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Improving manure nutrient management towards sustainable agricultural intensification in China

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ABSTRACT

Traditionally farmers in China have relied on organic manures to build the organic matter content in soil and to fertilise crops for both human and livestock consumption. However, with requirements to increase food production, the use of relatively cheap inorganic fertilisers has increased, and manure nutrients are not always used to their potential. In addition, farms of all sizes and even biogas plants, often lack the basic infrastructure to manage manures; poor containment facilities often result in untreated manures being discharged directly into watercourses, whilst transportation of manures to the field and land spreading is often not mechanised and relies on availability of suitable labour. There is already clear evidence of overuse of nutrients in some parts of China and this is causing undesirable impacts on the environment. With the increasing demand for livestock products from a burgeoning population and changes in dietary preferences towards animal protein, greater quantities of manure nutrients will be generated in the next twenty years, especially in peri-urban concentrated animal feeding operations and intensive farms. It is essential that China addresses the infrastructural, research and communication challenges to ensure that manures are integrated into nutrient planning at the field, farm and regional level to safeguard the environment, reduce the requirement for inorganic fertiliser production and use, and improve farmer incomes. This paper reviews the current manure management practices, both nationally and, where appropriate, at a regional scale, and assesses what barriers currently prevent efficient manure nutrient utilisation in China. We then address the future challenges for manure nutrient management in China, before summarising key gaps in knowledge and communication with implications for research and policy.

1. Introduction

Traditionally farmers in China have relied on organic manures to build the organic matter content in soil and to fertilise crops for both human and livestock consumption. In the 1950s, nutrients from organic manures supplied over 90% of the total nutrients applied to farmland (Yang et al., 2008), because of the lack of available chemical fertilisers. However, with requirements to increase food production, the use of relatively cheap inorganic fertilisers has increased, and manure nutrients are not always used to their potential.

Through the successful use of subsidies, China has dramatically increased its use of fertiliser N on agricultural land and successfully improved crop grain yields by 93% over the past 35 years (1978–2012) (MOA, 2009; NBSC, 2013). This increase in home-grown production has been supplemented by large quantities of imported feedstuffs, thus allowing China to feed it's increasing population and resulting in an increase in its total protein and animal protein consumption by about 50% and >100%, respectively. Total fertiliser use has increased more than 6-fold during this time (1978–2012) (ibid). But it is clear from national statistical data (MOA, 2009; NBSC, 2013), that N use efficiency (NUE) has decreased during the past two decades, with much of this excess N being lost to the environment. Since the 1990s there has been a major decline in NUE from 30–5% to 20–30% for the whole of China, and below 20% in some major grain producing provinces, compared with a global average of 40–60% (Zhang et al., 2008).

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There is a growing preference for greater consumption of livestock products in China (Pan, 2011), which has implications for numbers of livestock reared, manure generation and sustainable use of manure nutrients. This increase in livestock production (via increased livestock numbers and increased efficiencies of production) is most likely to be achieved through a greater number of concentrated animal feeding operations (CAFOs) and intensive farms, which tend to be landless systems, rather than via increased numbers of livestock per traditional household, or in co-operative livestock systems (in which multiple livestock producers operate using common management practices). There is therefore a need to plan how the manures from these CAFOs and intensive farms (and the nutrients they contain) can be effectively and sustainably utilised. Fig. 1 illustrates the different stages of manure management during the whole manure chain.

Note: in China, a CAFO is technically defined as any operation that has >50 pigs, 2000 broilers, 500 layers, or 5 dairy cattle (CLYEC, 2007). Chinese CAFOs are very small compared to CAFOs in developed countries, such as the United States where a large CAFO is defined as an operation with >10,000 pigs or 30,000 broilers or 82,000 layers, or >1000 cattle or cow/calf pairs (USEPA, 2009). An intensive livestock farm in China is defined as an operation that has ≥500 pigs (slaughtered), ≥100 dairy (stock), ≥100 beef (slaughtered), ≥10,000 laying hens (stock), ≥50,000 broilers (slaughtered) (IAESD and NIES, 2009).

In China, as in many Asian countries, livestock production has increased dramatically in the past 20 years, with little change in manure management practices, and there are deficiencies at all stages of the manure management chain, *viz* livestock housing, manure storage and processing, and land spreading (Fig 1; Chadwick et al., 2011). For example, there is poor containment of manure as it is generated and processed (in yards, livestock buildings, manure stores and composting plants), with much being directed to ditches and watercourses. In China, *ca.* 20% of manure generated is unmanaged (Wang et al., 2007), with a high risk of polluting watercourses. Similarly in Vietnam, Vu et al. (2012) estimate that 7–15% of livestock feed intake N is discharged in manures to watercourses. Manure nutrient utilisation is also poor because of inadequate mechanisation for transporting manure to the fields and difficulties in spreading manures with current labour demographics in rural areas (Sun et al., 2012). Whilst the key challenges in utilising manure nutrients effectively include inadequate knowledge of the requirements and times of peak nutrient demand by crops, the soil's nutrients supply, total manure nutrient content and the availability of their nutrients. The latter requires an understanding of the factors controlling nutrient losses (especially nitrogen and phosphorus) from manures and the rate of organic N mineralization (Chadwick et al., 2000). If this information is not known and inappropriate advice given to farmers, then either insufficient available nutrients in the soil will result in yield penalties, whilst excess nutrients in the soil will increase the risk of transfers to water (Burkart and James, 1999; Chadwick and Chen, 2003) and air (Aillery et al., 2005; Chadwick et al., 2011; Petersen et al., 2013). Some yield penalty may also result.

There is already clear evidence of overuse of nutrients in some parts of China (SAIN, 2010) and this is causing undesirable impacts on the environment (Norse, 2015; Guo et al., 2010; Le et al., 2010; Liu and Zhang, 2011), with key problems associated with the discharge of effluent (including the liquid fraction of solid manure, whole slurry and the liquid fraction from separated slurry) from livestock farms and over-application to many crop types in China (Ju et al., 2006; Lu et al., 2012; Sims et al., 2013; Xue et al., 2013b; Yan et al., 2013; Ostermann et al., 2014; Powlson et al., 2014). A more rational approach to the use of nutrients in Chinese agriculture, especially an improvement in manure nutrient efficiency should result in reduced inorganic N fertiliser use, which would deliver a range of benefits, including a reduced impact on the environment and improved farmer incomes, without crop yield penalties.

The proximity of livestock production systems to vulnerable surface and groundwater is a key factor effecting local pollution. Runoff and leachate from uncontained manure and over-fertilized

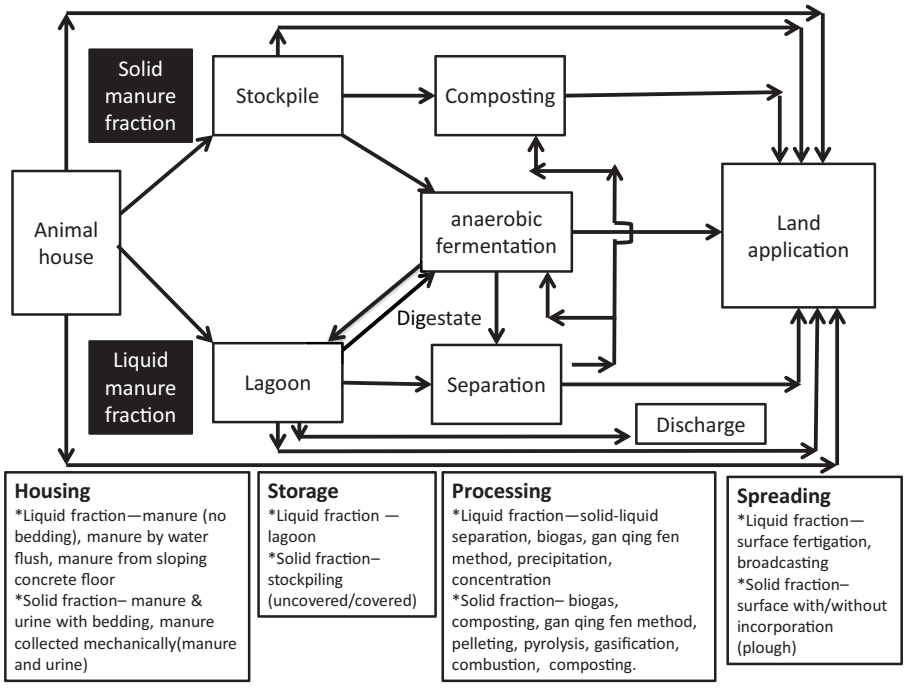

Fig. 1. Schematic overview of utilized routine and critical treatment steps for solid and liquid livestock manure based on integrated crop-animal systems in China. *Note*: the current situation in China is that much of the liquid fraction of manures is lost from housing, storage and processing prior to land spreading, representing inefficiency in nutrient use and impacting adversely on the environment.
(Adapted from Chadwick et al., 2011).

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