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Phosphorus as a limiting factor on sustainable greywater irrigation

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HIGHLIGHTS

- We assessed four residential lots that had been irrigated with greywater for four years.
- Each lot was monitored for irrigation volumes applied and various chemical and physical water quality parameters.
- A Mechlich3 Phosphorus ratio and Phosphate Environmental Risk Index was used to determine environmental risk of phosphorus.
- Reported soil phosphorus results were also compared to theoretical greywater irrigation loadings.
- Sustainable greywater reuse is possible however incorrect use can result in phosphorus impacting the environment.

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ABSTRACT

Water reuse through greywater irrigation has been adopted worldwide and has been proposed as a potential sustainable solution to increased water demands. Despite widespread adoption, there is limited domestic knowledge of greywater reuse. There is no pressure to produce low-level phosphorus products and current guidelines and legislation, such as those in Australia, may be inadequate due to the lack of long-term data to provide a sound scientific basis. Research has clearly identified phosphorus as a potential environmental risk to waterways from many forms of irrigation. To assess the sustainability of greywater irrigation, this study compared four residential lots that had been irrigated with greywater for four years and adjacent non-irrigated lots that acted as controls. Each lot was monitored for the volume of greywater applied and selected physic-chemical water quality parameters and soil chemistry profiles were analysed. The non-irrigated soil profiles showed low levels of phosphorus and were used as controls. The Mechlich3 Phosphorus ratio (M3PSR) and Phosphate Environmental Risk Index (PERI) were used to determine the environmental risk of phosphorus leaching from the irrigated soils. Soil phosphorus concentrations were compared to theoretical greywater irrigation loadings. The measured phosphorus soil concentrations and the estimated greywater loadings were of similar magnitude. Sustainable greywater reuse is possible; however incorrect use and/or lack of understanding of how household products affect greywater can result in phosphorus posing a significant risk to the environment.

1. Introduction

Water scarcity is increasingly becoming a problem worldwide (Godfrey et al., 2009; Jury and Vaux, 2007). Greywater irrigation has been adopted as one way to combat this scarcity (Maimon et al., 2010; Eriksson and Donner, 2009; Winward et al., 2008) and to help ensure the sustainability of this resource (Al-Jayyousi, 2003). It has been clearly demonstrated that greywater re-use is a potential solution to increased water demands (Gross et al., 2007; Jury and Vaux, 2007), however the sustainability of this practice has been questioned (Wiel-Shafran et al., 2006) as environmental pollution is probable if greywater is used incorrectly.

The commercial drive to produce low phosphorus cleaning products is low due to consumer habits and lack of legislation (Knud-Hansen, 1993). Consequently, high levels of phosphorus can be irrigated onto soil via greywater recycling (Patterson, 2004). To help change consumer habits Stevens et al. (2011b) promote a "GreySmart" web based tool, displaying information in a simplified manner by presenting consolidated research, allowing individuals to assess and potentially practice safe and sustainable greywater reuse (Greysmart, 2012). However even with web-based tools, consumer knowledge of the impacts and sustainability of greywater irrigation is inadequate (Whitehead and Patterson, 2007). Furthermore, guidelines and legislation on greywater irrigation tend to focus on human health (Maimon et al., 2010; Avvannavar and Mani, 2007) rather than environmental and sustainability issues. Additionally, both the Queensland (Department of State Development, Infrastructure and Planning, 2007) and Australian guidelines; (Environment Protection

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and Heritage Council, 2006) are incomplete due to limited scientific data and do not require the measurement of phosphorus loadings.

Research has clearly identified phosphorus as a potential risk for many forms of irrigation (Christova-Boal et al., 1996) and can accelerate freshwater eutrophication (Koopmans, 2002; Sharpley, 1995; Sharpley et al., 1995). A major source of phosphorus in greywater is sodium tripolyphosphate or potassium phosphates (ReVelle and ReVelle, 1988; Jenkins et al., 1973) used as builders in detergents (Lanfax Laboratories, 2009; Hammond, 1971). The primary role of builders is to reduce the hardness of the water and hence improve washing performance. This is achieved by binding to and neutralising calcium, magnesium, iron as well as manganese ions thus enabling the surfactant to work on the dirt and improving washing performance (Jenkins et al., 1973).

Greywater reuse typically occurs via irrigation (Travis et al., 2010; Wiel- Howard et al., 2007; Wiel-Shafran et al., 2006) although using it to flush toilets is becoming more common (Godfrey et al., 2009; March and Gual, 2009; Jeppesen, 1996). Other uses for greywater include; washing machines and washing paths, walls, and vehicles (Department of State Development, Infrastructure and Planning, 2007). These latter types of reuse need guidelines on the final quality of greywater since the runoff will go straight into the stormwater system and then local waterways without treatment. The economics of greywater treatment and reuse encourages the use of simple forms of irrigation and minimal treatment. Examples of simple forms of irrigation include bucketing laundry water, diverting washing machine waste water and (95 L per household per day) diverting shower water (140 L per household per day) (Beal et al., 2011). Due to minimal public education about the correct use of greywater, suburban subdivisions where greywater irrigation is practiced potentially face future environmental contamination issues.

When phosphate is irrigated onto soil, it can be taken up by plants (Barton et al., 2005) but the majority is absorbed to iron and/or aluminum oxy-hydroxides (de Mesquita Filho and Torrent, 1993; Lewis et al., 1981), and aluminosilicates (Barton et al., 2005) in soils via ligand exchange. The degree of phosphorus sorption to soil is directly related to the concentration of these minerals.

Once all the active phosphorus sorption sites have effectively been saturated and equilibrium reached, further irrigation results in a net increase in free phosphorus. The free phosphorus can move down the soil profile and potentially meet groundwater or move across the soil surface by interacting with surface water runoff. Two processes generally explain the chemical availability of free phosphorus; desorption of phosphorus from sorption sites on iron and aluminium oxy-hydroxides, associated with clay mineral surfaces and organic matter; and dissolution of phosphorus compounds present as soil minerals and or fertiliser (Moody, 2011). This movement of phosphorus can cause environmental contamination, and contribute to freshwater ecosystem eutrophication (Gross et al., 2005; Sharpley et al., 1996) thus potentially compromising the sustainability of greywater irrigation.

Two alternate approaches have been proposed to assess the sustainability of effluent irrigation, which contain phosphorus, on soils. Sims et al. (2002) suggested using a molar ratio of Mehlich3 extractable phosphorus to Mehlich3 extractable iron and Mehlich3 extractable aluminium ($M3PSR_{ICPAES}$) as an indicator of the potential loss of phosphorus from soils to surface and groundwater. Subsequently Maguire and Sims (2002) classified the potential for environmental harm posed by phosphorus in terms of Mehlich3 saturation ratios. Ratios of less than 0.10 indicate soil phosphorus saturations below environmental concern; ratios between 0.10 and 0.15 indicate soil phosphorus saturations where they may be an environmental concern; and a ratio greater than 0.2 indicates soil phosphorus saturations that are of environmental concern (Maguire and Sims, 2002).

The second approach, developed by Moody (2011), builds on earlier work that found P loss in irrigated soils was heavily governed by the water quality of the irrigated greywater (Roesner et al., 2006) and the chemistry and physical properties of soil (Travis et al., 2010; Wiel-Shafran et al., 2006). This method determines the ratio of Colwell P to the phosphorus buffering index and calls this the Phosphate Environmental Risk Index (PERI). A PERI value greater than 2.0 demonstrates a potential environmental hazard due to the loss of phosphorus from the soil.

In determining the sustainability of greywater irrigation two aspects should be considered. Firstly is there a net benefit from greywater irrigation in terms of water reuse? This has been demonstrated by many researchers and is not questioned by this study (Pinto and Maheshwari, 2010; Regelsberger et al., 2007; Whitehead and Patterson, 2007; Khalil et al., 2004; Al-Jayyousi, 2003). Secondly can potential impacts from greywater irrigation on soil, waterways and groundwater be managed sufficiently that there are no adverse effects? This research assesses the sustainability of greywater irrigation and its potential impacts.

To ensure greywater irrigation does not adversely impact the surrounding environment sustainable phosphorus irrigation loadings should be introduced into legislation. Furthermore, irrigation assessment models such as MEDLI (Gardner et al., 2002) should be utilised and enhanced (for sub-surface irrigation) to assess the suitability of the site to receive greywater. Guidelines for greywater application should be updated to address phosphorus impacts along with education programs to encourage residents to maintain the environmental sustainability of their land (Patterson, 2004). This paper assesses environmental impacts as a result of four years of greywater irrigation at four residential lots and evaluates the long term sustainability of these sites from phosphorus loading.

2. Methods

2.1. Research design

The design of this study included:

1) Collection of greywater and soil samples from four residential urban lots.
2) Collection of soil samples as controls from adjacent non-irrigated lots.
3) Surveys to determine households' use of products in the laundry and kitchen as well as the frequency of washing and bathing.
4) Chemical analysis of greywater.
5) Chemical and physical analysis of soil profiles.
6) Soil profiles were evaluated to ascertain phosphorus sustainability.
7) Actual phosphorus loadings in the soil were compared with estimated phosphorus loadings based on greywater chemistry and the results were used to estimate future sustainable phosphorus soil loadings.

2.2. Study area

The study area was a 22 lot residential subdivision with a total area of 3.8 ha, located approximately 10 km west of Brisbane, Queensland, Australia (Fig. 1). Individual lots ranged in area between 800 and 1800 m^2. The majority of the study area is steep with slopes up to 20% with each lot being terraced. Overland flow from the subdivision flows into Enoggera Creek — a high ecological value waterway (Sinclair Knight Merz, 2011; Brisbane City Council, 2010). Each lot has a 200 m^2 grassed transpiration area for greywater irrigation. The water supply for each household is captured rain water supplemented by mains potable water.

Four lots were chosen for this study. These were selected based on the results of workplace health and safety and site access considerations, and household demographics. The household of each selected lot was surveyed to determine what cleaning products were utilised in the laundry and kitchen. In addition, an adult from each household was interviewed on their knowledge and understanding of the importance and sustainability of greywater reuse as well as water efficiency. This gave insights into the residents' consumer attitudes and beliefs in and knowledge of greywater reuse.