STOTEN-19972; No of Pages 10

Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Manure and sorbent fertilisers increase on-going nutrient availability relative to conventional fertilisers

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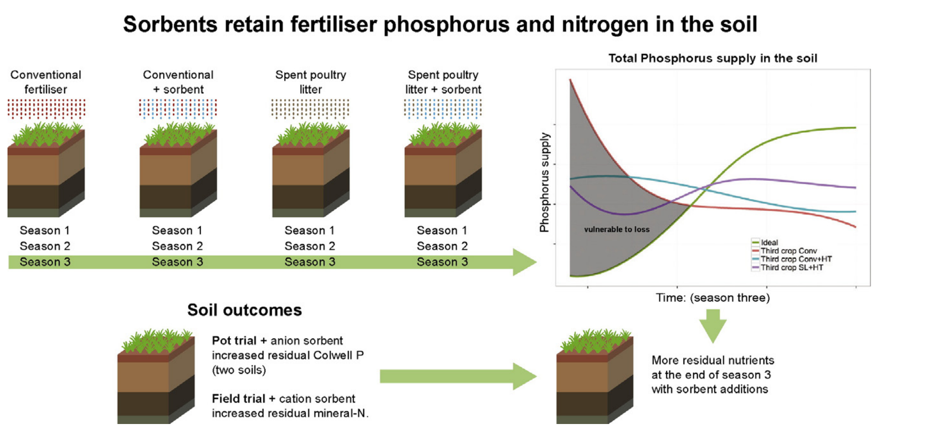
HIGHLIGHTS

- Field and glasshouse studies to investigate efficient in-season nutrient supply.
- Sorbent additions (hydrotalcite; HT) tended to defer P availability (2 soils).
- Spent litter derived nutrient (manure; SL) deferred P availability in some soils.
- Sorbent additions (bentonite, HT) increased residual nutrient (N, P respectively).
- Manures and ion-exchangers may match Conv N and P sources with lower losses.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 February 2016
Received in revised form 26 April 2016
Accepted 11 May 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Nutrient uptake
Nitrogen
Phosphorus
Fertiliser
Sorbent
Manure

ABSTRACT

The key to better nutrient efficiency is to simultaneously improve uptake and decrease losses. This study sought to achieve this balance using sorbent additions and manure nutrients (spent poultry litter; SL) compared with results obtained using conventional sources (Conv; urea nitrogen, N; and phosphate–phosphorus; P). Two experiments were conducted. Firstly, a phosphorus pot trial involving two soils (sandy and clay) based on a factorial design (*Digitaria eriantha*/*Pennisetum clandestinum*). Subsequently, a factorial N and P field trial was conducted on the clay soil (*D. eriantha*/*Lolium rigidum*). In the pot trial, sorbent additions (26.2 g of hydrotalcite [HT] g P^{-1}) to the Conv treatment deferred P availability (both soils) as did SL in the sandy soil. In this soil, P delivery by the Conv treatments declined rapidly, and began to fall behind the HT and SL treatments. Addition of HT increased post-trial Colwell P. In the field trial low HT-rates (3.75 and 7.5 g of HT g P^{-1}) plus bentonite, allowed dry matter production and nutrient uptake to match that of Conv treatments, and increased residual mineral-N. The SL treatments performed similarly to (or better than) Conv treatments regarding nutrient uptake. With successive application, HT forms may provide better supply profiles than Conv treatments. Our findings, combined with previous studies, suggest it is possible to use manures and ion-exchangers to match conventional N and P source productivity with lower risk of nutrient losses.

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http://dx.doi.org/10.1016/j.scitotenv.2016.05.068

1. Introduction

Despite decades of agricultural research, applications of conventional fertiliser products, such as urea and superphosphate, result in only 40 to 60% plant uptake of the target nutrients (Bolland and Gilkes, 1998; David and Gentry, 2000; Drinkwater and Snapp, 2007; Galloway and Cowling, 2002; Van der Molen et al., 1998). For P and N, losses take different forms via different paths. The residual value of previously applied conventional phosphorus fertilisers is indicated to decline with time after application (Bolland and Gilkes, 1998). This is due to the rapid conversion of soluble forms to more stable less soluble forms. In contrast, where high yields are sought without regard to nitrogen fertiliser efficiency, the result can be the contamination of adjacent environments (e.g. Di and Cameron, 2002; Perego et al., 2012).

This presents a severe problem, given that the productivity of agricultural land will be required to rapidly increase to meet international demands. For example it is foreseeable that China will require 30 to 50% more food to meet demand in the next two decades (Zhang et al., 2013). However, the problem is not restricted to China. There is both a requirement and an economic opportunity for food exporting nations to increase productivity.

To date, nations have achieved improved crop production at the expense of increasingly leaky fertiliser practices (Drinkwater and Snapp, 2007; Zhang et al., 2011). Decreasing the losses associated with crop fertiliser delivery is becoming a substantial community focus. For example in Australia, where intensive crop production may occur adjacent to sensitive environments (e.g. The Great Barrier Reef), community concern has increased after scientists have suggested causal links between water quality and reef health (Queensland Government, 2015). Solutions to enable efficient, yet high-yield, agriculture are being sought.

It is know that precise application of fertiliser nutrients just in time to meet a maturing crop's demand can substantially decrease system losses and inefficiency. By managing N fertiliser in a manner that ensured non-limiting N supply with minimum excess (and minimum losses) through in-season root zone N management. Chen et al. (2006, 2010) were able to almost double maize yields with no increase in fertiliser use (Zhang et al., 2011). In this management, total fertiliser N additions are divided into sub-applications that are applied throughout the growing season (Cui et al., 2010). This practice would only suit agricultural production systems where it is feasible to access the crop for additional fertiliser applications during the growing cycle. In many agricultural systems this approach may result in crop disturbance or excessive fertiliser application costs. In these circumstances, other options that are able to efficiently supply nutrients to meet growth requirements may enable the same benefits to be achieved.

Conventional fertiliser practice emphasises the uptake of inorganic nutrient forms. However, it is known that some organic nutrients are available to plants (Paungfoo-Lonhienne et al., 2008, 2012; Schmidt et al., 2013). The relative importance of organic nutrient uptake (compared to inorganic nutrient forms) remains unknown (Nasholm et al., 2009).

Models have been used to predict nutrient availabilities from manure or organic waste applications to soils in experimental crop management (e.g. composts and manures, Archontoulis et al., 2014; Beraud et al., 2005). However, no attempt appears to have been made to tie waste material nutrient release to in-season nutrient requirements of crops or pastures.

Innovation in fertiliser efficiency has a long history (e.g. Ellis, 1907), and a range of approaches have been taken to enhance the effectiveness of fertiliser materials, dominantly via controlled or slow release or via the application of nitrification or urease hydrolysis inhibitors (Halvorson et al., 2014; Timilsena et al., 2015). The nutrient delivering efficiency of these products tends to be higher than that of conventional fertilisers, due to their enhanced potential for in-season nutrient supply, and decreased potential for leaching, run-off, and gaseous nutrient losses (Dave et al., 1999; Trenkel, 2010). Another important advantage is a decrease in the damage to leaves and roots due to osmotic stress (Shaviv, 2001; Trenkel, 2010). While some of these approaches have demonstrated substantial agronomic or environmental advantages, they tend to be expensive (2 to 13 times the cost of equivalent masses of conventional fertiliser nutrient; Lammel, 2005).

Nitrogen transformation inhibitors (urease and nitrification inhibitors) may be less expensive than encapsulated fertiliser products, however, they tend to be temperature sensitive (breaking down as temperatures increase; Irigoyen et al., 2003; Ruser and Schulz, 2015), and there are health concerns regarding the application of some forms of inhibitors (hydroquinone; Trenkel, 2010). Even where there is no demonstrated health effect, observation of residues in agricultural products (e.g. Danaher and Jordan, 2013) can be a barrier to adoption of these technologies.

Ion exchange materials have been proposed as a means to tailor nutrient supply to meet plant demand without excessive nutrient availability and decreased leaching losses (Gillman and Noble, 2005; Gillman, 2011). The advantage of the ion-exchange mechanism in nutrient supply is that these materials will tend to buffer solution concentrations, potentially supplying further nutrient as the plant lowers solution concentrations in the rhizosphere. Materials investigated in this role include: hydrotalcite, an anion exchanger able to retain P and N as nitrate; and bentonite (Gillman, 2011; Redding, 2011) or zeolite (Li et al., 2013) which have an affinity for ammonium cations. Further studies have established that cation exchanger additions can decrease nitrogen leaching losses (Aghaalikhani et al., 2012; Ding et al., 2010; Gholamhoseini et al., 2013; Singh et al., 2010). This study seeks to further investigate this potential through the application of an anion exchanger for P delivery and a cation exchanger for N delivery.

One approach may be to utilise waste organic nutrient sources, not simply to match conventional fertiliser performance, but to provide a means of on-going nutrient mineralisation and release (Adeli et al., 2011; Kihanda et al., 2005; Smith et al., 1998). This may prove to be a means to re-couple the nutrient and carbon cycles, potentially resulting in less nutrient losses due to nutrient excesses (Drinkwater and Snapp, 2007). Conventional use of manures as fertilisers often do not achieve this end, as demonstrated by a range of studies into nutrient losses (e.g. Chardon et al., 1997; Rasouli et al., 2014; Smith et al., 2007). However, it is likely that continued seasonal applications of moderate quantities of manure nutrients will result in steadily increasing availability of nitrogen, phosphorus, and potassium with successive applications (Bar-Tal et al., 2004).

Initial groundwork identifying potential key advantages of manure use is already in place. A meta-analysis of available data suggests that while manure applications to soil (without formulation) as fertilisers resulted in significantly greater organic carbon (OC) in soils, the yield effects of these two nutrient sources were comparable (Edmeades, 2003). Given a history of annual manure application, it is possible to reach a point where annual N and P made available in the rhizosphere is equal to the manure N and P applied (Helgason et al., 2007). One study achieved on-going nutrient release matching crop requirements within 9 years using cattle manure and composted cattle manure (Miller et al., 2009). Effectively these observations suggest that manure nutrient forms defer nutrient availability relative to conventional fertiliser forms. As the agricultural paradigm shifts to a need for precise and efficient nutrient supply with low environmental losses, can these manure characteristics offer an advantage?

This is the starting point for our research. We sought to identify if we could use two ion exchange materials and a manure nutrient source (spent poultry litter; the bedding material collected from a commercial production facility after the production of a batch of broiler chickens) to defer N and P availability relative to a conventional fertiliser. To this end we conducted glasshouse and field trials over multiple seasons, observing a considerable offset of availability of P relative to the conventional source.

Please cite this article as: Redding, M.R., et al., Manure and sorbent fertilisers increase on-going nutrient availability relative to conventional fertilisers, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.05.068