Land Application System and Fate of Phosphorous

Introduction

Wastewater is an easily accessible but highly underutilized resource which could meet the agricultural irrigation needs while conserving fresh water for future generations. The use of wastewater for agricultural irrigation is often viewed as a positive means of recycling water, as potentially large volumes of water can be used, and recycled water is a constant and reliable source of water (Toze, 2004). However, only a small fraction of wastewater produced is reclaimed for beneficial use with less than 6% in the US and less than 3% in the global context (FAO, 2008). If the recycle rate was increased to 15%, the worldwide fresh water available would sustain the population to the year 2125 (Fedler, C. B., 2017).

Land application of wastewater is the oldest approach to treat and dispose of wastewater, and has the advantage of satisfying treatment efficiency, low costs, and easy operations (Duan R. and Fedler, C. B., 2007). In their later study (2010), they found that such combined treatment system can be used to effectively treat and safely dispose municipal wastewater, and save freshwater currently used for agricultural irrigation.

In addition to the irrigation water requirement of the crops, the wastewater effluents contain several plant-essential nutrients (N, P, K, and micronutrients) that improve the fertility status of irrigated soils. Thus, the land application could provide a viable solution of increased productivity and nutrient-rich water year-round through the reuse of wastewater, thereby reducing the chances of eutrophication if the wastewater was discharged to surface water.

However, the sustainability of agricultural reuse programs is often challenged by the fate of Phosphorous (P) in land application sites. Applied irrigation volume, the effluent P concentration, the P requirement of the crop grown, and even the timing of application relative to the crop growth cycle greatly impacts the ability of reclaimed wastewater to meet the crop P requirements. Different agronomic P requirements and varying concentrations of P in reclaimed wastewater has always been a challenge for the generalized and sustainable application of P-based effluent application. The Water Reuse Guidelines (USEPA, 2004) and Stevens (2006) suggests that P in wastewater is usually less than the crop's P requirement. On the other end, EPA Process Design Manual for Land Treatment of Municipal Wastewater Effluent (USEPA, 2006) states that municipal wastewater contains P in excess than plant requirements. Thereby, long-term sustainability of effluent irrigation is only possible with the understanding of soil P dynamics in effluent irrigation systems.

Despite several years of land application in practice, very few literatures discuss on the future impact of P on effluent irrigation practices (Hamilton et al., 2007; Paranychianakis et al., 2006; Toze, S., 2006). In the past years, P has generally not been considered as a limiting parameter for land application (Bond, 1998) and there exists no specifications for maximum P concentrations in the effluents used for irrigation (USEPA, 2004). Recently, guidelines are being developed for P concentrations in the effluent and regulatory agencies have started considering P as a limiting nutrient for land application of wastewater (USEPA, 2006). The main objective of this paper would be to perform an extensive review on the environmental fate of long-term application of effluent P on irrigation sites. The results from the published reports of effluent irrigation systems would be evaluated to discuss on the long-term impacts of reclaimed wastewater on irrigation sites.

Phosphorous and Slow Rate Land Application

Slow Rate (SR) systems are widely used in the treatment and reuse of municipal effluents in agriculture. The effluent application in such systems ranges from 60 to 610 cm/yr. or 1.2 to 10 cm/wk. (USEPA, 1977). These systems have been widely employed in the treatment/disposal of domestic wastewater since 1531 (Gerhard, 1909), and there has been growing interest on these systems due to its low construction, operation and maintenance costs, especially for small rural communities (Crites et al., 1998; Angelakis, 2001).

The loading rates for early SR were based on to match the soil infiltration ability to avoid effluent runoff or maintain N balance to avoid excess nitrate percolating to groundwater (USEPA, 1981).

Most soils have strong P retaining capacity and any excess P mostly gets accumulated in root zone. P accumulation in root zone not being an agronomic problem, little or no consideration was made for P in designing of such systems. Further, the longevity of LA sites was predicted based on the soil P sorption capacity and due to relatively longer life (20-60 years), no consideration was made for P in LA sites (USEPA, 1977; USEPA, 1981). However, soils have finite P sorption capacities and soil profile become saturated with P over time, eventually P percolates below the root zone. Nevertheless, recent studies have evaluated the fate of P on effluent application on LA sites and suggestions have been made for P concentrations in LA sites. Several factors such as difference in removal efficiency during treatment, loading, soil properties and crop type, and management practices greatly affects the extent to which applied P meets the fertility need of site vegetation of which all. Thus, a case by case study is required for the efficient land application.

Phosphorous application rate to the soil greatly depends on hydraulic loading rate and the P content of wastewater. Secondary effluent (3-4 mg/L TP) with half the maximum allowable application rate of SR (2.5 cm/wk.) is enough to meet the P requirements (~47 kg.P/ha) for most crops (USEPA, 2007). The soils irrigated with secondary effluent has statistically higher P concentrations than those treated with potable water (Mohammad et al., 2003). An early EPA study (Hinesly et al., 1978) observed significant increase in concentrations of extractable P throughout the soil profile in the LA sites in Bakersfield, CA and Lubbock, TX. The systems were in operation for more than 35 years, and no other soil chemical properties, except increased levels of P, were affected due to the effluent application. Over a 16-month period of study, Hayes et al. (1990a, b) observed an increase in Olsen-P of turf grass irrigated with secondary effluent from 16 to 36 mg/kg. Olsen-P test is a widely used test, originally developed in North America, to estimate plant available levels of P in soils. Rusan et al. (2007) did a similar study on barley irrigated with wastewater containing 5.1 mg/L PO4-P, and they observed the Olsen-P levels of soils after 0, 2, 5, and 10 years to be 10, 15, 40, and 45 mg/kg respectively. Likewise, Hinesly et al. (1978) observed the Olsen-P levels of plots receiving 0, 6, 19, and 38 year of effluent irrigation in Texas and was observed to be 1.3, 3.4, 36, and 82 mg/kg respectively. Results from the evaluation of published reports of effluent irrigation systems thereby concludes that the effluent-supplied P is in excess of plant P requirements. As shown in Figure 1 below, excess P is being applied in most of the LA sites.

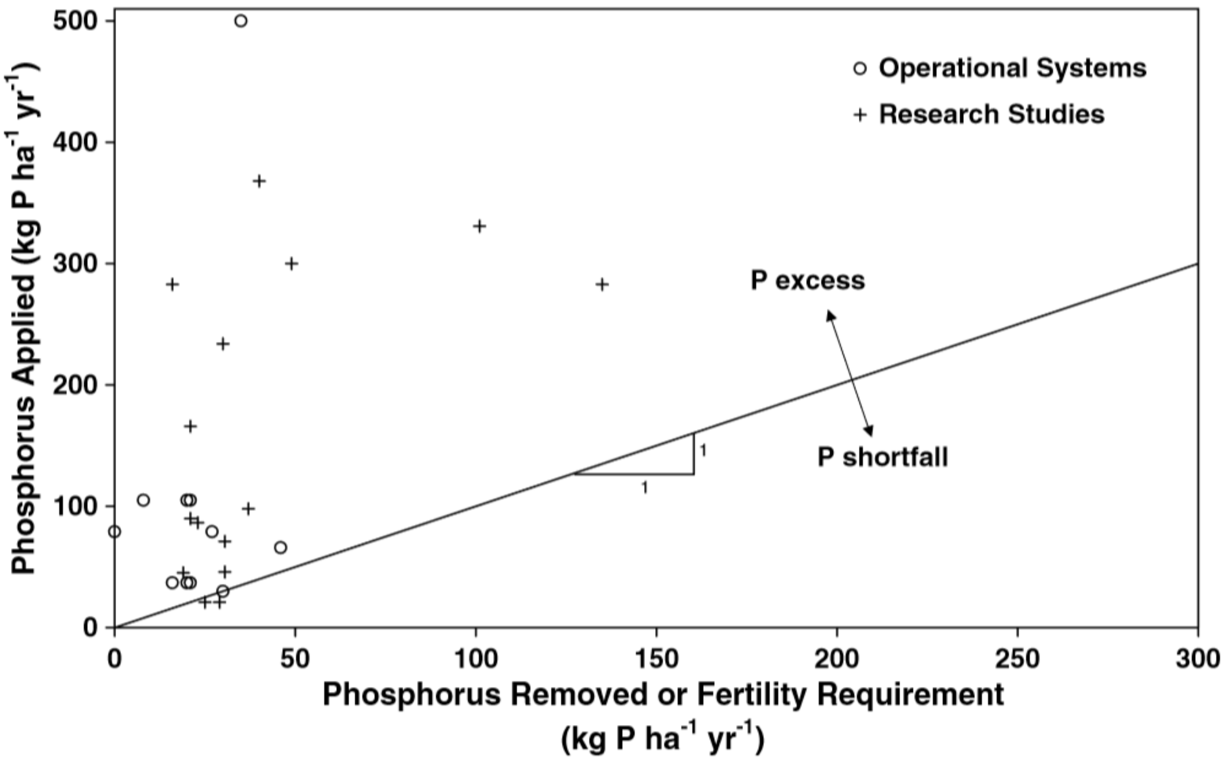

Fig 1: Phosphorous applied versus amount removed or fertility requirement for published municipal wastewater effluent land application systems; data points above the line represent systems where P is applied in excess of crop needs. Source: (Elliott, H. A., & Jaiswal, D, 2011)

On contrary, studies have shown that the effluent P are low enough to meet the agronomic P requirements, and such sites are characterized with low effluent P levels and/or hydraulic loading rates. A study of Muskegon County land treatment site by Hu et al. (2006) reported that most fields with effluent irrigation have less plant available P despite increase in total soil P over the life of system. This was possibly due to large amounts of added P being fixed in forms not available to plants. In contrast to the original design concept of SR systems based on excess irrigation (USEPA, 1981), the more recent " Type-2 optimum irrigation potential" (USEPA, 2006) and irrigation reuses of reclaimed water limited to supplemental irrigation (Virginia Administrative Code, 2008) dramatically lower the P loadings on effluent irrigation sites.

Environmental Fate of P in LA sites

P nutrient management policies are being developed and implemented, however is mostly targeted to manures and commercial fertilizers application and the land-applied P sources have mostly been overlooked (Elliott et al., 2006). The conventional P sources (fertilizers and manures) and wastewater effluent has some fundamental differences when it comes to LA. First, P is added to the soils incrementally in small amounts over time through effluent irrigation whereas the fertilizer and manures supply the entire annual P need of the crop to the soil in single application. And, improved crop P-use efficiency was observed with such continuous small application of P as compared to single high application (Sakadevan et al., 2000). Secondly, effluent irrigation systems involve subsurface placement of nutrients in contrast to the surface application of manures and fertilizers, and such subsurface application of nutrients greatly reduces the runoff losses of applied P. Despite, very few literatures have studied the environmental fate of P in LA sites.

The effluent-supplied P in the soil is either removed by plant uptake, lost by surface runoff, stored in the soil, or leached through the soil profile (Pratt et al., 1978). Plant uptake of P is the most common mechanism of P removal with low loadings SR system whereas soil storage is considered to be the primary mechanism for P removal in SR systems with high loadings. The removal in such high loading systems is probably due to sorption and chemical precipitation as iron or phosphate compounds (Reed et al., 1972). Soils, however, have finite sorption capacity and the life of SR systems is determined by the assimilative P retaining capacity of soil.

Erosion, runoff and leaching are the reported possible routes for land-applied P to reach aquatic systems. Most of the effluent applied sites are highly regulated and vegetated with forage or turf-grasses, thereby preventing significant erosion losses of P. Likewise, no significant runoff losses have been reported for effluent irrigation sites. However very few studies have been done assessing if environmentally significant runoff losses of P occur at effluent-irrigated site.

The SR systems is based on the design with no allowances for surface runoff (USEPA, 2006) and the runoff losses is often ignored for effluent-irrigated sites. P is primarily transported downward due to the infiltration process, thereby reducing the off-site P movement through runoff. To support the fact, a study by Barton et al. (2005) state that "wastewater-applied P can be chemically adsorbed by the soil, taken up by plants, or leached from the soil profile." Likewise, Kardos et al. (1976) considered crop removal, loss to drainage, and soil retention as the major fates of applied P.

To maximize the use of reclaimed wastewater, the early SR systems were designed with the primary objective of groundwater recharge. Thus, leaching was considered as the major off-site movement of effluent applied P. However, several studies (Barton et al., 2005; Kardos et al., 1976; Sugiura et al., 2008) have concluded that P leaching is not a major P loss process at effluent irrigation sites as P is readily fixed in moist soils. The soluble P at a depth of 1.2 m sampling depth in Tallahassee FL, was reported to be 0.02 mg/L, much lower than expected total P concentration suggested by the early design guidelines (USEPA, 1981). In addition, the study by Sakadevan et al. (2000) supports the fact as incrementally added effluent-based P tends to be less leachable than P in single applications of mineral fertilizer. However, for soils with low P-sorbing capacity, P leaching is often reported to be common process for P-loss (Harris et al., 1996; Sakadevan et al., 2000; Davies et al., 1994).

Conclusions

Slow Rate (SR) systems are widely used in the treatment and reuse of municipal effluents in agriculture and could provide a viable solution of increased productivity and nutrient-rich water year-round. The ability of reclaimed wastewater to supply adequate P to LA sites depend on the effluent P concentration, loading rates, applied irrigation volume, timing of application and the P requirement of the crop.

The effluent-supplied P in the soil is either removed by plant uptake, lost by surface runoff, stored in the soil, or leached through the soil profile. The LA sites are highly regulated and vegetated with forage or turf-grasses, thereby preventing significant erosion losses. High P-sorbing capacities and strong P fixation by soils irrigated with reclaimed water greatly controls the losses of P to surface or groundwater systems. Further, continuous small application of effluent P helps to minimize the runoff and leaching of effluent P. Such application of P in effluent can nourish the plant at a slower rate over a longer period thereby improving the crop P-use efficiency.

Municipal wastewater typically contains excess P than crop P requirements however little or no considerations has been made for P considerations in the design of such LA sites. The results from the published report indicates that effluent supplied P is in excess than most crop P requirements. Except in few of the LA sites, no detrimental effect of excess P has been reported so far. Effective management strategies should however be adopted for the long-term sustainability of effluent irrigation sites.

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