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Soil phosphorus spatial variability due to landform, tillage, and input management: A case study of small watersheds in southwestern Manitoba

Henry F. Wilson *, Sanjayan Satchithanantham, Alan P. Moulin, Aaron J. Glenn

Brandon Research and Development Centre, 2701 Grand Valley Road, P.O. Box 1000A, R.R. #3, Brandon, Manitoba R7A 5Y3, Agriculture and Agri-Food Canada, Science and Technology Branch, Canada

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ABSTRACT

Understanding spatial patterns of soil phosphorus is critical for efficient nutrient management and for the design of soil sampling in agricultural watersheds. This study describes patterns of soil test phosphorus (Olsen-P) concentration and variability for undulating/dissected agricultural landscapes in southwestern Manitoba under a range of management systems (no-input organic, organic with manure application, no-till, fertilized and tilled). Sampling occurred at 504 locations located in 16 small watersheds draining eight different fields. At a regional scale, most variance in Olsen-P for the 0–15 cm depth was associated with differences among fields (0.344 [log (mg kg^{-1})]^2, 47%). However, significant variance (0.263 [log (mg kg^{-1})]^2, 36%) was associated with differences among sampling plots within each field. Olsen-P for the 15–60 cm depth was lower and variance was more strongly associated with differences in field. Among-field differences in Olsen-P for 0–15 cm were strongly associated with management. Elevated Olsen-P was observed for fields that historically received application of fertilizer or manure in combination with tillage and lower Olsen-P was observed for low input organic and no-till fields. For six of eight fields sampled, a high proportion of variance in Olsen-P at the 0–15 cm depth was predicted by the Topographic Wetness Index (TWI) ($r^2 = 0.46$–0.96, $p < 0.01$), with better predictive ability observed in low input and no-till fields. Despite differences in this relationship associated with management history, a significant positive correlation with TWI was observed among all sampling plots ($r^2 = 0.25$, $p < 0.0001$, $n = 56$). The tendency toward P accumulation in low lying areas highlights the potential to reduce input rates in these locations for a variety of farm management systems practiced on the glacially formed landscapes of the Canadian prairies, but the need to develop management system specific recommendations for targeted application are also illustrated in this case study.

1. Introduction

Developing a better understanding of patterns of concentration and variance in soil test phosphorus is an important step in predicting those areas of agricultural watersheds susceptible to nutrient losses in runoff and patterns of crop productivity. Much research has been directed toward identifying spatial distributions of soil fertility in agricultural areas (Balkcom et al., 2005; Bennett et al., 2005; Gregorich and Anderson, 1985; Morton et al., 2000; Nolan et al., 2007), largely due to the potential for this information to aid in the development of relationships to predict spatial patterns in relation to soil erosion, topography and processes related to management.

For studies focused on undulating glacial till landscapes, fields under similar management tend to exhibit higher concentrations of most elements (including P) at lower landscape positions, possibly following aqueous transport or deposition of eroded or leached material (Gregorich and Anderson, 1985; Letkeman et al., 1996; Manning et al., 2001). Elevated concentrations of total soil P in topographic depressions receiving flow or runoff water has been clearly associated with pedogenesis of glaciated soils (Letkeman et al., 1996). However, this pattern has not been consistently observed among all sites where the spatial pattern of extractable P has been studied, and a number of authors have suggested that tillage or fertilizer input history may influence these patterns (e.g., Bennett et al., 2005; Nolan et al., 2007; Page et al., 2005). When spatial distribution of soil P has been examined among broader regional scales, predictability by terrain attributes is often poor and has been associated with a stronger influence of land use (Liu et al., 2013; Roger et al., 2014).

Studies examining the spatial heterogeneity of soil nutrients among multiple scales are less common than those focusing on field-scale or regional-scale patterns alone. In Wisconsin, Bennett et al. (2005) observed

* Corresponding author.
E-mail address: henry.wilson@agr.gc.ca (H.F. Wilson).

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higher among-field variance and reduced within-field variance of soil P at cropland sites in comparison to native prairie or pasture sites, and hypothesized that a history of repeated whole-field applications of P fertilizer at a spatially constant rate may have caused reduced in-field variability. Similarly, Nolan et al. (2007) speculated that multiple years of constant-rate fertilizer application and soil homogenization by conventional tillage resulted in the lack of a relationship between extractable P and landform for a set of eight small watersheds studied in Alberta, Canada. The potential influence of landscape position on within-field variance was not explicitly examined by Bennett et al. (2005), but given that relationships between landform and soil P have been observed in a variety of locations (Balkcom et al., 2005; Brubaker et al., 1993; Manning et al., 2001; Moulin et al., 2012; Wang et al., 2001) it can be expected that within-field variance should be higher for fields with more topographic variability. However, we hypothesize that any relationship to landform should be more predictable in the absence of fertilizer or manure input and tillage. In this paper, we examine whether predictability of extractable P by landform and the pattern of variance among spatial scales (among site, among plot or landscape positions, and among points within a plot) differs among fields under a variety of management systems (with and without fertilizer or manure application, tilled, and no-till).

The objectives of this research were to characterize the spatial distribution of extractable P (Olsen-P) in small cropland watersheds in an undulating glacial till landscape in southwestern Manitoba, Canada, and to assess the relationship with landforms within fields as influenced by tillage and fertilizer management.

2. Methodology

2.1. Study area

The data used in this analysis were collected as part of a larger study to investigate the relationship between Olsen and water soluble P following cropping, and snowmelt runoff P losses from small watersheds draining cropland in southwestern Manitoba. Eight fields were selected with contrasting fertilizer input and tillage management practices (Table 1), and all sites were located on Chernozems (Food and Agriculture Organization of the United Nations, 1985) also referred to as Black Chernozemic Soils (Canadian Agricultural Services Coordinating Committee - Soil Classification Working Group, 1998) or Haplocryolls (USDA soil classification – Soil Survey Staff, 2006). Management systems were defined by fertilization and tillage practices during the preceding five years (Table 1). Sites without tillage prior to or after seeding during the five-year period were classified as no-till (fields NTCF1 and NTCF2). Monoammonium phosphorus was applied in a side-band at seeding in no-till sites. Sites with more frequent tillage were classified as conventional with fertilizer (field CTCF), organic with no inputs of fertilizer (fields ONF1, ONF2, ONF3), organic with beef manure applied in crop season before sampling (field OM), or historically applied beef manure surface applied within the previous five years, but not water soluble P fertilizer (field OHM) (Table 1).

All fields were located within 50 km of Brandon, Manitoba, Canada (49.8333°N, 99.9500°W). The region has a humid continental climate with cool summers and no dry season (Köppen classification of climate) (Kottek et al., 2006). Three fields (NTCF1, NTCF2, ONF3) were located in the Harding Clay soil association formed on calcareous lacustrine deposits and classified as an imperfectly drained Gleyed Black Chernozem (Canadian System of Soil Classification). Four fields (OM, OHM, ONF1, ONF2) were located on the smooth phase of the Newdale Clay Loam soil association, a moderately well to well-drained Orthic Black Chernozem developed on calcareous loamy morainal till. One field (CTCF) was located on a well to moderately well drained Orthic Black Chernozem soil formed on calcareous fine loamy lacustrine sediments (Ramada Clay Loam) (Manitoba Agriculture Food and Rural Initiatives, 2010).

2.2. Landform classification and soil sampling design

A digital elevation model (DEM) was derived for each field from elevation data collected with a RTK GPS (Trimble R8 GNSS System with

Table 1
Field site characteristics.

Field	Soil	Crop in previous growing season	Management	Number of sampling plots (nine points per plot)				Number of watersheds	Tillage	P Fertilization (frequency, year of last application with tillage and method of application)
				U	L	M	D			
NTCF1	Harding clay	Wheat	No tillage	3	3	1		2	Last tillage operation 5 years ago	Annual or biennial side banding of monoammonium phosphate with seeding 5–10 kg^{-1} ha^{-1} P typical rate
NTCF2	Harding clay	Canola	No tillage	2	3	4		2	Last tillage operation 10 years ago	Annual or biennial, side banding of monoammonium phosphate with seeding 5–10 kg^{-1} ha^{-1} P typical rate
ONF1	Newdale clay loam	Hairy vetch	Organic	1	1	1		1	More than one pass per year, cultivator in fall 2012	>10 yr since last application, >10 yr since fertilization with tillage
ONF2	Newdale clay loam	Green feed oats/alfalfa	Organic	2	1	2		2	More than one pass per year, cultivator in spring 2012	>10 yr since last application, >10 yr since fertilization with tillage
OHM	Newdale clay loam	Barley	Organic historically receiving manure	1	1	2	1	1	More than one pass per year, cultivator in fall 2012	3–5 yr between manure applications, beef manure applied in fall of 2009 at 45 kg^{-1} ha^{-1} P
OM	Newdale clay loam	Hemp	Organic receiving manure	1	1	2	1	1	More than one pass per year, cultivator in fall 2012	3–5 yr between manure applications, composted beef manure applied in spring 2012 at 25 kg^{-1} ha^{-1} P
CTCF	Ramada clay loam	Canola	Conventional	3	1	3	2	3	Two tillage operations in three years, cultivation in fall 2011	Annual application of mixed blend for N, P, S with side banding for P at rate defined by soil test recommendations, surface application and incorporation by cultivation with potato crop in 2010
ONF3	Harding clay	Flax	Organic	4	4	4	1	4	Once or twice per year, spring 2012	>10 yr since last application, >10 yr

Abbreviations for filed names are based on tillage and P fertilization history: no-till with commercial fertilizer (NTCF),organic no fertilizer (ONF1), organic historical manure (OHM), organic manure (OM), conventional tillage with commercial fertilizer (CTCF), organic no fertilizer (ONF). Sampling plots were located in upper slope (U), lower slope (L), middle slope (M), and depression (D) landform facets as classified with fuzzy logic rule sets in LandmapR (MacMillan et al., 2000) and then generalized into four classes.