Impact of Degree of Fertilizer and Manure Incorporation and Timing of First Runoff Event on Phosphorus Losses to Surface Runoff

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Context

The 4R Nutrient Stewardship approach strives to maximize economic benefits to farmers while minimizing adverse environmental effects. Nutrient placement is one of the four "Rs", and it is particularly relevant to P. Recent studies in the US portion of the Lake Erie watershed suggest that a significant contributor to elevated dissolved P losses from cropland, and hence to algal blooms in Lake Erie, may be surface broadcast P fertilizer. There has been significant work done on the agronomic impacts of different fertilizer placement systems, but very little on the potential environmental impacts. This study proposes to address this shortfall by comparing the P concentrations in runoff from various application systems for both fertilizer and manure, under controlled conditions.

When dealing with P movement from agricultural lands, it is very important that one keeps in mind that there are two over-riding factors or processes that will influence losses. These are often referred to as being source factors and transport factors. By using controlled environment studies, we attempt to minimize variability in the transport factors (aside from some aspects that may be treatment or P-source material specific (e.g. manure increasing water infiltration) to better ascertain the impact of management and source effects on potential P losses in runoff. One can view the partial or complete incorporation of fertilizers or manures as limiting the amount of P that can interact with runoff waters, although P increased interaction between soil and P added can also affect the amount of P available for movement, particularly as dissolved P.

We hypothesize that losses of P from applied materials in a surface runoff event of a given intensity will be proportional to three factors:

- Solubility of P in the applied material
- Time after application
- Amount of the material exposed at the soil surface after incorporation or injection

With respect to the solubility of P in applied materials, the research published to date clearly indicates that with increasing water extractable P (WEP) in the source material, the concentration of dissolved reactive P (DRP) in runoff waters will also increase (Kleinman et al. 2002, Shigaki et l. 2006, 2007) and hence the consideration of source material WEP content as a factor in recently developed P indexes.

There have also been several studies assessing the impact of time after application on P losses (Allen and Mallarino, 2008; Hanrahan et al. 2009; Kleinman and Sharpley, 2003; O'Halloran 2013 (unpublished data); Smith et al. 2007; Westerman et al. 1983) with mixed results in terms of P losses either decreasing or not being affected by timing of first rainfall event. This in part, can be attributed to differences in cropping systems studied, rainfall intensities used (or received) and environmental conditions between application and first runoff event. Regardless, these studies have focused on either surface-applied manure on forages, or comparing surface application to incorporated manure. We have not yet found any studies that looked at comparing P losses from different levels of incorporation, or with banding systems that leave different amounts of manure exposed at the surface. This poses a barrier to predicting the actual impact of various mineral fertilizer and manure application systems on P losses, and thus to recommending BMPs for managing these losses. The focus of this study is to gain a better understanding the impact of various incorporation methods on P losses from applied materials and how this information can be related to improving phosphorus management on farms.

Several factors will be interacting when P from manure or fertilizer is applied to the field, which influence the amount that desorbs and is carried off the field with runoff. Apart from the solubility of the P, there can be physical limits to the P that actually interacts with precipitation in much the same way that dissolved P losses from soil are from a shallow layer at the surface (Sharpley 1985). Thus, only a portion of the soluble P in the manure or fertilizer will be available for desorption, and this quantity will vary with the physical characteristics of the manure (solid versus liquid; finely divided versus clumps). The thickness of the "active layer" at the surface will change over time, as manure that dries on the surface of the soil can form a hydrophobic crust that sheds most of the water that falls on it. This process would be in addition to those considered by Vadas et al. (2011), who in their SurPhos model attributed changes in dissolved P in runoff to the net effect of organic P mineralization, and P assimilation into the soil by bioturbation. There is also likely to be an interaction with rate, so that as the manure approaches 100% coverage of the soil surface, the potential for loss would follow a different pattern than the circumstances when the soil surface is partially covered. It has been well established that the dissolved P losses from soil are coming from a shallow depth of interaction with runoff water (Hart and Cornish, 2010; Sharpley, 1985), and it is reasonable to assume that manure may follow a similar pattern. The consequence of this is that P losses from manure applications that are made up of large clumps or that form a thick layer on the soil surface will not be directly proportional to the total application rates. We assume that this limitation does not exist for fertilizer P, but this assumption has not, to our knowledge, been tested.

Fertilizer or manure can also have an impact on the partitioning of water between surface runoff and infiltration, either through the mechanical effect of the incorporation equipment, the mulching effect of the added materials, or the impact on soil structure as the soil biota incorporate the applied manure into the soil. These impacts on water partitioning will also be affected by the physical characteristics of the manure. It is unfortunate that most scientific papers focus only on the concentration of P in runoff water, and do not include the data on the time to initiate runoff, or the partitioning between runoff and infiltration. This may in part be due to the fact that soil conditions prior to rainfall events are often manipulated to minimize differences in time to generate runoff (i.e. soils are typical wetted to near saturation). These interactions between applied P, water movement are all occurring in the context of the variations in the properties of the soil receiving the P, which adds another layer of complexity.

To address the key knowledge gaps in predicting the impact of incorporation on P transport, a runoff box study is proposed. The advantage to this approach is that the variables of slope, rainfall intensity and soil conditions can be controlled and thus the impact of the treatments can be assessed under similar conditions. The drawbacks are that the simulated conditions of incorporation may not reflect normal field conditions with farm implements and that saturation of the soil in a shallow box may influence the initiation of runoff. Because of the use of shallow boxes, it will be necessary to adjust manure rates for the different application systems to properly simulate exposure of manure at the surface of the soil in the shallow boxes.

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The project is directed at providing a better understanding of the role of differing methods of fertilizer and manure applications on the potential for P loss in subsequent surface runoff events. The information will be used to direct field research efforts as well as inform decisions with respect to the development and/or promotion of BMP, Ontario P index and nutrient management policy.

The experimental design will utilize the standard methodology for assessing P losses using repacked soil boxes and simulated rainfall ((NPRP), 2001), with manure and fertilizer applied to simulate various levels of incorporation. Briefly, the runoff boxes are composed of plexiglass and have the dimensions (l x w x d) of 100 cm x 20 cm x 7.5 cm. Drainage holes are drilled in the bottom of the chamber to allow water to flow through the soil and the wall of the chamber at the down slope position is only 5 cm (corresponding to soil depth) to allow runoff to enter a collector shielded from rainfall. Partially dried and coarsely screened (2 cm) soils will be packed into boxes (final depth 5 cm) at a field representative bulk density. Soil with then be wetted to field capacity and allowed to dry down to workable conditions prior to the application of P sources. Simulations will be performed on 3 different soil textures (sandy loam, loam and clay) with four different P sources (control – no P applied, MAP fertilizer, solid cattle manure, liquid swine manure, and solid poultry broiler manure). Materials will be applied to supply the equivalent of 100 kg P2O5 ha-1 to allow reasonable assurance of fairly uniform application rates over the surface of the runoff boxes where required. Application treatments will include:

1. Surface broadcast, no incorporation

2. Complete mixing of manure or fertilizer with soil
3. Surface broadcast, simulated disking (~80% of soil surface area disturbed for incorporation)
4. Surface broadcast, simulated vertical tillage (~30% soil surface area disturbed for incorporation)
5. Surface banding
6. Below surface application (2.5 cm of soil placed and packed in box, manure and fertilizer broadcast on surface and then remaining 2.5 cm of soil applied and packed to desired bulk density).

Bands will be applied perpendicular to the slope of the box at 25 and 75 cm from the down slope end. Since incorporation of manure in the field would typically involve a greater soil depth than 5 cm, manure rates will be reduced accordingly to simulate deeper incorporation depths (e.g. if field incorporation depth is considered 15 cm, the rate of manure applied to the complete soil incorporation/mixture would be reduced to 1/3 of the surface applied treatment). After disturbance, the soils will be tamped to prevent excessive erosion losses and minimize variances between runoff values. The purpose of the study is not to assess the changes in water flow partitioning as impacted by soil disturbance which has been studied extensively, but rather the impact of amount of P source exposure at soil surface on P losses.

Each treatment will be replicated 4 times, and each box will be exposed to two runoff events, the first event 7 d after P application and the second runoff event 7 d after the first runoff event. To reduce costs, the study will be conducted as an incomplete design as the control treatment (i.e. no P applied) would be similar for treatments 1, 5 and 6. Thus, for each soil there are 4 application treatments with 5 P sources and 2 application treatments with only 4 P sources for a total of 28 boxes per rep for a total of 112 boxes/soil and 224 sampling events/soil. Each sampling event will have water samples collected at 5 minute intervals for a total of 30 minutes after the initiation of runoff, so the total number of water samples will be 1344. For the three soil combined, there will be 336 boxes, 672 sampling events and 4032 water samples. These water samples will be analyzed for total P, total dissolved P and dissolved reactive P. Prior to initiation of the experiment, soils will be analyzed for available P (Olsen, Mehlich-3, WEP, Fe-O, total), pH, OM, texture. Manure samples will be analyzed for moisture content, total NPK, and water extractable P by the method of Kleinman et al. (2006) (200:1 water:manure ratio, shaken for 1 hour). To ensure uniformity of manure between simulations with different soils, bulk manure of each type will be well mixed, divided into 3 (one for each soil), subsampled and frozen. For simulations on each soil, manure will be thawed the day before application and again subsampled for analyses. We are proposing to use a rainfall intensity that is more indicative of a 1 in 5 or 10 year storm (< 30-40 mm/hr) rather than intensities that would be indicative of 1 in 50 or 75 year storms. We will need to verify that selected intensities will give reasonable amounts of runoff for the study.

Limited field comparisons of incorporation methods will be carried out at Ridgetown, using artificial rainfall simulator on small plots established using field equipment. These will reflect treatments of surface broadcast manures and fertilizer with no incorporation, disking, and plowed followed by discing.

Runoff simulations and water analyses would be carried out at the Ridgetown Campus, University of Guelph, and at the AAFC Research Station in Harrow, Ontario, under the supervision of Dr. Ivan O'Halloran and Dr. Tiequan Zhang.

Work Plan and Timeline:

Activity	Time
Selection and hiring of post-doctoral fellow	July – September, 2013
Literature Review	Sept., 2013 – Jan., 2014
Collection of soils and manures	Sept. – Nov., 2013
Analysis of soils and manures	Jan. – March, 2014
Preparation of runoff boxes	Jan. – March, 2014
Rainfall simulations and water sample analysis	April – Nov., 2014
Data analysis – runoff box data	Dec., 2014 – Dec., 2015
Field study to validate runoff box data	April – Nov., 2015
Report and manuscript preparation	Jan. – Sept., 2016
Communication of results – conferences, journal articles, meetings	July – Nov., 2016