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Sustainable use of sewage sludge as a source of nitrogen and phosphorus in cropping systems

by

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DECLARATION

I the undersigned, declare that the thesis, which I hereby submit for the degree of Doctor of Philosophy at the University of Pretoria, is my own work, except where acknowledged in the text, and has not previously been submitted by me for a degree at this or any other tertiary institution.

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LIST OF ACRONYMS AND ABBREVIATIONS

Al	Aluminium
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
CFU	colony forming units
ERWAT	East Rand Water Care Works
EU	European Union
Fe	Iron
FeO	Iron oxide
Hg	Mercury
LAI	Leaf area index (m^2 m^{-2})
MAE	Mean absolute error
M1-P	Mehlick-1 extractable phosphorus
M3-P	Mehlick-3 extractable phosphorus
N	Nitrogen
P	Phosphorus
Ni	Nickel
NO_3	Nitrate
NH_4	Ammonium
Pb	Lead
PFU	plaque-forming units
r^2	Coefficient of determination
Se	Selenium
US EPA	United States Environmental Protection Agency
WUE	Water use efficiency (kg ha^{-1} mm^{-1})
Zn	Zinc

ABSTRACT

Municipal sewage sludge is used as source of plant nutrients world wide for agriculture. However, many countries do not make full use of this opportunity. A lack of local knowledge about the benefits and disadvantages of sludge contributes to this low utilisation. For instance, only 28% of the sludge produced in South Africa is beneficially utilized on agricultural lands. The overall objectives of this study were 1) to determine responsible sludge loading rates for a range of cropping systems 2) to investigate the agronomic benefits and sustainability of using municipal sludge according to crop N demand, and 3) to develop a tool to enable extrapolation of these results to other regions (soils, climates) and other cropping systems. Field experiments were conducted on a wide range of cropping systems including dryland maize, irrigated maize-oat rotation, dryland pasture, and turfgrass sod production. An 8 Mg ha^{-1} control (South African old annual upper limit norm) was compared with sludge rates of 0, 4, and 16 Mg ha^{-1} for the agronomic crops and dryland pasture. Under the turfgrass sod production, the aim was to export large volumes of sludge with the sod without compromising the environment. Therefore, an 8 Mg ha^{-1} control treatment was compared with sludge rates of 33, 67, and 100 Mg ha^{-1} which are equivalent to depths of 5, 10, and 15 mm sludge, respectively. Doubling of the old annual upper limit significantly increased grain and forage yield of both the dryland maize and the irrigated maize-oat rotation. This rate also improved weeping lovegrass hay yield, water use efficiency and crude protein content. Residual nitrate in the soil profile after harvest, and solution samples collected from wetting front detectors were

used as indicators of groundwater pollution through nitrate leaching in the medium term. For the irrigated maize-oat rotation and dryland pasture, a low leaching risk was indicated even at high sludge loading rates of 16 Mg ha^{-1} in this clay loam soil. In contrast, residual nitrate for similar sludge rates under dryland maize cropping did reveal the potential for pollution through leaching. Sludge loading at all rates resulted in the accumulation of total P and loading rates of 16 Mg ha^{-1} increased Bray-1P in all agronomic and pasture cropping systems. In the case of turfgrass for sod production, sludge loading rates up to 67 Mg ha^{-1} significantly improved turfgrass establishment rate and colour. The ability of sods to remain intact during handling and transportation improved as the sludge loading rate increased to 33 Mg ha^{-1}, but deteriorated at higher rates. A sludge loading rate of 100 Mg ha^{-1} was needed to eliminate soil loss at harvest, but this rate was associated with unacceptably high N leaching losses and poor sod strength. The variation in sludge quality, crop nutrient removal across a range of cropping systems, and seasons indicates that a dynamic, mechanistic decision support tool is needed to estimate responsible sludge loading rates. A mechanistic N module was adapted and incorporated into an existing soil water balance/crop growth model (SWB). The model was calibrated with statistically acceptable accuracy for dryland maize, irrigated maize-oat rotation, and dryland pasture. The model was tested against independent data sets and was able to predict the measured variables of interest with acceptable accuracy for dryland maize, irrigated maize and oats. For dryland pasture, the model predicted similar variables of interest with lower accuracy for medium-term simulations, but this improved with updating the profile water content after every hay cut. The ideal sludge loading rate to satisfy crop N demand is dynamic and should be adjusted according to cropping systems, seasonal rainfall variability, sludge N concentration, and sludge application strategy (N or P based). The ultimate cumulative sludge loading of an area will depend on the accumulation of total and Bray-1P, and the risk this poses for pollution, as long as the risk from other pollutants remains minimal. The SWB model shows promise as a decision support tool for sludge management in agricultural lands.