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Stormwater harvesting for irrigation purposes: An investigation of chemical quality of water recycled in pervious pavement system

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ABSTRACT

Most available water resources in the world are used for agricultural irrigation. Whilst this level of water use is expected to increase due to rising world population and land use, available water resources are expected to become limited due to climate change and uneven rainfall distribution. Recycled stormwater has the potential to be used as an alternative source of irrigation water and part of sustainable water management strategy. This paper reports on a study to investigate whether a sustainable urban drainage system (SUDS) technique, known as the pervious pavements system (PPS) has the capability to recycle water that meets irrigation water quality standard. Furthermore, the experiment provided information on the impact of hydrocarbon (which was applied to simulate oil dripping from parked vehicles onto PPS), leaching of nutrients from different layers of the PPS and effects of nutrients (applied to enhance bioremediation) on the stormwater recycling efficiency of the PPS. A weekly dose of 6.23×10^{-3} L of lubricating oil and single dose of 17.06 g of polymer coated controlled-release fertilizer granules were applied to the series of 710 mm × 360 mm model pervious pavement structure except the controls. Rainfall intensity of 7.4 mm/h was applied to the test models at the rate of 3 events per week. Analysis of the recycled water showed that PPS has the capability to recycle stormwater to a quality that meets the chemical standards for use in agricultural irrigation irrespective of the type of sub-base used. There is a potential benefit of nutrient availability in recycled water for plants, but care should be taken not to dispose of this water in natural water courses as it might result in eutrophication problems.

1. Introduction

According to UNESCO (2007), about 70% of world water supply is used for agricultural irrigation and this statistic is expected to increase by 14% in the next 30 years with the ever rising world population and an increase in irrigated land by 20%. Also, agricultural land use is expected to rise by 10% in 2030 resulting in increased demand for water for irrigation (OECD, 2008). It is estimated that about half of the world population (47%) will experience severe water scarcity in 2030 if new water management policies are not introduced (OECD, 2008). This threat of global water shortage is exacerbated by global warming which is expected to make summer droughts more frequent and cause water scarcity even in developed countries.

The study reported in this paper provides data on the chemical quality and suitability of harvested stormwater using a SUDS technique (known as pervious pavements) for agricultural irrigation. This water management strategy meets the objectives of sustainable urban drainage by achieving source control and water reuse. It is different from other studies on the reuse of water derived from "alternative" sources to high quality water, but sustainable sources for irrigation such as sewage (Amahmid and Bouhoum, 2000; Yadav et al., 2002; Debasish et al., 2003; Butt et al., 2005; Wallach et al., 2005) and wastewater (Al-Jamal et al., 2002; Al-Shammiri et al., 2005). There are also reports that both treated and untreated wastewater have been used in many countries such as Ghana (Raschid-Sally et al., 2005), Pakistan, Mexico, Vietnam, Greece, Saudi-Arabia, Jordan and Israel for irrigation (Al-Shammiri et al., 2005).

As early as 1999, Pratt (1999) proposed that the pervious pavement system could be used as a reservoir for stormwater treatment and storage for reuse. Three years later, in the University of Florida, USA, Chen et al. (2002) conducted a two year comparison study on the potential of use of stormwater or rainwater collected from the roof of greenhouse, irrigation run-off from landscaped plant production bed and pond water for greenhouse

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production of bedding and foliage crops. At the end of their study, they produced high quality and market yields of the crops irrespective of the sources of the irrigation water used in the experiment.

It is becoming clearer, that with the application of innovative and sustainable construction methods and technologies, stormwater can become a resource which can be harnessed by various levels of governments, private enterprises, and even individuals in their homes (Nnadi, 2009). The sustainable use of stormwater for irrigation is now viewed in many cities as the way forward for providing sustainable irrigation to golf courses (Schwecke et al., 2007), recreational parks (e.g. Melbourne's Albert Park in Australia), sports fields and providing year round recreation in lakes (ADEWHA, 2007). In the city of Salisbury, South Australia, stormwater is captured in winter and treated by passing it through wetlands for ten days and then stored in limestone aquifers for use in summer (Midcoast Water, 2008). The state of Hawaii is utilizing small lot reuse, source reuse, stormwater capture, stormwater storage and distribution technologies on the Island of Hawaii for irrigation distribution system and deep infiltration trenches to capture stormwater for irrigation reuse on Oahu (Madison and Emond, 2007; DAH, 2008). In 2006, the local government in Sydney, Australia installed permeable pavements with sub-terrace water storage tanks – to reduce the flow of polluted stormwater from car parks and busy shopping plazas in the street into the Sydney harbour and at the same time provide clean water for reuse by the council for other activities such as irrigation, street cleaning, etc. (NSCA, 2006).

Due to the high volume of water used annually for irrigation proposes and the projected increase in the agricultural water requirements as indicated above, reuse of stormwater for irrigation is an attractive option in sustainable stormwater management. However, unavailability or irregular supply of irrigation water is not the only reason for the increasing use of alternative sources of irrigation water. High concentrations of nutrients such as nitrogen, phosphorus and potassium present in wastewater and other alternative sources of irrigation water as well as their relative continuous availability makes them more attractive to farmers as it enables them to grow crops all year round (especially vegetables) (Ensink and Hoek, 2007). However, there is need for water meant for irrigation to meet irrigation water quality standards in order not to pose a threat to soil structure, crops and consumers of edible crops (Hamilton et al., 2007).

The focus of this study was specifically on irrigation and the experiment was intended to provide information on the effects of hydrocarbons (which was an attempt to replicate oil dripping from parked vehicles onto PPS), leaching of nutrients from different layers of the PPS and in particular the effects of nutrients applied to enhance bioremediation on the suitability for irrigation of the stored water.

The experimental operation of the model system used followed the practice of Bond (1999), Coupe (2004) and Puehmeier (2008) in that microbial degradation of simulated mineral oil spillages was encouraged by the addition of slow release fertilizer pellet. It also utilized two different types of sub-base, the traditional stone sub-base (Pratt, 1999) and one based on the Permavoid plastic crate system. These sub-bases have a higher void ratio and thus an increased storage volume for a given excavation depth. They are also capable of storing the water at shallower depths than both stone systems with the same volume and other types of plastic crate void formers which all require a considerable depth of stone cover to provide the required load bearing capability. This can also have important energy/physical effort advantages because of a reduced lift requirement when the water is recovered for reuse at the surface.

2. Materials and methods

It was proposed that irrigation of plants using water derived from the stone and plastic box based systems might show different performances due to differences in hydrocarbon (and hydrocarbon degradation product) contamination in the irrigation water and in the utilization or sorption of the slow release nutrients added to the pavements to encourage biodegradation. The controls used in this experiment could be said to have represented pedestrian paved areas not subjected to oil contamination and thus with no requirement for inorganic nutrient application.

The pervious pavement studied in this work was designed in accordance with those studied by previous researchers (Bond, 1999; Coupe 2004) and originally designed by Chris Pratt in 1999. The pervious surfaces are based on non-porous concrete blocks in which water is allowed to percolate through the surface through a block design which provides infiltration channels of one type or another. Although the oil retention capability of pervious pavements, under heavy loadings, has been shown to be limited (Newman et al., 2002), under loadings simulating day to day oil drippings in car parks, the structure is shown to support the establishment, growth and development of biofilms of oil degrading microbes (Newman et al., 2002; Coupe et al., 2003). It has also been shown to possess the capability to retain a high proportion of added oil provided it is added over a long period (Bond, 1999).

2.1. Construction of the pervious pavement model used in experiment

The experimental pavement models were built into welded HDPE containers equipped with a system to allow withdrawal of irrigation water by siphon from the base of the models. Care was taken to ensure that the models were never fully emptied and thus any free product would not have been withdrawn as part of the irrigation waters. In effect, this replicates the action of a Permaceptor® which could be incorporated into the pervious pavement system to remove hydrocarbon and silts from stormwater before it is channeled to water courses (Puehmeier et al., 2005). Thus any negative effects would be limited to dissolved contaminants and this was considered as a reasonable approach to the management of the pervious pavement structures.

The cross sections of the models are reported by Nnadi et al. (2014). The depth of the stone sub-bases was 150 mm which is equal to the depth of the Permavoid units. A 50 mm bedding of 10 mm pea gravel was used to support the layer of Formpave Aquaflow® paving. The stone aggregates used for the stone base and bedding layer were sieved to 50 mm and 10 mm respectively. The aggregates were washed with clean water in order to remove dusts and silts before they were used in the experiment. The geotextile (Inbitex Composite®) was sandwiched between the sub base and the bedding layer in all the models.

Table 1 shows the experimental set up and treatments applied on of the test rigs.

Table 1
Showing experimental test rigs set up and treatments applied.

Test model	Additions	Type of sub-base	No. of replicate(s)
1	+Oil and +NPK fertilizer	Permavoid plastic	3
2	+Oil and +NPK fertilizer	Stone	3
Control 1	+Oil and +NPK fertilizer	Permavoid plastic	Control 1
Control 2	+Oil and +NPK fertilizer	Stone	Control 1
Total number of test rigs			8