et al., 1990; Brown, 1996; Zerkoune, 1996). As the amount of fertilized soil affects a growing crop's acquisition of P (Barber, 1984), estimation of that P supply with soil testing is also affected. Conventional soil sampling methodology assumes a homogenous nutrient concentration within the plow layer (Cline, 1944). Most attempts to estimate P availability where residual bands exist are based in this conventional approach, as they quantify an average P value that includes band affected soil and surrounding nonband affected soil (Mahler, 1990; Kitchen et al., 1990; Tyler and Howard, 1991; Ashworth et al., 1994; James and Hurst, 1995; Rehm et al., 1995; Brown, 1996; Zerkoune, 1996). However, except for adjustments in the number of cores sampled, such an approach ignores

the different soil P populations that exist in no-till culture from applying P bands (James and Hurst, 1995) and their relation to P availability.

Because of the rapid reaction of soil constituents with fertilizer P, large amounts of P may be immobilized in short distances. Several studies have shown that point application of fertilizer P as granules or as injection of a liquid results in short-term (days to week) P movement of 3 to 5 cm (Lawton and Vomocil, 1954; Heslep and Black, 1954; Blanchar and Caldwell, 1966a; Khasawneh et al., 1974; Eghball and Sander, 1989). However, lateral P movement of 25 kg P ha⁻¹ applied in bands was no more than 1 to 2 cm in 70 d (Nayakekorola and Woodward, 1995). In a Nora (fine-silty, mixed, superactive, mesic Udic Haplustolls)-Crofton (fine-silty, mixed, superactive, calcareous, mesic Typic Ustorthents) soil and measurements taken on 1-cm increments, Eghball et al. (1990) observed that P moved in a band a maximum distance of 3.9 cm after 94 d with a 60 kg P ha⁻¹ rate, and the band-affected soil volume, for a 30-cm depth, was 5.2%. Zerkoune (1996) observed lateral P movement in a band did not exceed 5 cm from the injection point, and the perimeter of band-affected soil and the band P concentration decreased during a 4-yr period.

As the distance of P movement from a band ultimately affects the volume of fertilized soil and the soil P distribution, both volume and distribution affect P availability to a crop (Black, 1992; Barber, 1984). Plant availability of P from individual bands depends on the quantity and the fertilizer source of P, the reversion to less available forms, the soil volume occupied by the bands, and the difference in soil P concentrations inside and outside the band (Strong and Soper, 1974). Repeated band application in no-till culture increases the volume of fertilized soil, such that there is an additive effect on P availability (Brown, 1996; Zerkoune, 1996).

While most of the studies cited above measured residual band dimensions and concentrations, they did so on a scale to primarily evaluate soil sampling methods. Also residual P bands have not been well characterized in three-dimensional space as they appear to roots beyond the first few months following application. Because a residual P distribution from bands in no-till systems is expected to influence subsequent crops, an understanding of the degeneration of P bands in concentration and size is needed to evaluate residual availability for crops and to better estimate available soil P via soil sampling. This study's objective was to quantify spatial and temporal dynamics of undisturbed banded P in a no-till system, which will assist in the assessment of soil P availability.

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Abbreviations: BC, band center; BOC, band off center; EPC₀, zero net sorption.

Table 1. Soil classification and chemical characteristics of study sites†.

Site	Soil	Classification	Particle-size analysis			pH‡	Organic matter	Initial Bray-1 P	NH ₄ OAc K
			Sand	Silt	Clay				
			g kg ⁻¹						
Bradford	Mexico	fine, montmorillonitic, mesic Mollic Endoaqualf	130	550	320	5.9	28	12	239
Greenley	Putnam	fine, montmorillonitic, mesic Vertic Albaqualf	120	560	320	6.7	25	15	226
Graves	Dockery	fine-silty, mixed, non-acid, mesic Aquic Udifluvent	100	680	220	7.3	18	20	224

† Soil data for surface soil (0–15 cm).

‡ Measured in 0.01 M CaCl₂.

MATERIALS AND METHODS

Soil P distributions were studied in 1996 and 1997 from two starter band treatments (10 and 20 kg P ha⁻¹ with 22 kg N ha⁻¹) for no-till corn. The field studies were conducted in Missouri at the Bradford Agronomy Research Center near Columbia, the Greenley Memorial Center near Novelty, and the Graves Memorial Field near Corning. The Bradford and Greenley sites were cropped no-till for 2 yr and the Graves site for 8 yr prior to initiating this study. Soil information for these sites is in Table 1. The Mexico and Putnam soils formed in loess and are representative of the poorly or somewhat poorly drained soils of central and northeast Missouri. The somewhat poorly drained Dockery soil formed in alluvium of major secondary streams of the Missouri River.

In 1996, at Bradford starter bands were applied with the corn planting on 26 April. Bird damage necessitated replanting on 17 June, and corn was replanted directly over the rows of the first planting. Because of cool and wet conditions, planting was late at the Graves (22 May) and Greenley (5 June) sites. Corn rows and fertilizer bands were spaced 76 cm apart. In 1997, plots at all sites were planted to soybean [*Glycine max* (L.) Merr.], and no additional P was applied. At the Bradford and Graves sites, soybean was planted in 76-cm wide rows. Greenley plots were drilled to soybean in 18-cm rows.

Bands were applied 5 cm to the side and 5 cm below the seed with coulter-knife assemblies attached to each planter row unit. Pressurized CO₂ delivered the fertilizer solutions to the knives through a manifold fitted with zero-pressure orifices. The applied fertilizer solutions were prepared with ammonium polyphosphate (10-15-0, N-P-K) and urea ammonium nitrate solution (32-0-0). Fertilizer solution volume delivered per meter of row was 28.6 mL for the 10 kg P ha⁻¹ treatment and 37.7 mL for the 20 kg P ha⁻¹ treatment. Based on an assumed cylindrical band, the calculated theoretical band diameter was 5.2 mm for the 10 kg P ha⁻¹ treatment and 6.9 mm for the 20 kg P ha⁻¹ treatment. Soils were wet at planting, barely dry enough to allow planting. Bands were marked by threading monofilament line through additional tubes that were welded onto the back of the knives. The line was placed into the soil at or very near the injection point of the starter solution.

Bands were sampled by removing a 20.3 by 20.3 by 7.6-cm block of soil centered on the band (Fig. 1A). Plots were sampled on ~6-mo intervals (Fall 1996, Spring 1997, and Fall 1997). Collection of soil blocks from the field was very dependent on having sufficient soil moisture so that soil blocks remained intact during removal from the field and subsampling. In 1996, soil blocks were sampled within 30 d of corn maturity. The Spring 1997 soil blocks were collected prior to planting. The Fall 1997 soil blocks were collected after soybean harvest. Soil blocks were subdivided within a month of sampling. For each site and sampling time, one block of soil was sampled per replicated treatment. Only bands from the middle two rows were sampled, and a new sampling site in the plot was chosen at each sampling time.

Individual bands were sampled by digging a trench perpendicular to the crop row and exposing the line. A steel sampling box was positioned such that the top of the box was level to the soil surface and then driven into the smoothed vertical soil face. In 1996, a 20.3 by 20.3 by 3.8 cm sampling box was used, and two consecutive blocks were sampled from each sampling site (resulting in an effective 7.6-cm dimension). In 1997, a box with a 7.6-cm dimension was used such that only one soil block was taken per sampling site. The 7.6-cm dimension was oriented in the direction of band application. Because the effective band application depth varied as a result of surface roughness, the depth to the line was measured from the soil surface for each sampled block. The depth was later used to guide subdivision of the sampled soil block. To prevent soil adherence to the steel box during sampling, the box was lined with wax paper prior to sampling. When removed from the steel box, soil blocks were wrapped in plastic wrap, placed inside sealed plastic bags, and stored at room temperature until being subdivided.

Soil blocks were subdivided to obtain 7.6 (3.8 in 1996) by 1.3 by 1.3 cm samples (cell samples) in the vicinity of the band (Fig. 1A). The process of subdividing soil blocks consisted of first slicing off 1.3-cm thick horizontal layers (layer samples), and then where appropriate, cell samples were cut from the individual layers. Cell samples were collected from individual layers using a predetermined sampling pattern around the fertilizer injection point (Fig. 1B). After collecting cell samples from a layer, the remaining soil of the layer was combined to consist of a layer sample for that depth. The sampling pattern of cell samples was chosen so that after cell samples were removed from a layer, the remaining soil (now a layer sample) was assumed to not have increased P concentration from the band. Subsequent laboratory analysis supported this assumption. The number of cell samples cut from each soil block varied, as adjustments were made each sampling time, in order to adequately encompass the presumed band size and to maintain a practical number of samples for analysis. The total number of cell samples per soil block ranged from 56 in Fall 1996, to 108 to 114 in Spring 1997, and 100 to 112 in Fall 1997.

Cell samples were oven dried at 40°C and ground to pass through a 1-mm screen. Soil P concentrations were determined on weighed 2-g samples with a Bray-1 extraction and color development as described by Brown and Rodriguez (1983).

After analyzing the Spring 1997 samples and noting the P concentration variation across replications, we suspected that soil P concentrations varied significantly along the band (in the direction of application). Consequently, in addition to the Fall 1997 block samples, 10 consecutive 2-cm soil cubes (8 cm³ in volume) were collected from the 20 kg P ha⁻¹ bands in the direction of application at each site. Soil was sampled from directly under the monofilament line so the samples would represent the most concentrated P volume of the band.

Soil of each layer sample (less the cell sample soil, see Fig. 1B) was assumed to be unaffected by the band, i.e., no increase in P concentration. Band-affected soil of cell samples was

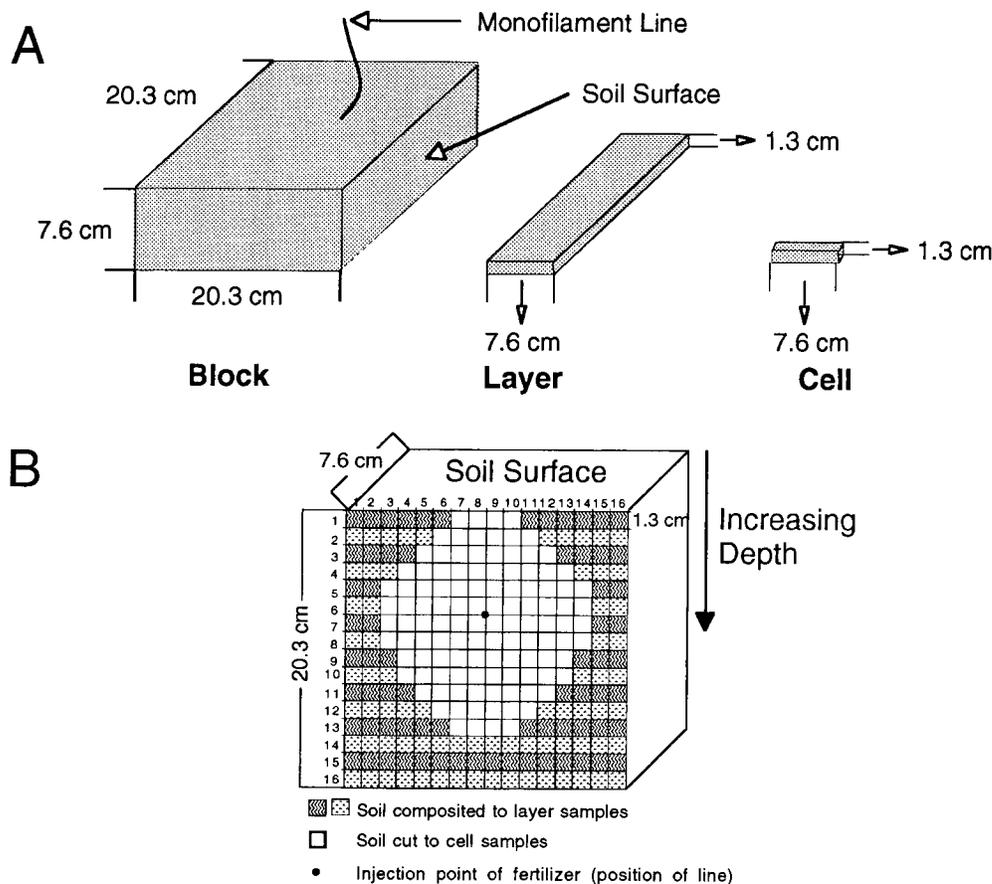


Fig. 1. Diagram showing (A) the method of subdividing soil blocks into block, layer, and cell samples, and (B) a soil block and the pattern from which cell and layer samples were cut. Numbers represent those used to code the samples.

defined as that which had a P concentration that was at least 1.5 times that of soil in the adjacent layer sample. Because the center of each band, as identified by a cell sample, did not have the same position within a soil block, P concentrations of the four replicate sample blocks were averaged by centering each block's set of P concentrations on the highest cell sample P concentration. To effectively show data graphically, data were transformed by a log base 1.5 function, as P concentrations decreased logarithmically from the band center. This allowed an outside isoline value of one to show the outer dimension and shape of bands. Each isoline of P concentration inward represents an additional 1.5 times increase in P concentration. Because isolines were developed from values that compare cell to layer P concentrations within individual layers, a contour value of three at the top of the band would represent a different actual P concentration than the same contour at the bottom of the band.

Phosphorus sorption was measured on selected cell samples of the Putnam soil for each sampling time. The selected cell samples included the largest P concentration cell sample in the band (band center, BC), a cell sample immediately adjacent (horizontally) to the BC cell sample (band off center, BOC), the layer sample from which the BC and BOC samples were taken (Nonband), and the surface layer (0–1.3 cm) sample. To measure P sorption 1 g of soil was equilibrated with 25 mL of solutions composed of 0, 1, 3, 5, 7, and 10 mg P L⁻¹ in 0.05M NaNO₃. The soil and P solution were placed in 44-ml plastic test tubes and shaken for 24 h at 160 opm. The test tubes were centrifuged at 1375 ×g for 5 min., and an aliquot of the supernatant was used for P analysis as described by

Brown and Rodriguez (1983). Due to the limited amount of soil per cell sample, only one analysis was made per sample.

Each P sorption curve was described by a logarithmic function. From each curve two soil P parameters of P sorption were calculated, the equilibrium P concentration at which there is zero net sorption (EPC₀) and buffer capacity. Using the function describing P sorption, EPC₀ was calculated as the x-intercept. Plots of P sorption against a solution concentration are known as quantity/intensity plots or Q/I plots (Barrow, 1978). The relationship between quantity and intensity varies by the slope of the sorption curve, which is expressed as the buffer capacity. In this study, buffer capacity was calculated as the derivative of the curve at EPC₀. It is expressed as the amount of P (mg kg⁻¹) added to soil (quantity) that effects a P solution change in mg L⁻¹ (intensity). Both EPC₀ and buffer capacity are useful in assessing the external P supply to a crop. The EPC₀ is the solution P concentration supported by the solid phase of soil P, and buffer capacity refers to the ability of the soil solution to resist change when P is added or removed from the pool of labile P (Sharpley et al., 1982).

To compare Bray-1 extractable P to a more complete accounting of soil P, samples from individual soil blocks were extracted with 6 M HCl. This extraction is an incomplete estimate of total inorganic P (Olsen and Sommers, 1982). Ten milliliters of 6 M HCl were added to 1 g of soil in 50-mL Erlenmeyer flasks. Samples were shaken for 20 min. at 180 opm, diluted to 40 mL with distilled water and filtered. Phosphorus concentrations in the filtrate were determined using an ascorbic acid color development procedure similar to that used with the Bray-1 procedure. However, because of the

Table 2. Extractable Bray-1 P concentrations and cross-sectional area of residual starter bands.

Sample Time	10 kg ha ⁻¹ Band P						20 kg ha ⁻¹ Band P					
	Six cell P concentration†			Cross-sectional area of isolines			Six cell P concentration			Cross-sectional area of isolines		
	Mean	Std. dev.‡	Range	Isoline 1	Isoline 3	Isoline 5	Mean	Std. dev.	Range	Isoline 1	Isoline 3	Isoline 5
	mg kg ⁻¹			cm ²			mg kg ⁻¹			cm ²		
	Mexico											
Fall 1996	69¶	21	25–147	28	10	2	167	35	103–313	40	19	10
Spring 1997	87	11	45–171	34	8	2	193	34	111–275	63	27	14
Fall 1997	39	7	18–70	18	4	–	146	21	79–237	52	21	10
	Putnam											
Fall 1996	111	23	56–179	23	6	<1	201‡	34	100–276	30	13	3
Spring 1997	108	34	65–179	35	12	2	135	28	56–254	50	16	5
Fall 1997	90	22	52–153	31	9	1	113	49	63–188	26	12	5
	Dockery											
Fall 1996	106‡	19	66–170	52	18	2	209¶	58	148–268	48	20	7
Spring 1997	79	11	44–140	24	6	–	241	22	138–415	63	27	10
Fall 1997	52	18	42–89	32	6	–	134	29	67–222	49	20	7

† The six cell P concentration mean refers to the six most concentrated cells that were measured in the band.
 ¶ Means between sampling times differed linearly as determined by orthogonal contrast ($P > F \leq 0.10$).
 § Means between sampling times differed quadratically as determined by orthogonal contrast ($P > F \leq 0.10$).
 ‡ Standard deviation.

greater acidity level of the extracted and diluted solution, 1.5 M H⁺, the acid molybdate solution was made to be 10 M HCl, so that the final color developing solution would be 0.5 M H⁺. To minimize laboratory variation, all subsamples were

weighed to the nearest milligram, and all samples for a given sampling time and P treatment were extracted and analyzed in the same laboratory run. Graphical representation and regression of the data were

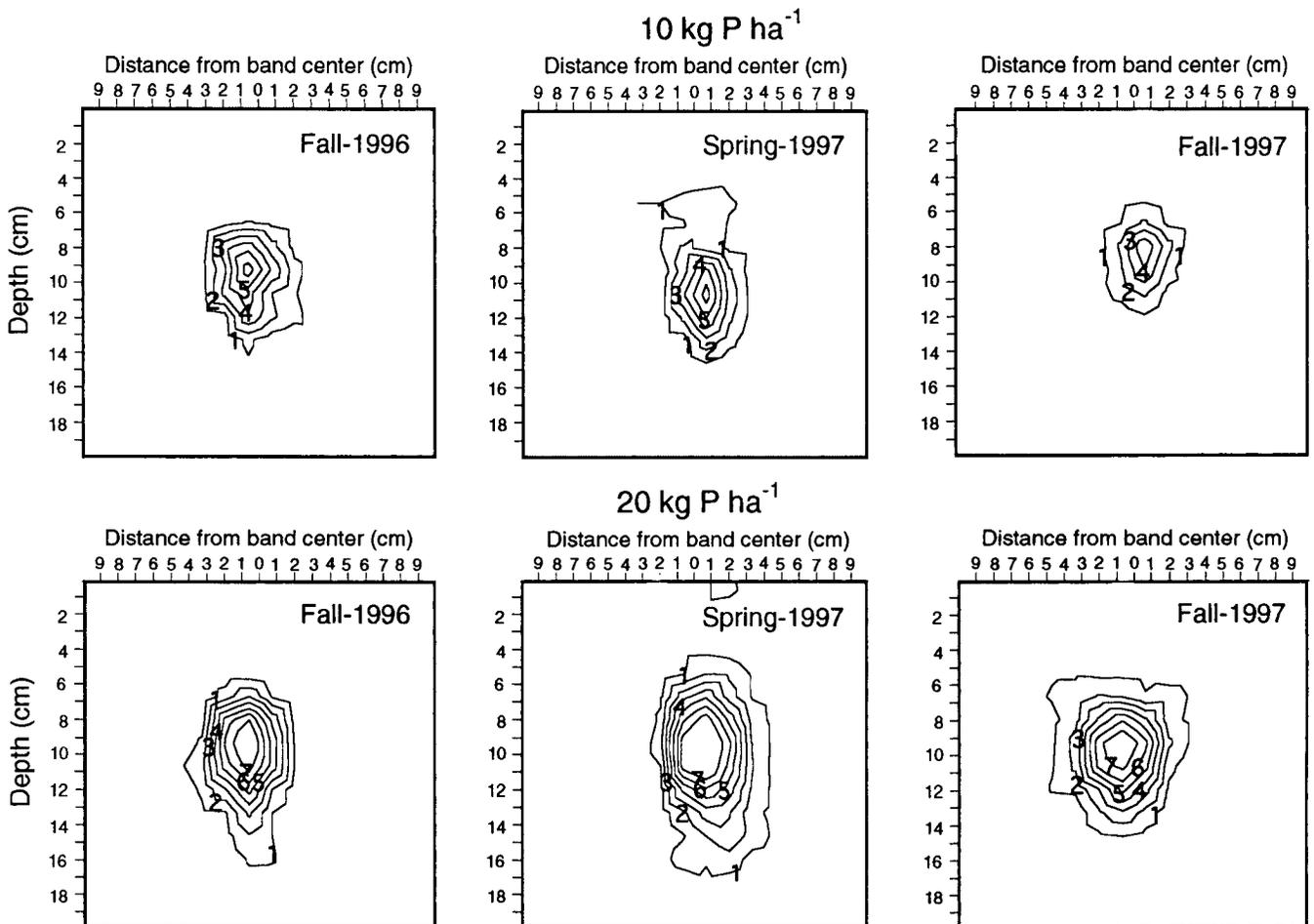


Fig. 2. Bray-1 P distribution from bands of 10 and 20 kg P ha⁻¹ applied to a Mexico soil. Values are relative to soil in adjacent nonband-affected soil and converted to log base 1.5.

done using the software DeltaGraph 3.1.1 (DeltaPoint Inc., 1991).

RESULTS AND DISCUSSION

Band Cross-Sectional Phosphorus Distribution and Concentration

For both band size and P concentration, changes with time were not consistent when comparing P rate and soil type. However, general trends were evident. The bands' maximum size occurred with the Spring 1997 sampling (Table 2 and Fig. 2-4). In two of the six combinations of P rate and soil type, the Spring 1997 increase in band size was associated with an increase in the six cell P concentration. In two others, the concentration was unchanged. Maximum P concentrations within the 20 kg ha⁻¹ bands decreased with each sampling, except for the Dockery soil. By the Fall 1997 sampling, the 20 kg ha⁻¹ bands decreased in size to become similar to or slightly larger than bands from the Fall 1996 sampling (apparent from the 1, 3, and 5 isoline areas).

The cross-sectional area occupied by the bands ranged from 18 to 52 cm² for the 10 kg ha⁻¹ bands, and 26 to 63 cm² for the 20 kg ha⁻¹ bands. For comparable sampling times, the 10 kg ha⁻¹ band varied in size from 35 to 117% of the 20 kg ha⁻¹ band. Band width was in most cases 6 to 8 cm for all three sites, regardless of the measurement time. With the 76-cm spacing these band

widths correspond to a 8 to 11% probability of hitting a band by random soil sampling. Band length (vertical dimension) ranged from 6 to 12 cm. In 75% of the bands, band length was greater than width, and the longer part of the vertical axis tended to be below BC. The difference between band length and width was greatest with the Spring 1997 sampling.

Downward movement of P in the band from the spring sampling is likely attributed to movement of water soluble P (Blanchar and Caldwell, 1966b) in the absence of root P uptake. Nayakekorola and Woodard (1995) also observed significant vertical movement of P in a band, and they concluded that it could not be explained by diffusion alone. Horizontal P movement was similar to that observed from fertilizer granules (Heslep and Black, 1954; Blanchar and Caldwell, 1966a; Khasawneh et al., 1974), and the observed distances were likely reached soon after application (Hashimoto and Lehr, 1973). Larger band dimensions observed by Kitchen et al., 1990) and Zerkoune (1996) can be attributed to a coarser sampling procedure than used in this study. Based on a 15-cm depth and 76-cm band spacing, the 20 kg P ha⁻¹ bands occupied 2.6 to 4.1% of the soil volume, which is consistent with Barber's (1974) estimation that 2 to 3% of the plow layer soil is fertilized by a single starter fertilizer application.

Phosphorus concentration in most bands decreased logarithmically from the BC. Maximum P concentration

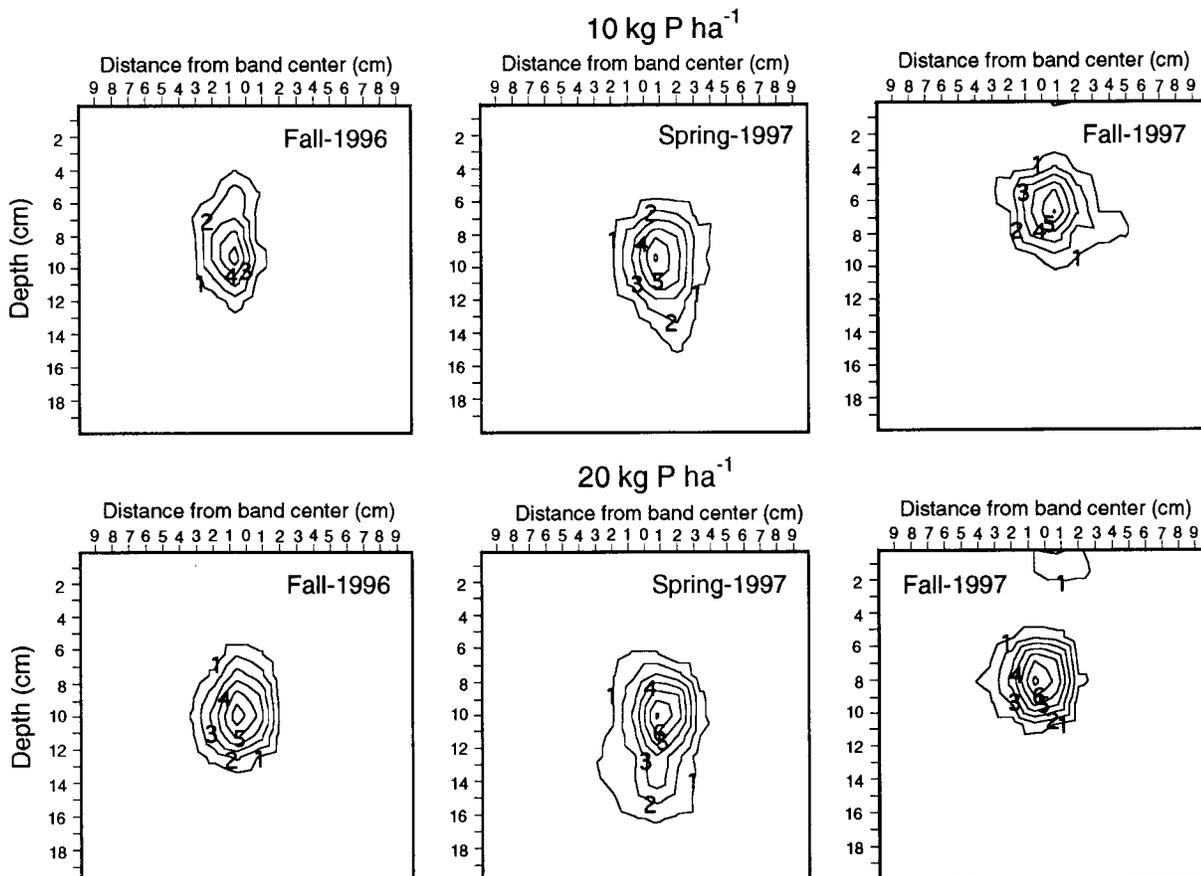


Fig. 3. Bray-1 P distribution from bands of 10 and 20 kg P ha⁻¹ applied to a Putnam soil. Values are relative to soil in adjacent nonband-affected soil and converted to log base 1.5.

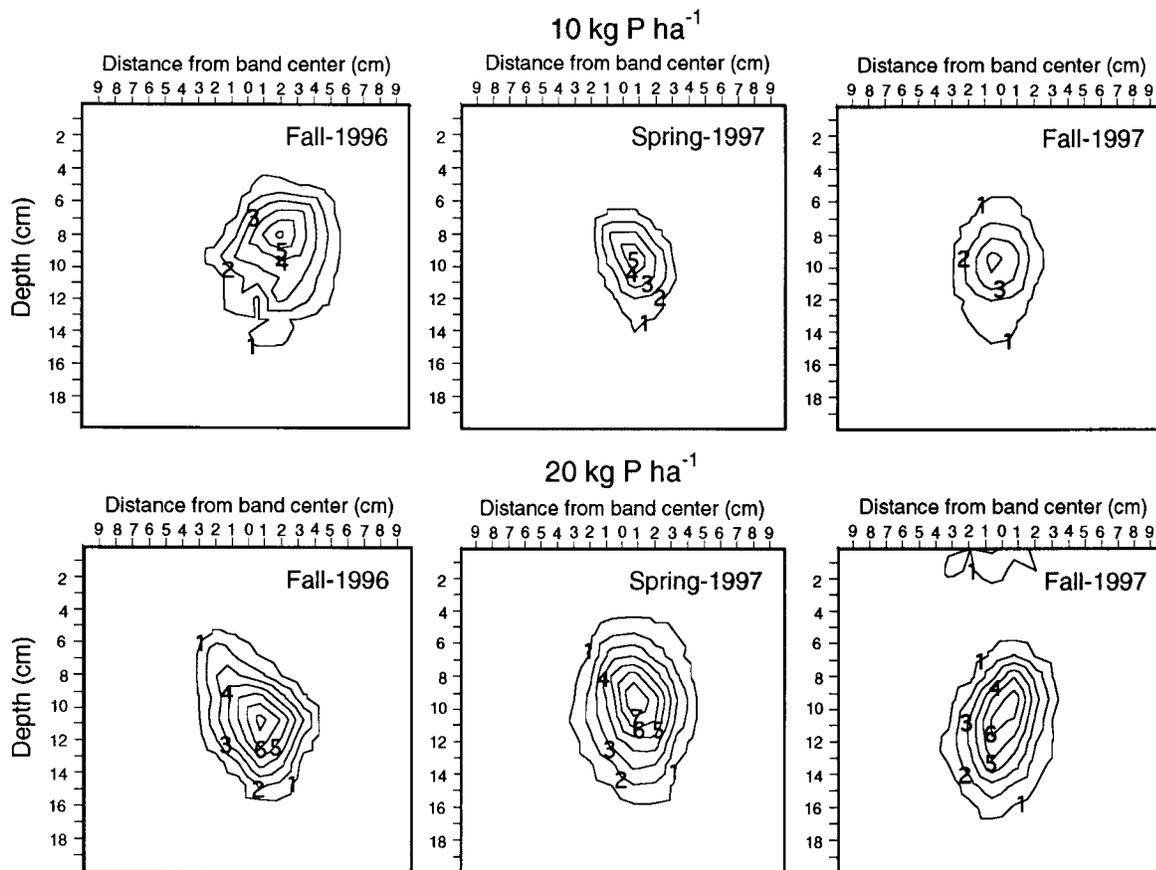


Fig. 4. Bray-1 P distribution from bands of 10 and 20 kg P ha⁻¹ applied to a Dockery soil. Values are relative to soil in adjacent nonband-affected soil and converted to log base 1.5.

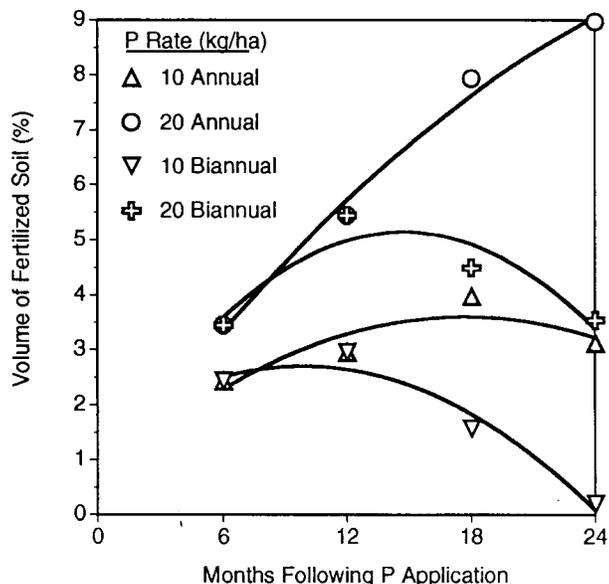


Fig. 5. Predicted volume of band-affected soil in the surface 15 cm from annual and biannual band applications on a 76-cm spacing in a Mexico soil. Assumes cumulative volume of undisturbed bands. Band volume at 18 mo for annual applications is sum of 6 and 18 mo volumes; at 24 mo, it is the sum of 12 mo and an extrapolated value from 18 mo.

ranged from 188 to 415 mg kg⁻¹ for the 20 kg ha⁻¹ P rate and 70 to 179 mg kg⁻¹ for the 10 kg ha⁻¹ P rate (Table 2). Among the six most concentrated P measurements (cells) for each P band, P concentrations ranged from 135 to 277 mg ha⁻¹ for the 20 kg ha⁻¹ P rate. The cross-sectional area (9.7 cm²) of the six cells represents the core of the bands, approximately the Number 3 and 5 isolines of the 10 and 20 kg ha⁻¹ P rates, respectively.

Soil directly above most of the bands had increased P concentrations relative to adjacent soil, however, only in some cases did the concentrations become at least 1.5 times that of adjacent soil (see Fig. 2, Spring 1997, 20 kg ha⁻¹; Fig. 3, Fall 1997; Fig. 4 Fall 1997, 20 kg ha⁻¹). Such concentration of P above bands is likely the result of redistribution and deposition via crops growing over the bands. Large organic matter levels in a no-till surface soil can reduce P adsorption on soil colloids (Weil et al., 1988), which may result in increased P extractability by the Bray-1 extractant.

Available P from fertilizer applied in bands has been observed to decrease exponentially with time (Cox et al., 1981; Brown, 1996; Zerkoune, 1996). In this study, the lack of a continuous decrease of band P concentrations may have been the result of changing oxidation levels, which could affect P solubility in these somewhat poorly drained soils. Blanchar and Marshall (1981) observed the E_H of the surface 15 cm of a Mexico soil change from >800 mV in September to 300 mV in

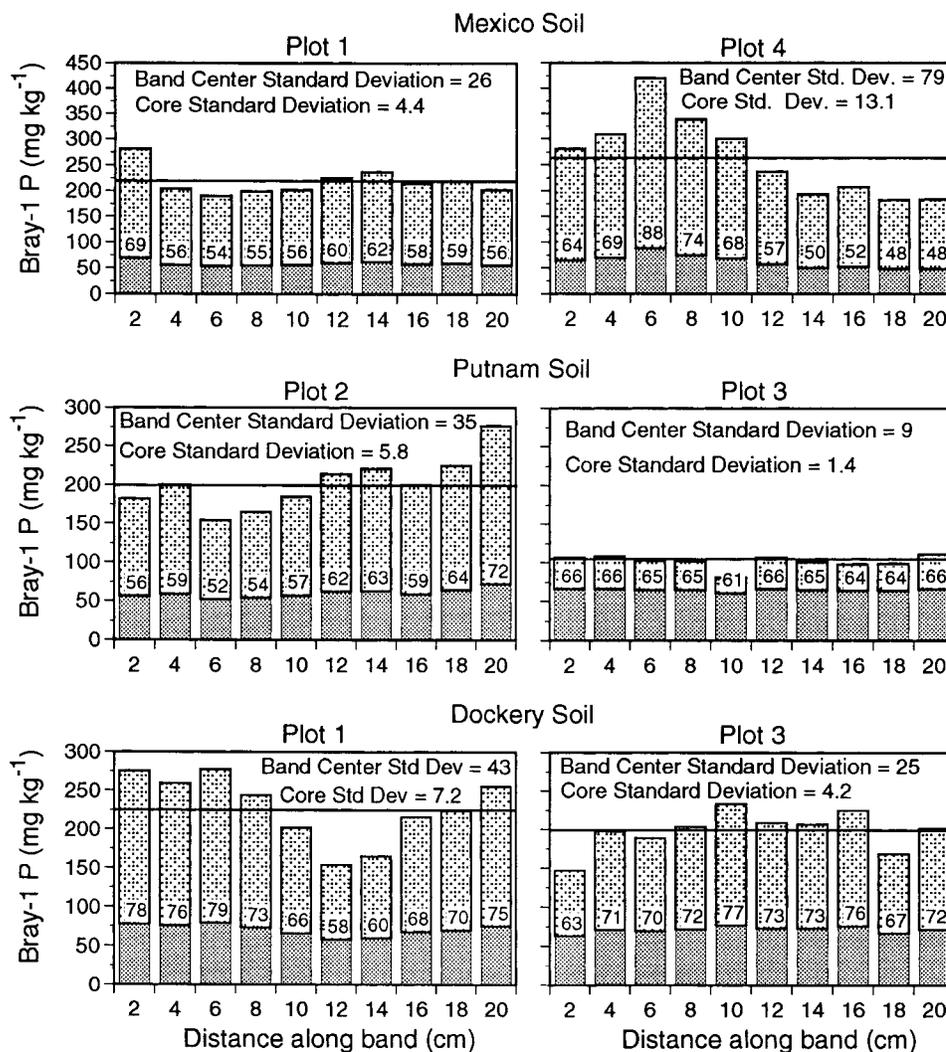


Fig. 6. Residual band Bray-1 P concentrations in the direction of application for the 20 kg P ha⁻¹ treatment for two plots each of the Mexico, Putnam, and Dockery soils, Fall 1997 sampling. The line represents the mean of the 10 subsamples. The upper bar represents the P value from the 2-cm band center sample. The lower bar represents an average of cell samples and the 2-cm band center sample that would represent a probed sample of 0 to 15 cm.

June—the result of fall and winter rainfall. At the lower E_H levels, stability diagrams suggest that Fe compounds would dissolve which could increase extractable P (Patrick and Mikkelsen, 1971). With the high soil test P levels measured in this study at 18 mo following application, several years would be expected before P levels in bands return to prefertilization levels.

Although this study measured bands applied to only one crop, in actual cropping systems (continuous corn or corn-soybean) bands would be applied annually or biannually. Because of slow band degeneration, overall volume of band affected soil would reflect repeated applications. Using the band sizes measured at 6, 12, and 18 mo (isoline value of 1 in Table 2), and a linearly extrapolated value for 24 mo, estimated cumulative band volumes (of undisturbed bands in the Mexico soil) in the upper 15 cm with 76-cm spaced band applications are shown in Figure 5. For one P application, fertilized soil volumes were less than required for optimum soybean and corn P uptake (Anghinoni and Barber, 1980;

Borkert and Barber, 1985). With applications other than the 10 kg P ha⁻¹ the estimated volume of fertilized soil appeared to remain steady or increase. By increasing the probability of root interception (Eghball and Sander, 1989), repeated band applications could have an additive effect on yield (Alessi and Power, 1980; Brown, 1996; Zerkoune, 1996).

Phosphorus Concentration Changes Along the Band

Data from individual soil blocks of the first two sampling times suggested large band P variation in the direction of band application. When the core of the bands were sampled directly by 2-cm increments, the 7.6-cm soil block dimension was found to be too small to effectively integrate variability along the band. Figure 6 shows P concentration variability when measured along the band. The graphs show the greatest and least variability (as determined by standard deviation) of the four plots measured at each site. In some plots, band P

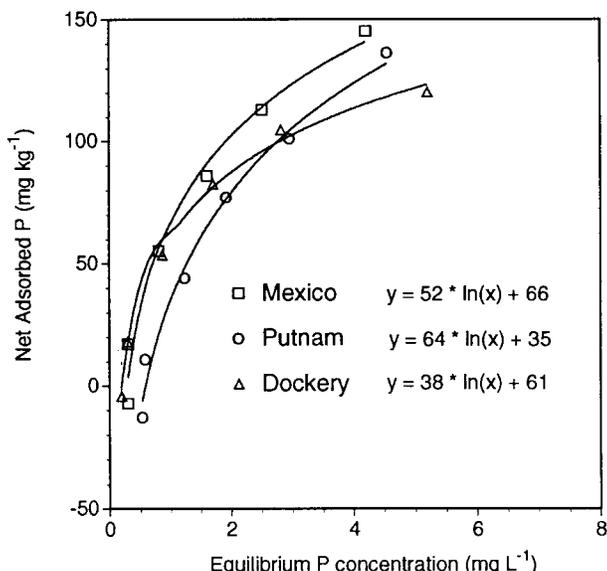


Fig. 7. Phosphorus sorption curves for the Nonband soil of the Mexico, Putnam, and Dockery soils that were sampled in Spring 1997.

concentrations varied by more than 50 mg kg⁻¹ between adjacent 2-cm band samples. Using data from the soil blocks (layer values averaged with appropriate cell values), core P concentrations were calculated to emulate a 15-cm-deep core sample taken through the band. These varied by as much as 40 mg P kg⁻¹ in a 20-cm distance and by 19 mg P kg⁻¹ between adjacent samples. Within individual plots or set of 10 samples, standard deviations ranged from 9 to 79 mg P kg⁻¹ for the 2-cm BCs and 1.4 to 13.1 mg kg⁻¹ for the calculated core concentra-

tions. Such P concentration variability is substantial enough to merit consideration when using soil sampling methods that attempt to weight band fertilized soil with nonband soil in the sample.

Causes of this variation could include: breakup of the fertilizer solution stream leaving the knife, wheel slip that causes variation in ground speed, variation in soil pores that affects flow of fertilizer solution from the knife, and microsite differences in P retention. Because the fertilizer solution in this study was delivered using constant pressure CO₂ system, even greater variability would be expected with piston or squeeze pump delivery of fertilizer solutions.

Phosphorus Adsorption Curves

Phosphorus adsorption curves for the Mexico, Putnam, and Dockery soils show similar adsorption characteristics (Fig. 7), which suggests P movement and crop response to fertilizer placement should be similar among these soils (Anghinoni and Barber, 1980). While the shape of an adsorption curve is characteristic of the soil, the position of one curve relative to another is dependent on the amount of P in the soil (Bache and Williams, 1971). The Putnam soil had a greater Bray-1 P concentration than the Mexico soil, which resulted in the Putnam curve being to the right of the Mexico curve. Alternatively, the Dockery soil was buffered similarly to the Mexico soil at low equilibrium P concentrations, but it adsorbed less P.

Phosphorus sorption curves developed from four soil positions in and near the band of the Putnam soil show the potential for varying P behavior (Fig. 8). The EPC₀

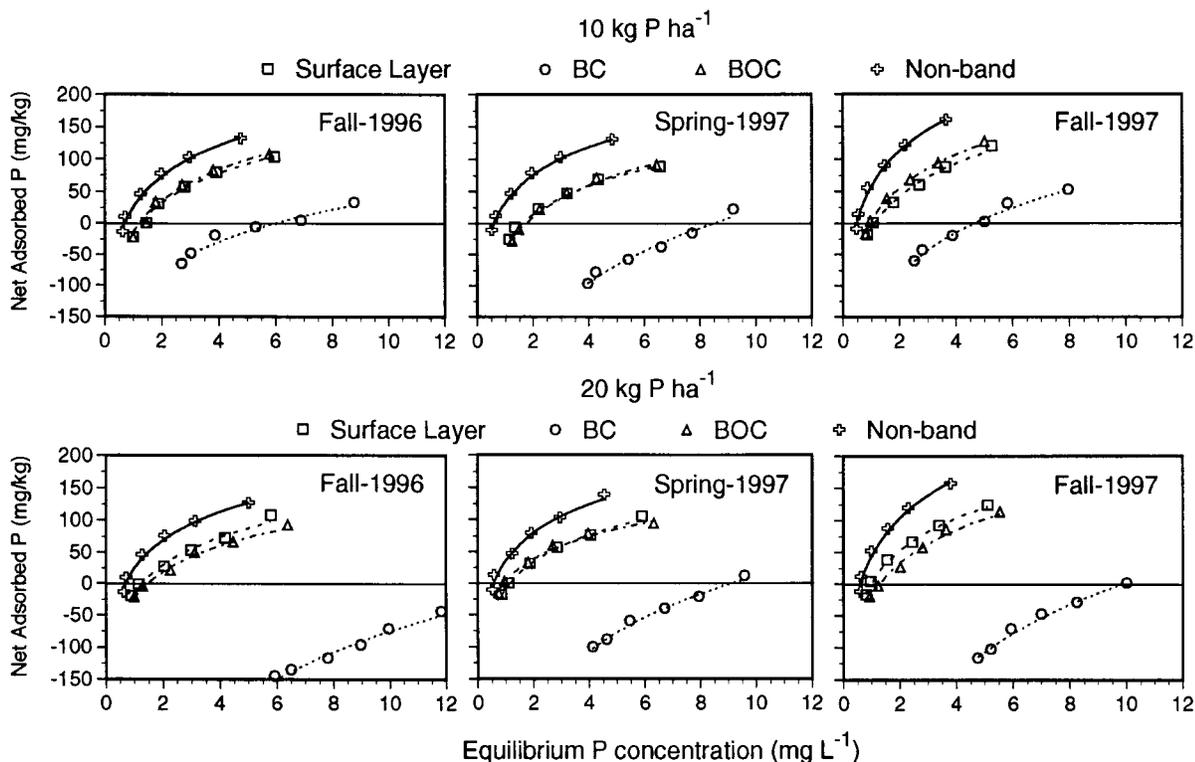


Fig. 8. Phosphorus sorption curves for soil around residual P bands of the Putnam soil for 10 and 20 kg ha⁻¹ P rates at three sampling times.

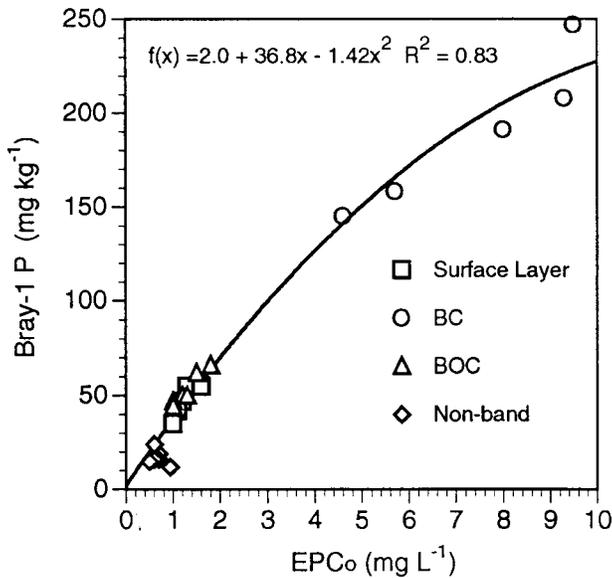


Fig. 9. Relationship between Bray-1 P and zero net absorption (EPC₀) for the Putnam soil, sampled Spring 1997. BC represents Band center soil, and BOC represents Band off center soil.

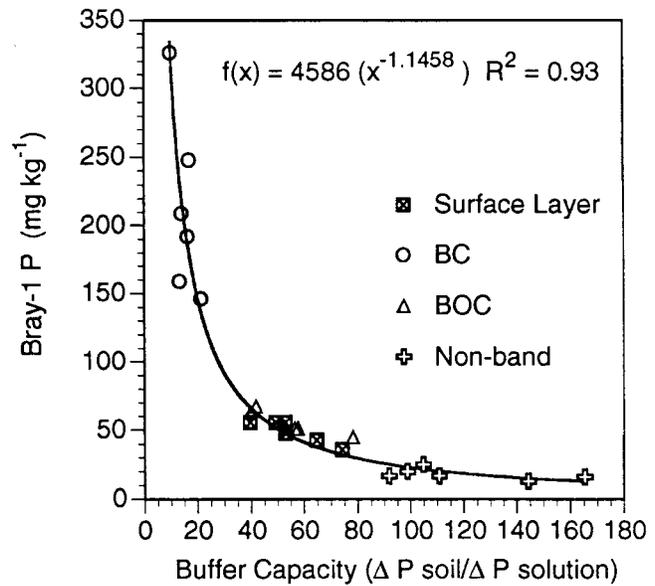


Fig. 10. Relationship between Bray-1 P and Buffer Capacity for the Putnam soil, sampled Spring 1997.

of the BC soil was consistently much greater than that of all other soil positions with values that ranged from 4.6 to 15.4 mg L⁻¹. In contrast, the EPC₀ of the BOC soil, which was just 1.3 cm adjacent to the BC soil, ranged from 1.0 to 1.8 mg L⁻¹. The EPC₀ of the BC, BOC, and even the surface layer soil positions exceeded the level at which plant roots become saturated with respect to P uptake (Edwards and Barber, 1976).

Band placement of P has been suggested as a means of decreasing P loss from land in runoff. The sorption curves in Fig. 8 show the effectiveness to which band placement may restrict P loss. Despite the BC soil's ability to support a large solution P concentration, adjacent soil yet within the band supports a much lower solution P concentration. A typical band placement depth of 7 to 9 cm would result in the poorly P buffered soil with large P concentrations safely below the 1- to 2.5-cm zone of interaction with surface water (Sharpley et al., 1994). However, crop redistribution of P to the soil surface over residual bands may negate some of the advantages of subsurface banding.

Phosphorus sorption related strongly to Bray-1 P levels (Fig. 9 and 10). The high Bray-1 P concentrations of the BC soil were indicative of easily desorbable P and low P buffering. The large change in buffering at Bray-1 P concentrations <50 mg kg⁻¹ (Fig. 10) suggests a significant change in the nature or number of P absorbing sites (Guertal et al. 1991). Buffer capacity for each soil position increased linearly with time during the 18-mo study period (data not shown). Proportionally the buffer capacity increase for the BC soil was greatest at 42%, relative to 31 to 36% for the other soil positions. Increasing buffer capacity indicates changes in metastable reaction products as fertilizer P equilibrates with the general soil P pool (Sample et al., 1980). Esilaba et al. (1992) concluded that there is a potential for large fertilizer P recommendation errors when residual fertilizer P is measured before it equilibrates. Soil P in and

near a band would conceivably require more time to equilibrate.

Using the Mexico soil, Bray-1 concentrations increased exponentially with the ratio of Bray-1 to 6 M HCl extractable P (Fig. 11). Bray-1 extracted P increased greatly at about the same Bray-1 concentration where buffer capacity changed when plotted against Bray-1 extracted P. Apparently at the larger soil P values, the ease of extractability by the Bray-1 extractant changes. This may be explained by a tendency for the Bray-1 extractant to overcompensate for buffering and overestimate available P in weakly buffered soils (Holford, 1980). Current University of Missouri soil test interpretations for P place the range for a high P rating at a similar Bray-1 P value as where the slopes of both

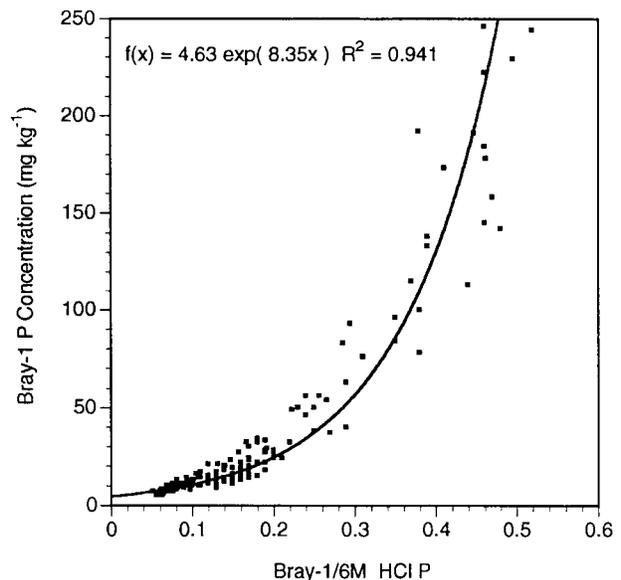


Fig. 11. Relationship between Bray-1 P and the ratio of P extracted by the Bray-1 extractant and 6 M HCl for the Mexico soil sampled Spring 1997.

curves in Fig. 10 and 11 change significantly. So with Bray-1 P values just larger than the range that infers likely crop responsiveness to fertilizer P, P extractability by the Bray-1 extractant increases. Soil sampling a heterogeneous soil environment with residual soil bands and the inclusion of band affected soil then likely introduces a potential error of over estimating P availability, as the index of extractable P to crop availability appears to shift at high Bray-1 P values.

SUMMARY AND CONCLUSIONS

Residual starter P bands increased in size only slightly between 6 and 12 mo before shrinking in size by 18 mo. Bray-1 P concentrations in bands consistently decreased with time, but even after 18 mo maximum concentrations in bands consistently exceeded 100 mg kg⁻¹. Bray-1 P concentrations decreased logarithmically with distance from the BC and in several instances changed 100 mg kg⁻¹ or more in only 1.3 cm.

Farmers and consultants often want to include residual bands in a soil sample for the sake of crediting that fertilizer P to available soil P. This study's characterization of bands confirm some of the difficulties one would encounter to accurately determine a value of plant available P from bands. The large cross-sectional variation of soil P (relative to crop rows) is supplemented with substantial variation in the direction of band application. Additionally because of slow band degradation, any cropping system with repeated band application would increase the heterogeneity of soil P, as sequentially applied bands would unlikely superimpose on one another and the volume of fertilized soil gradually increases. The risk to the farmer by attempting to include bands in a sample would be to overestimate available P, both by the sampling method as well as by the laboratory extraction. Interpretation of a soil test could then result in a yield-limiting under recommendation of fertilizer P. If fertilizer is applied in a predictive manner such as with controlled traffic planting, bands provide a small target for soil sampling (5- to 8-cm width) with a conventional soil corer and likely could be avoided.

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DIVISION S-5—PEDOLOGY

Spatial Distributions of Soil Chemical Conditions in a Serpentinic Wetland and Surrounding Landscape

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ABSTRACT

Soils formed from serpentinite contain an abundance of Fe, Mn, Cr, Ni, and Mg, and low concentrations of the plant-essential nutrients Ca and K. The resulting vegetation is commonly xeromorphic and characteristically stunted. This study was conducted to (i) determine the spatial distributions of heavy metals and exchangeable cations (M_e) in an ultramafic wetland and surrounding landslide terrain, and (ii) to interpret the distributions relative to environmental conditions and pedogenic processes on the component landscape positions. Distributions of dithionite-extractable metals (M_d) and M_e in surface soils (0–15 cm depth) were assessed by kriging and by landscape units, characteristic landscape position, soils, and vegetation. Abundance of M_e s ranked in the following order: Mg > Ca > K > Mn > Na > Ni. The Ca/Mg ratios range from 0.13 to 3.77 (mean 0.43), with the highest ratios in a landscape unit with nonserpentine metamorphic colluvium over serpentinitic residuum. Exchangeable cations are concentrated within the wetland relative to surrounding terrain. Dithionite-extractable Fe, Mn, and Ni are concentrated in soils on the oxidizing, nonhydryc lower landscape positions, near the hydrologic discharge point of the wetland. Chromium and Al are concentrated in the nonhydryc upper landscape positions. Due to reducing conditions, the wetland contains low concentrations of M_d relative to the surrounding nonhydryc terrain. Large vegetation differences between moisture class coupled with moderate vegetation differences between landscape units within the same moisture class, suggest that vegetation occurrence within the study area is controlled primarily by hydrology, and secondarily by elemental conditions.

ULTRAMAFIC ROCKS OCCUPY a small portion (<1%) of the earth's land surface, but are locally abundant in ophiolite belts along tectonic plate margins (Brooks,

1987; Coleman and Jove, 1991). In North America, ultramafic rocks form two discontinuous bands along the east and west side of the continent. Of these, the largest area of ultramafic terrain is in the Klamath Mountains province of northern California and southern Oregon (Irwin, 1977).

Serpentinite is a metamorphic rock formed from the low temperature (300–600°C) hydrothermal alteration of igneous ultramafic rocks (O'Hanley, 1996). These rocks are generally classified as peridotite, common varieties of which are dunite, harzburgite, and lherzolite (Wyllie, 1967; Coleman, 1971; Moores, 1973). The major minerals are olivine, orthopyroxene, clinopyroxene, and chromite (Moody, 1976). Quartz is absent and feldspar is minor or absent in all of these rocks (Ehlers and Blatt, 1982). Most ultramafic rocks have been partially hydrated or completely serpentinized (Moody, 1976). Nearly all serpentinite masses are serpentinized peridotites that have been tectonically emplaced along continental margins (Coleman and Jove, 1991). Serpentine minerals (antigorite, lizardite, and chrysotile) are the predominant minerals in serpentinite, while magnetite, brucite, and Mg- and Ca-aluminosilicates are common accessory minerals (O'Hanley, 1996).

Total elemental analysis of peridotites and serpentinites from the Klamath Mountains show low Ca and Al, and extremely low or no measurable K (Table 1). Potassium is a trace element in ultramafic rocks with total concentrations on the order of 200 mg kg⁻¹ (Goles, 1967). Ultramafic rocks are noted for their elevated levels of heavy metals compared with more common aluminosilicate rocks.

Soils formed from ultramafic rock are strongly influenced by the geochemistry and mineralogy of the parent material. Common constituents of ultramafic soils in-

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Abbreviations: e [subscripted], exchangeable cation; d [subscripted], dithionite extracted metal; CEC, cation-exchange capacity; ICP-OES, inductively coupled Ar plasma optical emission spectroscopy