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Eco-engineering strategies for soil restoration and water conservation: Investigating the application of soil improvements in a semi-arid climate in a medical facility case study, Abu Dhabi

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ABSTRACT

The purpose of this research is to investigate the application of three different soil additives on existing selected draught resistant plants in 2016 and 2017 and how these can help improve soil conditions and the reduction of desalinated water for landscape irrigation in the UAE. The methodology of this Doctorate in Sustainable Built Environment (D.SBE) action research project, designed, developed and implemented by the first author, uses a mixed method. The case study is a 364 beds hospital located in Abu Dhabi, capital city of the UAE, with a vegetated open space and decorative water features representing more than 50% of the building footprint. The primary source of the medical facility landscape irrigation and water feature is designed to be air conditioning condensate water to avoid usage of any desalinated water in an arid environment. For four months of the year, the irrigation demand will not be met by the condensate water in winter because peak condensate formation occurs in summer. This shortfall availability during the winter months is proposed to be met by soil amendment and by use of other alternative water types. The soil test results show rapid plant growth with one of the soil conditioner solution whereas water savings is inconclusive due to irrigation system hydraulic irregularities and the lack of irrigation standardized rating for building operation. The next steps are to firstly balance the soil pH with a gypsum solution, to secondly reprogram the irrigation system controller with tested and audited hydraulic building parameters and to thirdly include all adequate parameters including ET_o and rainfall to estimate the irrigation demand so that water savings can be accurately monitored. This intervention study will help understand the correlation between soil water quality together with irrigation rate and irrigation distribution system's audit and how these factors impact on the environment, operation and maintenance cost and practices, greenhouse gas emissions, and building systems water and energy consumption. The results may be relevant to local authorities responsible for making and adjusting standards for outdoor irrigation strategy for all types of building.

1. Introduction

The work documented in this paper is part of the first author's Professional Doctorate change project in Abu Dhabi, at a newly built medical facility in use since April 2015. The medical facility is in Abu Dhabi capital city of the United Arab Emirates (UAE), a hot desert type climate (Abdelfattah, 2011; Abdelfattah and Pain, 2012) and a Middle East Country laying between latitude 22° 29 N and 24° 53 N and longitude 56° 10 E and 51° 37 E (Shahid et al., 2013). The facility landscape is greater than its building footprint representing more than 50% of the site or a 36,546-square meter (m^2) vegetated open space including decorative water features. The project is investigating the application of three different soil additives on existing selected grass, trees, and plants and how they can help offset the challenge of reducing landscape irrigation demand while improving soil conditions. The water irrigation demand has been estimated at 386 cubic meter (m^3) per day at peak by the landscape contractor (Table 1), which will be discussed in this paper at Section 3. The design of the 364 beds hospital includes an existing Air Handling Unit (AHU) Air Conditioning (A/C) condensate water treatment sys-

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Table 1
Daily water requirement for vegetated landscape based on ADM Standard, 2013 (Bondzic, 2017).

Plant types	Winter Litres of water/unit (December–February)	Summer Litres of water/unit (May–September)	Autumn and Spring Litres of water/unit (October–November and March–April)
Date palms	75 l/palm	150 l/palm	110 l/palm
Small trees	40 l/tree	40 l/trees	30 l/tree
Shrubs	10 l litres/m^2	20 l/m^2	15 l litres/m^2
Groundcover	5 l/m^2	10 l/m^2	7 l/m^2
Pennisetum spp.	10 l/m^2	20 l/m^2	15 l/m^2

tem, which is intended to treat condensate water from the air cooling system to a quality suitable for use as landscape irrigation and water features. The short fall in condensate water availability during the winter months in Abu Dhabi (December–February) is proposed to be met by applying soil test-based applications of soil conditioners coupled with organic fertilizer use to increase the soil water-holding capacity. The strategy requires careful water management (King et al., 2013) based on soil factors such as texture structure and drainage (Benton Jones, 2012).

The main objective of this action research project is to provide an account of water and soil conservation strategies for sites located in semi-arid climates, such as the Emirates of Abu Dhabi, classified by the United States Department of Agriculture (USDA, 2012) as soil having a very low water holding capacity (Fig. 1b). The anticipated outcome of this action research project is to demonstrate how soil enhancement with soil conditioners and locally standardized irrigation rates can help improve water conservation for irrigation. The strategy is to encourage the local authority to amend their water standard so that projects with irrigated outdoor space optimize their water need and increase the use of treated non-potable water use. Thus, impacts upon the environment, operation and maintenance cost and practices, greenhouse gas emissions, and building systems energy and water consumption can be minimized.

2. Context to climate and water availability and use in the UAE

The Middle East region including the UAE has the lowest fresh water resource endowment in the world (World Bank, 2012). The water regional availability is as little as <100 m^3 per capita per year (Cisneros, 2014). The UAE depends heavily on non-renewable groundwater and augments supplies by desalination of sea water to produce freshwater. The overall water need is supplied by groundwater supplemented by desalination and wastewater treatment plants (Shahid et al., 2013). 72 percent of the groundwater is used for agriculture, 29 percent of the desalinated water is used for commercial and residential need while wastewater accounts for 4 percent of the overall water demand (Almaeeni et al., 2014). Because rainfall is very small (<100 mm/year) and the recharge of the groundwater is less than 4 percent per year, Abu Dhabi has no choice, but to supply municipal water from seawater desalination (Almaeeni et al., 2014). Water systems can save energy by reducing the amount of water that must be withdrawn, treated, and distributed (Ferrell et al., 2016) especially in place like Abu Dhabi where the technique of desalination is high energy intensive as it uses Reverse Osmosis technologies, which also have a very high cost (0.5–1 United States Dollars per cubic meter) in compare to conventional sources (0.05 USD/m^3) (Cisneros, 2014). Beyond the water problem, Abu Dhabi is challenged by a lack of healthy soil to support locally grown food (Heid, 2009). Furthermore, land degradation areas (Fig. 1a), have been identified in the Emirates of Abu Dhabi (King et al., 2013) based on factors limiting plant growth. Fig. 1a shows the state of the soil near the medical facility, which is classified as highly degraded. Although the soil classification in Abu Dhabi city has been excluded from the soil classification survey for unknown reason (Shahid et al., 2011). Abu Dhabi is dominated by sandy and salty soil, and high temperature and humidity (MOEW, 2015). In arid and semi-arid regions, soil qualities are reputed for being physically, hydraulically and chemically deficient because of their sandy natural state and the exposition to harsh climate conditions (Benkhelifa et al., 2008; Shahid et al., 2013; King et al., 2013). Hence 75 percent of the UAE land is classified as sandy soil (ICBA, 2015).

Irrigation is the primary water consumption worldwide (Shashua-Bar et al., 2009). In arid regions, where the mean annual precipitation (P) is substantially less than the characteristic potential evapotranspiration (ETo), appropriate selection of plants and efficient irrigation systems can conserve a great amount of urban irrigation water (Ferguson, 2007). In addition, wasting water in sectors such as agriculture and landscaping in arid regions, is further aggravating water scarcity and emphasizing the need for developing ways to improve irrigation efficiency (Ferguson, 2007). This also point to the need for a more unified water conservation standard for city's such as Abu Dhabi. In a country like the UAE where water has become a critical challenge (Dziuban, 2011) solutions to conserve this precious resource has also become a priority. Irrigation is a water consumptive concept, which also cost energy to deliver (Ferguson, 2007). Consumptive water use is the sum of two factors: transpiration and evaporation (Benton Jones, 2012). Unlike agriculture water conservation techniques for crop fields, urban landscape is characterized by site modifications, diverse use, and complex microclimates (Ferguson, 2007). To deliver the correct quantity of water for landscape irrigation, the plant nutrition need and the soil quality should be analysed. The choice of essential plant nutrient to include in applied irrigation water are factors that require considerable skills. The danger here related to water need and environmental conditions occurs when an essential plant nutrient element is needed and water is not needed (Benton Jones, 2012). Sustainable land management practices build on attributes to measure land and water quality (Hannam, 2000; Paoletti, 2000). However global soil conservation policy and legislation ineffectiveness is a misunderstanding of its definition which cause the degradation of soil (Hannam, 2000). Countries, which have based their soil conservation concept solely on the prevention, mitigation or control of soil erosion and degradation with the aim of enabling stability and productivity to be maintained for future generations have proven to be ecologically unsustainable (Hannam, 2000).

3. Case study

3.1. Background of the research

The medical facility irrigation system is mostly subsurface to limit the evaporation of water during cycles, thus reducing the quantum of irrigation. The irrigation system comprises 111 zones with automatic valve control directing the flow of water to the irrigation zones. The irrigated areas (33,257 sqm), mainly occurring at night, include native and draught resistant plants at ground level and at level five green roof such as succulents, ground covers, shrubs, palms, trees, turf grass areas, and in the future, a planned crop area (Medical Facility, 2015). Large outdoor water features (1352 m^3 total combined capacity) are located on the ground floor