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Efficiency of intensive green roof in high intensity rainfall for stormwater treatment: selection of vegetations

Khairul Rahmah AYUB*(1),Aminuddin AB. GHANI(2), Nor Azazi ZAKARIA(3) & Syafiq SHAHARUDIN(4)

(1) *Research Officer, River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Penang, Malaysia. Email: redac03@usm.my*

(2) *Professor & Deputy Director of REDAC, Universiti Sains Malaysia, Penang, Malaysia. Email: redac02@usm.my*

(3) *Professor & Director of REDAC, Universiti Sains Malaysia, Penang, Malaysia. Email: redac01@usm.my*

(4) *Science Officer, REDAC, Universiti Sains Malaysia, Penang, Malaysia. Email: redacsyafiq@usm.my*

ABSTRACT

Receiving an average 3000mm of rainfall depth with high intensity, Malaysia is known as a tropical climate country. Currently, Malaysia proactively promotes the use of Sustainable Urban Drainage Syatem (SUDS) as indicated in the Malaysian's Stormwater Management Manual namely the Urban Stormwater Management Manual of Malaysia (MSMA) 1st and 2nd version. The manual is promoting the implementation of SUDS facilities whether as a single facility or integrated ones which is a combination of two or more SUDS facilities. However green roof is not included in this manual. Thus the objectives of this paper are to share the preliminary study of intensive green roof tested under high intensity rainfall (159mm/hr) using rainfall simulator and four intensive green roof test bed with different vegetations. Three species selected for each test bed namely *Kalanchoe pinnata* (*K.pinnata), Axonopus compressus* (*A.compressus)* and *Arachis pintoi* (*A.pintoi*). Another test bed is to leave in a baren condition without vegetation as a control unit. Media or substrate use for these test beds are similar which consists of drainage cells, geotextile, river sand and top soils. Parameters studied are potassium (K), Total Phosphate (TP), Total Nitrogen (TN) and Ammoniacal Nitrogen (AN). Results show that *K.pinnata* performed well in the reduction of TP (37.50% - 89%) and AN (68.90% - 95.34%) followed by *A.pintoi*(TP: 36.68% - 82.50%, AN: 59.92% - 92.68%) and *A.compressus* (TP: 20.11% - 80.15%, AN: 89.52% - 93.44%).Another studied parameters (K and TN) show leaching in outflow of test bed. It is believed due to the fertilizer used for plant growth.In term of quantity control, all test beds showed reduction percentage of runoff hydrograph in the range of 9% to 67.

Keywords: *intensive Green Roof, Stormwater Management, Sustainability, Urban Runoff, vegetation*

1. INTRODUCTION

Malaysia located near to the equator consists of two major parts namely Peninsular Malaysia and East Malaysia (Sabah and Sarawak) which is located in Borneo Island. By receiving high rainfall depth throughout the year Malaysia notable has tropical climate and also has big area of tropical rainforest as a water catchment area. Even though average of rainfall per year is 3500mm, Malaysia facing major stormwater problems like flash flood, water shortage and water pollution. Year by year the problems getting worse, thus holistic methods need to be applied. Conventional method in stormwater management like using concrete drain in new development area cannot fulfill the expectation in control the volume and quality of runoff water. It is due to the concept applied by concrete drain known as rapid disposal. Rapid disposal means stormwater runoff have to convey to downstream as soon as possible. This scenario will cause the failure of existing concrete drain in downstream area due to the high amount of water compare than the drain was designed. Hence, flash flood will occur in the area and will bring whether tangible or intangible loss to the community. Flash floods also sweep away all litter, debris, dead leaves and etc to the nearest water bodies. So obviously it will cause deterioration the quality of water bodies and affect the water resource of the community. Therefore, management of stormwater need to improve and solve these three major problems as a whole.

Related to the issues, Department of Irrigation and Drainage, Malaysia (DID) launch a new Urban Stormwater Manual of Malaysia (USWM) in 2001 and second edition of USWM was launched in August 2012. This manual introduces the new perception in stormwater management. The integrated approach have been promote where quantity, quality and amenity of stormwater runoff and surrounding catchments area are taken equally into consideration for design the urban drainage system. This integrated approach known as Sustainable Urban Drainage System (SUDS) or Best Management Practices (BMPs). SUDS replace the concept of rapid disposal in conventional method to the new paradigm called control at source.

The numbers of facilities are promoting in SUDS like swales, detention storage, wetland, bioretention and etc. which can be applied in series.

Due to the new USWM, Engineering Campus, Universiti Sains Malaysia was chosen to be a pilot project for implementation of SUDS' facilities in stormwater management. The system implemented in Engineering Campus USM known as Bio-Ecological Drainage System (BIOECODS) facilitate by River Engineering and Urban Drainage Research Centre (REDAC), USM. Thus, REDAC has involved from early stage of implementation USWM in Malaysia. By promoting the implementation of SUDS facilities, REDAC also starting to study the implementation of green roof as additional facility in stormwater management in Malaysia. Objectives of this paper are to share the preliminary result found regarding the capabilities of three different vegetations species for intensive green roof in attenuation runoff and as pollutants removal in simulated rainfall.

2. RESEARCH BACKGROUND

Bioretation is a part of Sustainable Urban Drainage System (SUDS). The contributions of bioretention in stormwater management especially in urban area are noticeable and in the same time provide a new habitat and create a new biodiversity. Besides reducing and attenuating runoff volume, bioretention also improve the quality of runoff water due to the biological process helping by the selected trees species planted in the bioretention area. Bioretention area normally will be designed to blend with the surrounding landscape. Thus its give extra benefits in implementation of biorentention. However with limited land space in densely built urban area, implementation of landed bioretention is quite difficult to fulfil. It is believe that green roof also can play a same role as biorentention in stormwater management especially for new buildings or retrofit the existing buildings. Green roofs also referred to as vegetated roofs, living roofs and eco-roofs are roofs covered with soil and vegetation. The roofs or system allows vegetation to grow on and cover a roof surface (Berndtsson et. al., 2009 & Siegler, 2006).

Implementation of green roofs also documented as having numbers of benefits. It recorded can reduce peak flows and stormwater volume (Berndtsson, 2010). Berndtsson (2010), Getter et. al. (2007), VanWoert et. al. (2005) and Villareal et. al. (2004 & 2005), discovered that benefits also can create new habitat, filter pollution, decrease noise, improve air quality, reduce microclimate and etc. Thus, green roof can become as one facility in urban area in order to control environmental problem as mentioned above. However, Berndtsson (2010) reviewed that little attention is paid to the quality of runoff water. Large differences in runoff quality from green roofs can be found by comparing result reported by a few existing studies. Rainwater is generally considered as non-polluted but may be acidic and contains substantial amounts of nitrates. However comparison made by researchers from Japan and Sweden about performance of green roof in treating heavy metals in rain water (Berndtsson et. al., 2009).

A green or living roof is a roof or deck onto which vegetation is intentionally grown or habitats for wildlife are established. There are different types of green roof and it is important to understand that each type functions and looks different. This is because each green roof is unique and provides a different type of habitat, water storage capacity and energy saving potential (http://www.greenroofguide.co.uk/what-are-green-roofs/). Basically, green roof have been used traditionally in Europe countries as a part of their garden and to beautify their four seasons buildings. However, In Malaysia, implementation of green roof consider rare and new. There is no legislation or rule regarding to the green roof construction. Public awareness recently raise from time to time due to the environmental problems (flash floods, water pollution and etc.) occur directly comes from the developments and human activities. Thus, implementation of green roof as a part of facilities that can used together with other SUDS or BMPs facilities in order to intercept rainwater that can reach to the ground consequently control the volume of rainwater on the ground. Besides, rain water quality also can be controlled.

Green roofs are typically divided into two main engineering categories namely intensive and extensive. Intensive green roofs are established with deep soil layer to support larger plants and bushes and require maintenance in the form of weeding, fertilizing and watering. Extensive green or vegetated roofs are established with thin soil layers, planted with smaller plants that in the final stage are expected to provide full coverage of the vegetated roofs. It also expected to be maintenance free.

3. STUDY AREA AND METHODOLOGY

The study carries out in physical laboratory of River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia. Three major steps involve in the study to achieve the objectives. Details of these steps are explained below.

3.1 Rainfall Simulator

A rainfall simulator is constructing to create heavy and light rainfall. A plastic tank probably 2m x 2m x 1m is support with 2.5m or 3m above a potable desk. The base of the tank is drill with grid holes of 2mm diameter at 48mm intervals. Needles will attach to the base of each hole to create regular drops similar to real rainfall.

3.2 Intensive Green roof testing platforms

Four water proof test beds or roof platforms with dimension of 1m x 1m was constructed at study area (Figure 1). Three platforms represent different plant species and 1 platform is bare and act as control bed. 30mm PVC pipe will attached on the low end of the beds to direct stormwater runoff or simulated runoff through the measuring device used to quantify runoff and water sampling collection purpose. Every beds will consist of 25mm of drainage cell, cover with filter fabric (geotextile). 50mm clean river sand (diameter 2mm) are put on top and follow with 150mm top soils with coefficient of permeability, k, value is 9.05x10-5cm/s follow by vegetation seeds. The degree of permeability for the top soils is low and it quite important to retain the runoff of rainfall.

3.3 Plants establishment

Seed will sow or spread on it. Base on literature review, species *Kalanchoe pinnata (*Family: Crassulaceae) and *Arachis pintoi* (Family: Fabaceae) due to it resistance to insects, weeds and others are planted. Base on Bio-ecological Drainage System (BIOECODS)'s experience, species *Axonopus compressus* (cow grass) (Family: Gramineae) also study.

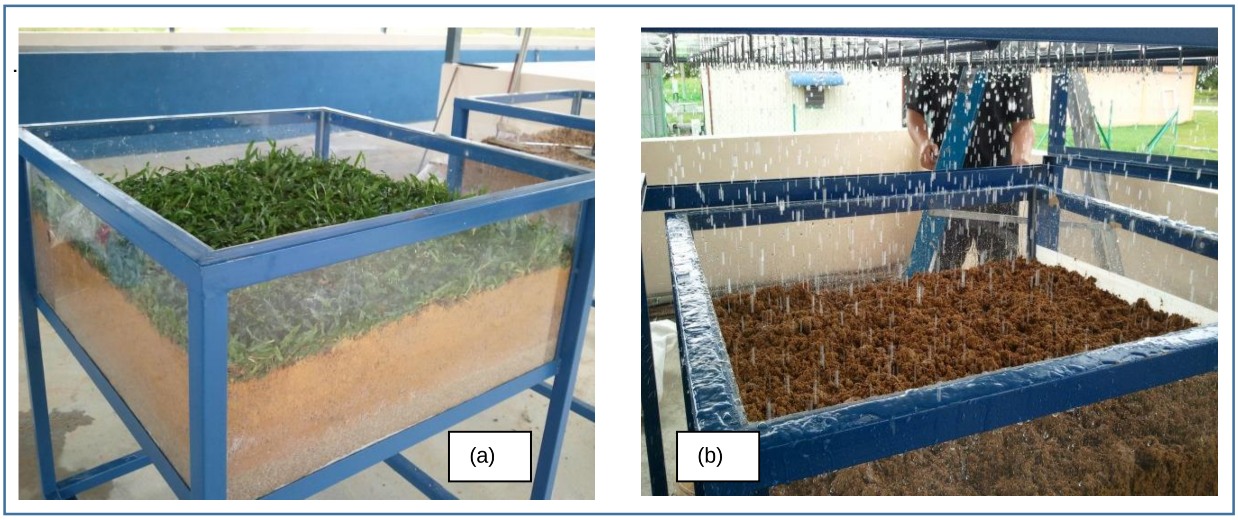

Figure 1 Green roof prototype. (a) Test beds for *A.compressus*, (b) simulated rainfall on control test bed.

4. DATA COLLECTION

4.1 Rainfall Simulation

The inflow used for simulated rainfall was 2.0L/min (intensity = 159mm/hr) for one hour continuously. The value of outflow from green roof was checked until one hour after simulated rainfall stopped. All green roofs were exposed to dryness for 96 hours (4 days) before the experiment start.

4.2 Water quality data

Runoff generated from simulated rainfall (control environment of pollutants) for all green roof platforms will be collected for water quality analyses. Four parameters will be analyzed namely Total Phosphorus (TP), Total Nitrogen (TN), Ammoniacal Nitrogen (AN) and Potassium (K).

5. RESULTS AND DISCUSSION

5.1 Peak Flow Reduction

Four simulated rainfall has been done and Figure 2 show the reduction of peak flow for all species studied. *A.compressus* gave a highest percentage in flow reduction in all experiments made. Data recorded this species manage to attenuate peak flow in the range of 51% to 67%. It is believed due to the density of the grass that fully covers the surface of the green roof test bed area compare to other species studied. Second species that gave good performance in attenuation of peak flow is *K.pinnata* which is gave the peak flow attenuation in the range of 28.5% to 46.5 %. Base on the observation during the experiment in the laboratory, this species able to intercept simulated rainfall water before it reach the ground even though the density of the plants is less than *A.compressus.* This is due to this succulent species have wide and big size of leaves. In all simulated rainfall, *A.pintoi* shows lowest capable in peak flow reduction compare to other species and even compare to the control test bed. Lowest value of peak flow reduction by this species was recorded is 9% whereas higher reduction value is 46.5%.

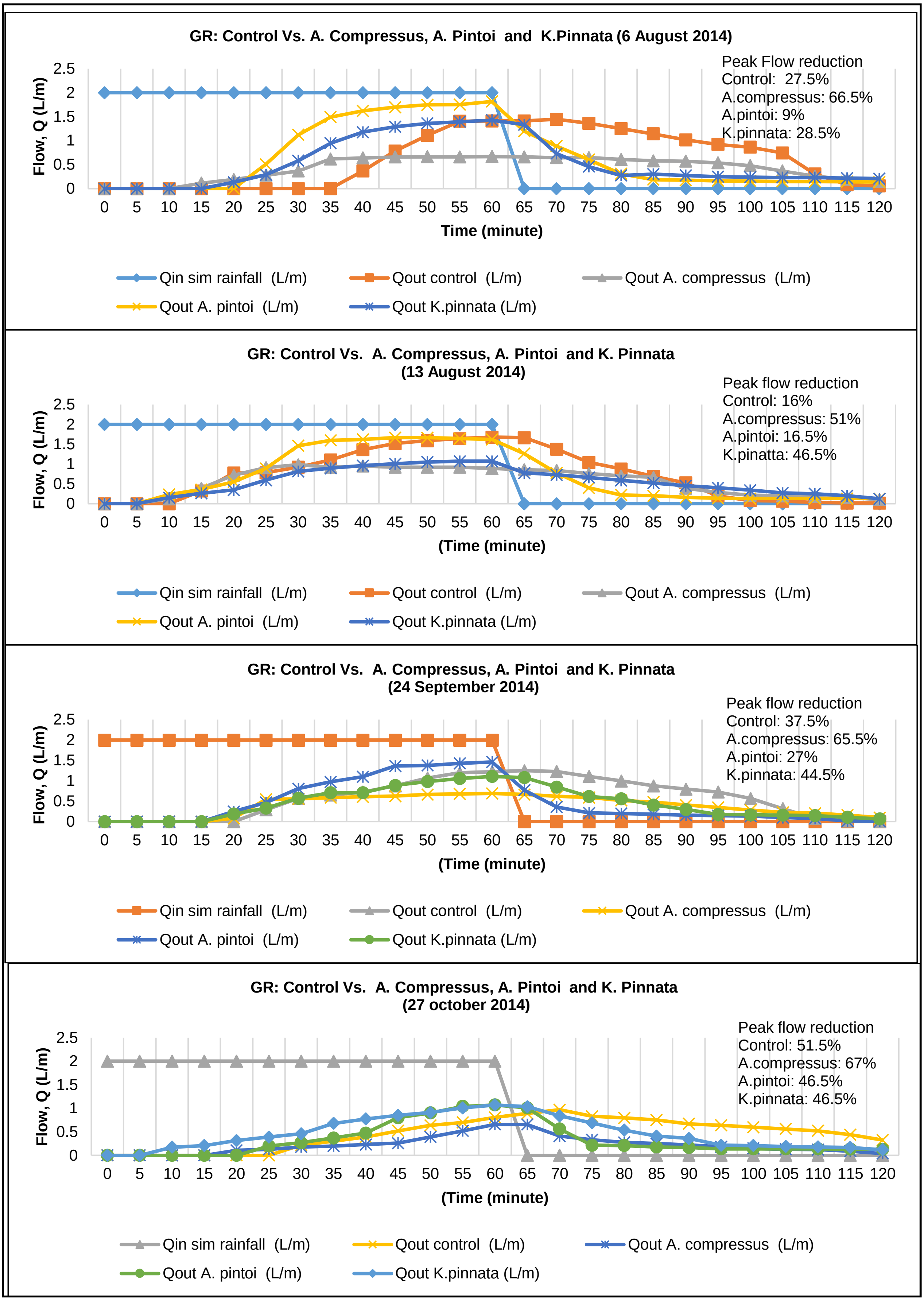

Figure 2. Peak flow comparison among vegetation

5.1 Pollutants Removal

In this study, all vegetations studied have the ability in pollutants treatment namely Total phosphate (TP) and Ammoniacal Nitrogen (AN). However, the most effective species which is give highest percentage removal of both pollutants is *K.pinnata* (TP: 37.5% - 89.10%, AN: 68.92% - 95.34%) followed by *A.pintoi* (TP: 36.68% - 82.50%, AN: 59.92% - 92.68%) and *A.compressus* (TP: 20.11% - 80.15%, AN: 89.53% - 93.44%). Simulated rainfall on 13 August 2014 show that only K.pinnata manage to remove total nitrogen with the values 27.05% whereas the simulated rainfall on 24 September 2014, all vegetations manage to remove TN except *A.compressus* (-27.54%). Figure 3a and 3b show the details results from this study. Negative reduction for potassium in all events as show in the results are believe due to the fertilizer used to help plants growth. Consequently, these test beds leach with the potassium and total nitrogen.

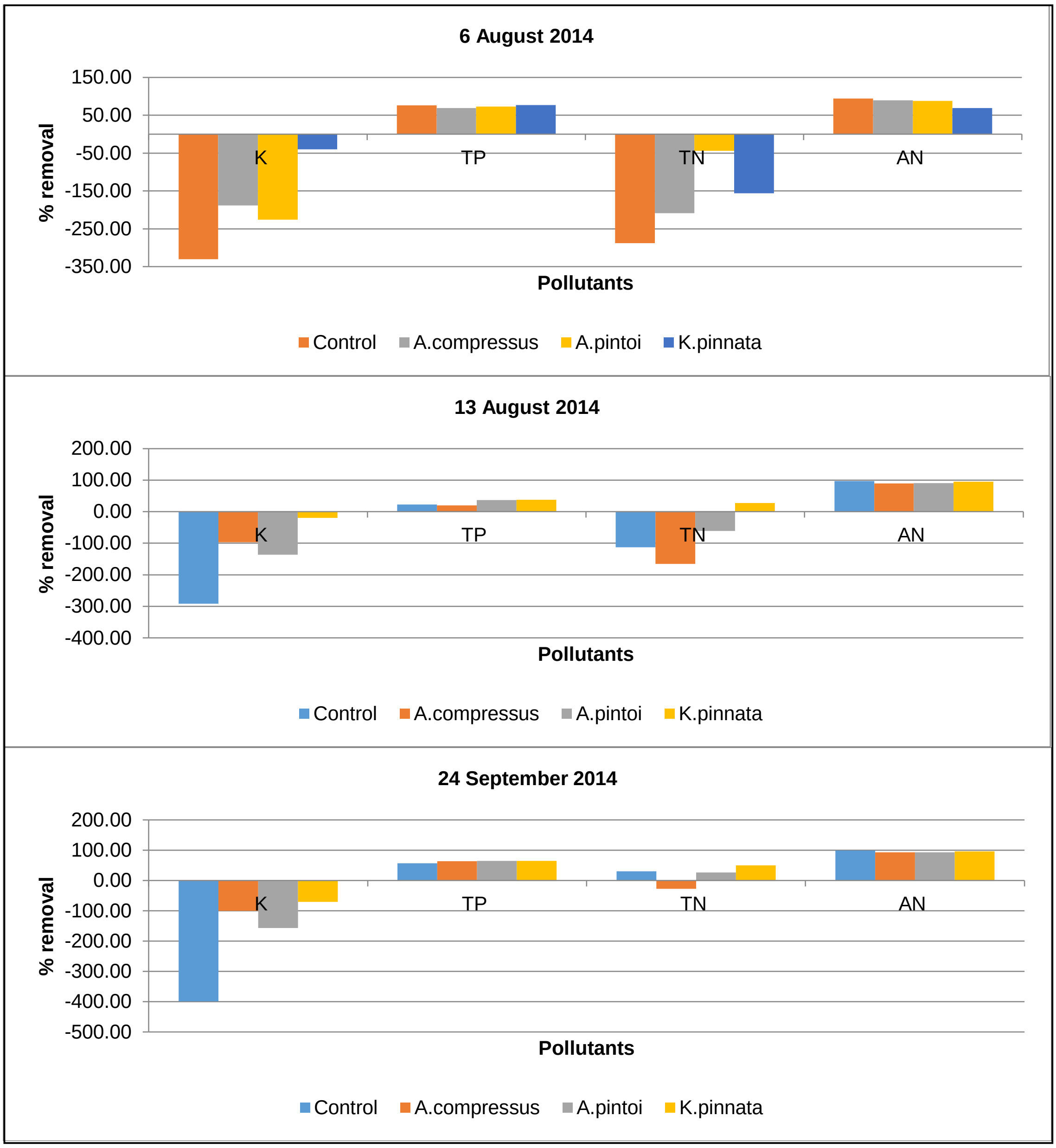

Figure 3a Capability of vegetation in pollutants removal

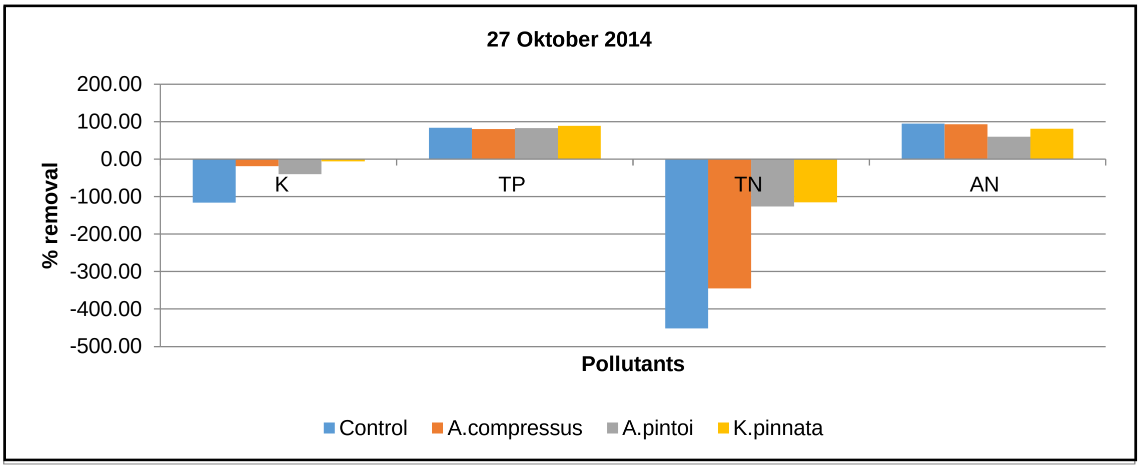

Figure 3b Capability of vegetation in pollutants removal

6. CONCLUSIONS

All test beds behave as sinks of potassium in all events and total nitrogen for several events. Base on capabilities in flow reduction and pollutants removal, this study found the *K.pinnata* is suitable as green roof vegetation beside this species succulent, manage to survive in long period of dry season and less maintenance. Second species that suggest for green roof is *A.pintoi.* This species is able to survive during dry period and also less maintenance. However, further details study related both species under different intensity of rainfall is needed.

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