Soil & Tillage Research 135 (2014) 1–8

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Is tillage an effective method to decrease phosphorus loss from phosphorus enriched pastoral soils?

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ARTICLE INFO

Article history:
Received 8 April 2013
Received in revised form 28 August 2013
Accepted 31 August 2013

Keywords:
Phosphorus enriched soil
Water quality
Subsurface flow

ABSTRACT

The enrichment of soil phosphorus (P) can increase the potential for P loss via surface run-off and subsurface flow and impair surface water quality via eutrophication. The potential for P loss via surface runoff can be decreased by adding less P fertiliser and redistributing P within the plough layer through tillage. We tested the hypothesis that tillage would also decrease subsurface losses by disrupting preferential flow pathways and increasing P sorption as water moves via matrix flow. A 455-day lysimeter trial, carried out between February 2011 and May 2012 investigated subsurface P losses from four contrasting New Zealand soils (USDA soil taxonomy: Udand; Dystrudept; Fragiochrept and Vitrand) where P fertilisers were withheld and pasture was established following conventional tillage (to 20 cm) or conservation tillage (of the top 2 cm of soil-termed ‘direct drilled’). Our main objective was to assess the effectiveness of implementing conventional tillage methods during a farm regrassing program as a method to decrease P loss via subsurface flow from pasture soils. In the tilled and direct drilled treatments, Olsen P, water extractable P and calcium chloride extractable P concentrations decreased by 5–59% over the length of the trial in the top 0–75 mm. The tilled soils showed a larger decrease in soil P concentrations than the direct drilled soils, but this was not consistent across all soil types. One month after tillage, the dissolved reactive P load in subsurface flow of three of the four soil types was 30–70% less than the direct drilled treatment, but thereafter no effect was noted. Moreover, a 4–15 fold increase in nitrate leaching across all soil types for the first month after tillage. Our study suggested that tillage was not an effective method in the long-term to decrease subsurface P losses (in contrast to surface run-off) and may increase nitrate leaching in the short term.

1. Introduction

Agricultural soils with high phosphorus (P) concentrations are receiving growing attention as P sources with the potential to impair surface water quality (Sharpley et al., 1994). As a method to decrease soil P concentrations, and hence the potential to decrease P losses in surface runoff, halting P fertiliser inputs takes a long time to be effective (McCollum, 1991; Ma et al., 2009). Furthermore, in examining high-P pastoral soils, Dodd et al. (2012) suggested that halting P fertiliser may lead to a decrease in farm productivity within 0–7 years. Changes in farm management practices may be required to speed up the rates of soil P decline without impairing farm productivity. One possible solution is the use of conventional tillage to redistribute P within the plough layer during the reseeding of grazed pastures.

Pasture renewal every 10–15 years is part of the normal rotation cycle of highly productive pastures. However, in recent years, there has been a growing trend towards the implementation of conservation tillage including zero tillage systems, such as the direct drill sowing of seed. In 2008, roughly 25% of all New Zealand cropland, including pasture, forage and arable crops were reportedly under conservation tillage (Derpsch and Friedrich, 2008).

The main driver towards conservation tillage is a decrease in soil erosion (Logan et al., 1991). However, maintaining P fertiliser applications without periodic mixing within the plough layer (conventional tillage) can lead to P accumulation in the surface soil and stratification within the soil profile (Cade-Menun et al., 2010; Mathers and Nash, 2009; Vu et al., 2009). The loss of P to surface runoff is generated within the top 2 cm of surface soil that interacts with rainfall (Sharpley et al., 1981). Sharpley (2003) demonstrated that the mixing of high P surface soils with low P subsoils decreased Mehich-3 P concentrations in the top 0–5 cm of soil by

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Abbreviations: $CaCl_2$-P, calcium chloride extractable phosphorus; DRP, dissolved reactive phosphorus; DOP, dissolved organic phosphorus; FIA, flow injection analysis; WEP, water extractable phosphorus.

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0167-1987/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.still.2013.08.015

66–90% and total P concentration in surface runoff following a simulated rainfall event by 47%. Schärer et al. (2007) showed that tillage could decrease water soluble P concentrations and P losses in surface runoff from grassland soils that had been enriched with P via over-application of manure, but the effect was only significant during the first year after tillage.

While tillage has been shown to potentially decrease P losses via surface runoff, studies examining the effect on losses in subsurface drainage are few. Thomas et al. (1997) found evidence of preferential flow in a long-term arable soil in the UK and, much like Djodjic et al. (2002) hypothesised that by mixing soil within the plough layer through tillage, preferential flow pathways would be disrupted. This would force water to move as matrix flow and thereby decrease P losses since the P in matrix flow would be exposed to more low-P (and P-sorptive) soil in the plough layer. Djodjic et al. (2002) found no significant difference in P loss between the tilled and no-till treatments and attributed this to the possible re-formation of macropores and or matrix flow in all soils under ponded conditions. However, large applications of P fertiliser (100 kg P ha^{-1} yr^{-1}) were applied to the soil surface on two occasions over three years. This is clearly different from a system where little or no P fertilisers are used. There has been no investigation of the effect of tillage under these conditions.

One potential drawback of this strategy is the effect that tillage may have on soil organic matter and the associated nutrients. Re-introducing conventional tillage can increase mineralisation of organic matter including organic nitrogen (N), which may lead to nitrate leaching (Whitmore et al., 1992). If large amounts of N are lost, this could compromise the utility of this strategy in nitrate sensitive catchments. Furthermore, the effect on organic P is less clear. For example, McDowell and Monaghan (2002) simulated tillage in a lysimeter study of a high organic matter pastoral soil and found that there was no significant difference in the total P loss from the tilled or intact cores despite a significant decrease in DRP, due to the large contribution from the dissolved organic P (DOP) fraction which was unaffected by tillage. The size, composition and stratification of P fractions in soil and subsurface flow can vary greatly (Turner et al., 2003; Vu et al., 2009), but DOP is often regarded as less sorptive to soil than DRP (Condron et al., 2005). With the growing recognition that some DOP compounds may be bioavailable to algae (Whitton et al., 1991) there is need to consider the effect of tilling on DOP loss from undisturbed pastoral soils.

The overall aims of this study were to: (1) test the two hypotheses that: (a) tillage would quickly decrease topsoil P concentrations and disrupt preferential flow paths and thereby decrease P losses in subsurface flow; and (b) compared to DRP, DOP loss would be less affected by tillage; and (2) assess the effectiveness of implementing conventional tillage methods during a farm regrassing program as a method to decrease P loss via subsurface flow from pasture soils.

2. Materials and methods

A lysimeter trial was designed to compare the effect of direct drill and conventional tillage of a range of soil types on the loss of dissolved P fractions to sub-surface flow (otherwise called leachate). A combination of Olsen P, water extractable P (WEP) and calcium chloride extractable P ($CaCl_2$-P) measurements were used to assess agronomic and environmental soil P concentrations at depth and measurements were also made of pasture yield and dissolved nitrogen fractions to make a wider assessment of the agronomic and environmental risks of tillage.

2.1. Lysimeter setup

Grazed pasture sites were selected on contrasting soil types with similar known topsoil Olsen P concentrations, namely, a Horotiu silt loam, Waikiwi silt loam, Warepa silt loam and Taupo sandy loam (Table 1). These soil types cover the four most prevalent soil orders under pasture in New Zealand, Allophanic, Brown, Pallic and Pumice, respectively (Hewitt, 2010). The pasture was a mixture of ryegrass (*Lolium perenne* L.) and clover (*Trifolium repens* L.). Ten lysimeter cores (22 cm deep by 16 cm diameter) were taken of each soil by carefully excavating around the soil core and gently lowering a PVC pipe. When the pipe was completely lowered, the soil beneath was cut with a knife to ensure a clean break. The soil cores were transported to the Invermay Agricultural Centre in Mosgiel, New Zealand. Five replicate soil samples were taken from each site from three depths, 0–75 mm, 75–150 mm and 150–220 mm at the time of lysimeter core collection. The top 2 cm of soil from each core was removed with a knife and the pasture shoots and roots removed by hand. Half of the cores of each soil type were broken up by hand and combined with the 2 cm initially removed from the top of each core; the soil was mixed, sieved <6 mm and repacked into the PVC pipes to simulate a tillage event. The remaining cores were left intact and the top 2 cm of soil initially removed was mixed and re-deposited on each lysimeter, mimicking the action of a seed drill. An end cap, filled with acid-washed silica sand, was attached to the base of each lysimeter and petroleum jelly was used to seal the gap between the edge of the intact soil core and the PVC pipe to prevent edge-flow along the lysimeter sides. An outlet hole in the end cap allowed collection of the leachate. Each of the lysimeters was re-sown with a mix of ryegrass (16 kg ha^{-1}) and clover (4 kg ha^{-1}). The assembled lysimeters were then dug into the bank of a dedicated outdoor collection facility.

Table 1
Location of field sites from which the lysimeters were taken, the soil type and soil properties at the 0–7.5 cm depth. Values in parenthesis show one standard error of the mean.

Sampling location	Soil type (New Zealand soil classification/USDA soil taxonomy[a])	pH	Particle size (g kg^{-1} sand; clay; silt)	P retention (%)	C/N
Ruakura Research Centre, Waikato, NZ	Horotiu Silt Loam (Typic Orthic Allophanic soil/Udand)	4.9 (0.04)	600 200 200	72 (4)	9.1 (0.15)
Woodlands Research Station, Southland, NZ	Waikiwi silt loam (Typic Firm Brown soil/Dystrudept)	5.0 (0.02)	200 300 500	53 (1)	10.3 (0.30)
Invermay Agricultural Centre, Otago, NZ	Warepa Silt Loam (Mottled Fragic Pallic soil/Fragiochrept)	4.6 (0.02)	300 200 500	16 (1)	12.0 (0.16)
Rerewhakaaitu Farm, Bay of Plenty, NZ	Taupo sandy loam (Immature Orthic Pumice soil/Vitrand)	4.4 (0.02)	800 100 100	51 (2)	11.0 (0.22)

[a] New Zealand soil classifications converted to US soil taxonomy according to Hewitt (2010).