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Author's post print

Geotextile Incorporated Permeable Pavement System as Potential Source of Irrigation Water: Effects of Re-used Water on the Soil, Plant Growth and Development

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Permeable pavement systems are important part of the Sustainable Urban Drainage System (SUDS). Over a decade ago, it was proposed that the pervious pavement system (PPS) has the capability to store water for reuse, the possibility of using the SUDS device simultaneously in source control and water recycling applications have not been holistically investigated by previous studies. This paper reports experiments where waters from geotextile incorporated permeable pavement system models on which 24ml per m^2 of hydrocarbon was applied as a pollutant. A single dose of 17g of NPK slow release nutrients (applied to encourage biodegradation) was administered to the surface. The PPS recycled waters was used to irrigate tomato plants (Lycopersicon esculentum (fantasio hybrid)) and rye grass (Lolium Perenne) for 10 weeks. The growth, development and heavy metal content of the organs of these plants were compared to that of plants from untreated rigs and with plants treated with de-ionized water (DI) as well as the pH, Sodium Adsorption Ratio (SAR) and Electrical Conductivity (EC). The comparative performance of the plants indicated that the water from the treated rigs supported plant growth more than the water from the untreated test rigs and DI. Heavy metal analysis of the plants organs indicated that the metals were at normal levels and below toxicity levels for plants and livestock. Soil structure tests showed that there were no salinity or soil structure issues. Heavy metal analysis of soil also indicated that the metals were within normal range and below toxicity levels. These results further demonstrate the water recycling capability of the PPS and its potential use for irrigation purposes.

KEYWORDS
Water Re-use, Irrigation, Permeable Pavements, Hydrocarbons, Eutrophication.

LIST OF ABBREVIATIONS

SUDS: Sustainable Drainage System
NPK: Nitrogen, Phosphorus and Potassium
HDPE: High Density Polyethylene
SAR: Sodium Adsorption Ratio
EC: Electrical Conductivity
CIRIA: Construction Industry Research Information Agency
DEFRA: Department for Environment, Food and Rural Affairs
EA: Environment Agency

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USEPA: United States Environmental Protection Agency

1. INTRODUCTION

Permeable pavement systems (also referred to as pervious or porous pavement systems) are important part of the Sustainable Urban Drainage System (SUDS) approach to urban drainage [1] [2]. [3] identified nine categories of porous surfacing options: decks, open-celled paving grids, open-graded aggregate, open-jointed paving blocks, plastic geocells, porous asphalt, permeable concrete, porous turf, and soft paving. These pavements have found much use in car parks and pedestrian walkways as a sustainable and effective replacement for the conventional system which involved the use of impermeable surfaces [1] [4]. The ability of permeable pavements to control drainage at source makes it an important approach to SUDS [2] [5]. This recognition of PPS as an effective tool for source control is as a result of its capability to infiltrate stormwater into hard surfaces and gradually attenuates it into the soil or a drainage outlet [4][17]. Their use as car park surfaces among others has attracted attention from many researchers [3] [4] [6] [7] and some environmental institutions such as CIRIA, DEFRA, EA, USEPA. The increasing use of permeable pavements in the UK, New Zealand, Canada [4] and the USA [1] [3] among others indicates the acceptance of this SUDS technique as an effective replacement for conventional impermeable surfaces.

More than 500,000 m^2 of permeable pavements were installed in the United Kingdom [4] and about 18 million m^2 in Germany annually [8] this figures have since increased to over 20 million m^2 and a record 500,000m^2 concrete block paving installed on retail development in Ireland in 2001-2008 [9]. Over 70% of these installed permeable pavements were under sealed, thus having the potential of being used as a stormwater storage device [2]. Hence, it would be logical to use the water storage capacity of the permeable pavement system instead of separate water tanks in places where their installation is specified [10]. Recently, domestic sized kits have become available such that homeowners can easily retrofit them (see: http://www.skeletank.co.uk/). The permeable pavement system has been shown by numerous studies to be capable of removing stormwater pollution especially hydrocarbons through filtration, sorption and biodegradation [7] [11] [12] [13] [14] [15][16]. Hence, permeable pavements offer a solution to urban drainage problems, pollution of downstream and underground aquifer especially with increased use of cars [7].

The permeable pavement system often consists of the natural stone base layer which serves both as a load bearing structure and a water storage reservoir, gravel layer sometimes separated from the sub-base by geotextile material and matrix of concrete blocks with voids necessary for stormwater infiltration [2] [7] [17] . The geotextile material is considered by some as an important component of the permeable pavements system design which is effective in trapping pollutants in stormwater and serves as the site for biodegradation process within the system [10] [2] [16] [17].

Since [5] recognized that, provided provision is made to allow for extra storage volume to deal with storm events, the permeable pavement system has the capability to store water for reuse, the possibility of using the SUDS device simultaneously in source control and water recycling applications have not been holistically investigated by previous studies. Whilst use for sanitary purposes etc. is an obvious use for this low grade water in parts of the world which are subject to water stress, the use for irrigation and fertigation (simultaneous application of water and fertilizer) in both aesthetic applications and within the food chain are uses which would also be highly beneficial. Tourists from temperate regions are naturally attracted to the more arid zones of the world but, possibly unreasonably seem to demand from tourist infrastructure the quality of paved areas and parking surfaces found in their home countries and a standard of soft landscaping which may not be reconciled with the rainfall regime in the area. This leads to requirements for irrigation with scarce water resources sometimes in countries where public access to safe water supplies cannot be assumed. Pressures on water for irrigation for aesthetic purposes is also growing as a result of an increasing trend for overseas holiday homes and retirement to the sun with a tendency to maintain links with home by growing non-native plants which have high water demands. This is often accompanied by the desire for each property to be provided with a driveway to park a car. Thus there is increased runoff of the stormwater and at the same time an apparent overuse of potable water for both domestic and hospitality based irrigation. For example, in the Costa Blanca region of Spain, the average rainfall is about 330mm, a quantity which could easily be accommodated if collected in a PPS based water harvesting system and which would provide around 30,000 litres of irrigation water if the system were installed in a typical ex-patriot's driveway. In 2007, [18] proposed that stormwater harvested , treated and stored in PPS would only be used for outdoor irrigation due to limited data on water quality of such waters. The overall aim of this study is to determine the suitability of waters stored in a typical permeable pavement system for irrigation.

In arid zones the irrigation of plants must be done with the need to control soil salinity and alkalinity. If the amount of water applied to the soil is not sufficient to allow downward percolation of the applied water below the root zone it is inevitable that minerals from the irrigation water will accumulate at that level. In such circumstances it is important to take into account , amongst other things the total concentration of soluble salts and SAR which is a parameter dependent upon the relative molar concentrations of sodium to other cations [19] [20] The assessment of impact of irrigation water on the suitability of soil as a growing medium will therefore usually be based on Electrical conductivity (EC) (as a surrogate for the concentration of total salts and (SAR) [21] as well as the concentration of boron or other elements that may be toxic. Some work has been done on studying direct application of free phase oil to growing plants e.g. [22] where significant harm had been detected at relatively low dosing but the potential effects the use of water stored in oiled PPS systems on seed germination, plant growth and development on water from such systems was not clear. This is particularly the case when, for purposes of enhancing biodegradation of hydrocarbon pollutants, the surfaces are supplied with slow release fertilizers since irrigation with fertilizer laden waters in which the balance of nutrients has been disturbed by selective removal by an oil degrading biofilm or sorption onto pavement materials seems not to have been studied. Another important characteristic is the metal content of the stormwater. It has been shown that stormwater contains significant amount of toxic metals [23] and used motor oils have been shown to be a contributory factor [24].

2. MATERIALS AND METHODS

The experimental pavement models were built into welded HDPE containers equipped with a siphon device fitted into a void space created by a small section cut from a permavoid unit 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. Thus any negative effects would be limited to dissolved contaminants. The cross sections of the models are illustrated in Figure 1. The depth of the stone sub-bases was 150mm, equal to the depth of the Permavoid Units. A 50mm bedding of 10mm

Pea gravel was used to support the layer of Formpave Aquaflow block paving. Simulated rainfall intensities of 7.4mm/hr over 1 hour (sterile de-ionized water (DI)) were applied at 3 events per week. This rainfall rate was decided with consideration to the need to provide enough rain for the amount of watering required for the plants and to minimise the dilution of the waters stored in the PPS in order to give worst case effect on the parameters investigated in this study.. A weekly dose of 6.23ml of lubricating oil was added to the series (3 replicates each for stone sub base and permavoid sub base) of 710mm x 360mm model permeable pavement structure a day before rainfall in order to simulate realistic events of oil dripping from cars parked on PPS before rainfall. [11] concluded that about 0.2ml/m^2/week was the typical daily dripping of oil onto a car parking area, and in order to simulate worst case scenario, applied 6.62g of oil/week on a pavement area of 0.3721m^2. The oil application dose in this study was selected to simulate worst case scenario without overloading point areas and was felt to be a representative of a heavily used car park being used by older vehicles. As used successfully by [11], oil was injected randomly into infiltration slots between pavement blocks by means of a calibrated 10ml syringe to simulate worst case scenario whereby almost all oil drippings from vehicles parked on PPS are expected to enter the construction and not be adsorbed onto pavement blocks. A single dose of 17.06g of slow release NPK granules (Osmocote® Plus-slow release fertilizer granules) was administered to the surface of the pavement systems and brushed into the infiltration slots which delivered N (1706mg/17.06g), P (819 mg/17.06g) and K (2542 mg/17.06g). Throughout the experiment the systems were maintained in the dark as much as possible to discourage algal growth in the siphon arrangement which was a slight problem in a study conducted by [25].

Plant Growth Experiments

Two plant types were selected for the greenhouse experiments representing both horticultural (tomato) and landscaping (rye grass) applications of the irrigation water

Tomato Experiments

A total of 36 plastic plant pots (120mm high 14mm diameter) were filled with 200g of John Innes potting compost and each was planted with two tomato seeds (*Lycopersicon esculentum - fantasio hybrid).* 3 pots were assigned to each of the models and 4 pots were designated for watering with DI water. The watering of the pots, using a watering can, was carried out 3 times per week. 100% germination was achieved and after 1 month the weakest seedling in each pot was removed. As indicated above, each model had 3 replicates assigned to it and these (and the DI water control pots) were arranged within an unheated greenhouse using a randomised block design for the plants irrigated with oiled rig water and the appropriate controls with DI-irrigated samples dealt with separately as an additional row. The plants were inspected daily except for most Sundays with the first flowering date and first detectable setting of fruit being recorded for each plant. Where necessary, bamboo canes were used to support the growing plants. After 70 days, when the first plants had reached a height of around 1m, the above-soil parts of the plants were harvested and the wet and dry weights of the stems leaves and fruit were separately determined.

Rye Grass Experiment

The rye grass experiment was again carried out using 3 pots per model and 4 pots for DI watering (identical to tomato experiment). A total of 36 pots were sown with 0.5g of rye grass (*Lolium perenne*) seed into the same compost as was used in the tomato experiment. An identical randomised block design to the tomato experiment was adopted for the rye grass. The same watering regime was used as in the tomato experiment. In this experiment the rye grass was harvested at soil level at 55 days and at 93 days. Wet and dry weights of the harvested grass were determined.

Chemical Analysis of Irrigation Waters

Water samples were analysed by inductively coupled plasma optical emission spectrometry (ICP-OES) for sodium, calcium and magnesium and the EC and pH were determined on a weekly basis. From the cation data, the ratio of ratio of level of available sodium to the levels of magnesium and calcium (calculated in milliequivalent/litre (Meq/L)) in waters from PPS (SAR) [20] was determined according to the formula in [26].

Chemical Analysis of Plant Organs

The Harvested plant organs were dried in a forced-air oven at 80^{o}C for 3days after which they were homogenized according to irrigation water treatments and digested in 70% analytical grade HNO_3 and H_2O_2 in the ration of 3:2 using wet dissolution method. They were analysed for heavy metals (Cd, Cu, Pb, Ni, Fe and Zn).

3. RESULTS AND DISCUSSION

The basic quantitative results obtained from the two experiments are presented in Tables 1 and 2. It is clear from these tables that there is little difference in performance between the plants watered with water from the two oiled sub-base type rigs. There is however considerable difference between the plants irrigated by waters from oiled and control rigs and the oiled rigs and the DI water irrigated plants. These differences were all found to be significant at the 5% level. This is almost certainly due to the excess nutrients released from the oiled rigs enhancing the growth of both sets of plants. Clearly any inhibition caused by the presence of hydrocarbons in the water was more than made up for by the addition of the nutrients.

It is noteworthy that that this experiment was originally conceived as one to compare the two rig types and the tremendous difference in performance of plants irrigated with water from the oiled/fertilised rigs compared to the untreated controls was unexpected since earlier work by [22] had indicated that the hydrocarbons would be expected to inhibit the plants and work by [11] indicated that the release of inorganic nutrients from the rigs would be minimal other than just after first application of the fertiliser. This leads us to consider that whilst the waters might be suitable for release via infiltration where attenuation on soil strata and dilution would be operating (and the effects would be little different from using the fertilizer in horticultural applications directly to soil) the release of effluent from pavements fertilised to give enhanced rates of biodegradation into a watercourse would be likely to cause eutrophication. This illustrates perhaps that except where the released nutrients are to be recycled or where the effluent from permeable pavements is to be used for such applications as toilet flushing the use of normal slow release fertilizers should not be encouraged in systems where the stormwater is collected in a sub-surface tank for release to the surface water network of a separate drainage system. In such circumstances three approaches are suggested. The first of these is the very slow release system reported by [15][27] but as yet this system is not available commercially. The second might be to use a system capable of holding greater amounts of oil before saturation. [[28] showed that even without enhancing the biofilm with an outside supply of fertilizer microbial activity (as measured by Adenosine Triphosphate (ATP) determinations) is still present. Thus perhaps the key would be to hold the oil in the system long enough for natural attenuation process to take place. Finally, there is the prospect of supplying phosphorus in the form of apatites (calcium phosphate and related compounds) within the laying course. These highly insoluble compounds offer a potential to supply phosphorus to the microorganisms responsible for oil biodegradation which would also, act beneficially, as a means of immobilising heavy metals in the same way as it is able to do so in permeable reactive barriers used in groundwater remediation.[29]

Chemical Analysis of Irrigation Waters

The results for pH, electrical conductivity and SAR are presented in Figures 2, 3 and 4 respectively. For plants, the range of tolerable pH in irrigation waters for plant growth is between 6.5 and 8.5 although this depends on the species being grown. Under the conditions of the experiments reported here the pH is not a limiting factor but for certain plants pH adjustment could be required. When EC starts to exceed around 0.95dS/m the benefits of the increase in nutrients starts to be counteracted by the osmotic harm caused by the dissolved salts in very sensitive crops with the maximum limit is around 1.2dS/m [21]. Again it can be seen that EC should not limit the use of the stored pavement water for irrigation even when salts are supplied as fertiliser nutrients. Indeed there is leeway to allow for significant evaporation during storage before the harmful dissolved salt concentrations are exceeded. Sodium absorption ratio is important in climates where there is likely to be significant evaporation of irrigation water. The accepted limit for SAR is around 12-15 [30] and thus the pavement water should not, at first sight, offer a problem. However the ratio of SAR and EC is also important for certain soil types and according to [21] the ratios obtained here are such that one might need to be cautious with certain soil types or, if in doubt, add supplementary calcium or magnesium salts before irrigation. If pH reduction is also required this could be conveniently achieved by addition of gypsum. However on a note of caution it is appropriate to report that the fertiliser balance aspects of this use of pavement water is far from simple and further work is required before the system could be said to be optimised. As an example it was found that after the experiment there was found to be a depletion of iron in the tomato growing medium following the experiment. It remains to be found whether the cause of this was uptake by plants or selective leaching.

Determination of Impact of Application Waters from PPS Test Rigs on Soil

[21] indicated how the relationship between EC and SAR of water can be used to predict the possibility of soil structure problems if the water is used for irrigation. In Figure 5, if the water quality (EC and SAR relationship) falls within the solid line, it is considered suitable for use for irrigation as it would not pose a problem to soil structure. However, quality that falls outside the solid line but within the dotted lines and within the coloured region indicate that the water should be used with caution and considerations made of the soil characteristics before used for irrigation. Furthermore, water quality outside the two lines is considered unsuitable for use for irrigation. The determination of the suitability of the waters from the PPS test rigs for irrigation using the [21] model is shown in Figure 5 and the average values of ECi and SAR of water from the test rigs and their potential effects on soil structure are shown in Table 3. It can be deduced from the chart in Figure 5 and Table 3 that the waters from the stone and Permavoid Sub bases would not pose a problem to soil structure and are suitable for irrigation on all types of soil without additional water management processes. It is necessary to highlight that this water quality was achieved despite high cumulative oil loadings and nutrient addition to replicate worst case scenario. However the waters from the control test models which were not treated with oil and nutrient would require consideration of soil characteristics to see if management is required before application as irrigation fluid due to the relatively low nutrient content of waters of these systems as shown in Table 3.

Chemical Analysis of Plant Organs – **Tomato**

A relatively higher concentration of 20.1mg/kg of Zn was observed in the stem of tomato plants irrigated with DI water and the lowest level of 9.2mg/kg was observed in the stem of tomato plants treated with water from control Permavoid test rig as shown in Figure 6. However, there was no significant difference (ANOVA: $p>0.05$) between the levels of Zn in the stem of tomato plants that were treated with water from the Stone, Permavoid and control Stone sub-Base test rigs with Zn concentration range of between 14 – 16.5mg/kg. Similarly, there was no significant difference (ANOVA: $p > 0.05$) between the levels of Cu, Ni, Pb, and Zn in all the leaf samples analyzed including those irrigated with DI water as shown in Figure 6 (b). The level of Cu, Ni, Pb and Zn in all the tomato leaves was within the normal range as reported in [29]. There were no fruits from the tomato plants irrigated with water from control stone sub-base test rig and DI water (Figure 6 (c)). It was observed that Cd and Pb were undetectable in all the fruit samples analyzed. This was considered as an indication of good fruit quality achieved even after high dosing of pollutant on the stone and Permavoid sub-base test rigs to simulate worst case scenario. Furthermore, the levels of Cu, Zn and Ni remained at similar levels found in the leaves of the tomato plants and below the limits [31]. Fe concentration was < 40mg/kg in the fruits from tomato plants irrigated with water from the Stone and Permavoid test rigs, but high accumulation of Fe was observed (>120mg/kg) in tomato fruits from plants irrigated with water from Control Permavoid test models. However, these concentrations were within the normal range found in plant organs as reported in [31][32] [33] [34]

Chemical Analysis of Plant Organs – Rye Grass

In the 1st and 2nd harvests (Figures 7 (a) and 7 (b)), it was observed that the concentrations of Cd, in rye grass that was irrigated with water from all the test rigs including DI water was within the normal range found in plant leaves in dry foliage (0.1 - 1mg/kg) [35] and below the FAO toxicity level of Cd in animal feeds (10mg/kg) [36] as well as the maximum tolerable concentration by animals in dry diet (0.5mg/kg) [33]. Also, Cu was within the normal range found in dry foliage (3 – 20mg/kg) (Table 5) and below the FAO toxicity level of Cu in animal feeds (40mg/kg) [36] as well as the maximum tolerable level by animals in dry diet (100 – 500mg/kg) as stated in [30]. The concentration of Ni was in the range of 1.4 – 3.69mg/kg in all the test rigs including DI water with the highest concentration of 3.69mg/kg observed in rye grass plants that was irrigated with DI water, but the concentrations were within the normal range of Ni in plant leaves as shown in Table 1, normal level in dry foliage and below the maximum tolerable concentration by animals in dry diet as well as the phytotoxic levels in plants as reported in [31]. Similarly, concentrations of Pb observed were within the normal range of Pb in plant leaves (5 - 10mg/kg) as shown in [31], normal level in dry foliage (2 - 5mg/kg) and below the FAO toxicity level of Pb in animal feed (40mg/kg) [36] as well as the maximum level of Pb tolerated by livestock (30mg/kg) [1]. Higher concentration of Fe was observed in the rye grass that was irrigated with DI water where the concentration was 91.96mg/kg compared to the range of 51.4 - 59.31mg/kg of Fe observed in rye grass that was irrigated with water from test rigs. However, these concentrations of Fe observed in rye grass were below the FAO toxicity level of Fe in animal feed (1000mg/kg) [36] and within the normal range of Fe in dry foliage (30 – 300mg/kg) [31]. The level of Fe in rye grass was also below the maximum level tolerated by livestock (500 – 5000mg/kg) [31].

Figure 8 is a photograph of tomato plant and rye grass 10 weeks post planting showing growth and development of both plants irrigated with waters from treated PPS.

4. CONCLUSION

This study has shown that in situations where water collected from and stored under car parking surfaces receiving relatively large amounts of oil appears to be suitable for use as irrigation water from the point of lack of inhibition of seed germination, plant growth and development. It also seems that at least part of the fertilizer used to enhance biodegradation can be used a second time to enhance plant growth. The type of subbase seems to be immaterial when such effects are examined. Initial results indicate that the chemical nature of the irrigation water is such that it should not lead to problems of salinity in the soil. However the recycled nutrients provided in excess in an attempt to stimulate biodegradation in a permeable pavement may not be suitable in all circumstances as plant's needs differs, but this study has shown that the waters are suitable for one of the most common landscape crop and that heavy metals were below FAO toxicity levels for both plant parts and fruits for both human and livestock consumption. Further work is required to determine what nutrient additions would be required to ensure optimum growth for a range of plants if this approach is to be used for irrigating gardens and to establish the availability of metals in waters stored in other SUDS devices that possess water storage and recycling capability. Furthermore, further work is suggested using stormwater runoff in a field study.

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Table 1 Growth Parameters –Tomato Experiment

	Source of Irrigation Water				
	DI	**Control**		**Treated**	
Parameter	**Water**	**Stone**	**Permavoid**	**Stone**	**Permavoid**
Mean Height After 10 Weeks. m	0.85	0.82	0.92	1.01	1.12
Max. Height After 10 Weeks. m	0.74	0.80	0.80	0.81	0.87
Leaf Biomass-Wet Wt .(Mean) g	7.4	14.7	13.6	27.3	19.3
Stem Biomass-Wet Wt. (Mean) g	7.8	17.3	16.4	22.5	23.3

Fruit Biomass-Wet Wt (Mean) .g	0.0	0.0	5.3	26.2	33.6
Mean Non-Root. Biomass - Wet g	15.2	32.0	33.3	76.0	76.2
Leaf Biomass-Dry Wt. (Mean) g	2.1	3.0	3.7	4.3	3.0
Stem Biomass-Dry Wt. (Mean) g	2.5	3.5	4.3	4.2	3.6
Fruit Biomass-Dry Wt. (Mean) g	0.0	0.0	0.5	1.9	2.4
Mean Non-Root. Biomass - Dry g	4.6	6.5	8.5	10.4	9.0
First Flowering Days from Sowing	51	55	49	48	51
First Fruit Set Days from Sowing	NA	NA	68	60	61

Table 2 Growth Parameters –Rye Grass Experiment

	Source of Irrigation Water				
	DI Water	**Control**		**Treated**	
Parameter		**Permavoid**	**Stone**	**Permavoid**	**Stone**
Wet Weight 1st Harvest g/pot.	4.32	8.92	8.75	11.18	11.23
Wet Weight 2nd Harvest g/pot.	2.53	3.71	4.63	11.57	8.52
Dry Weight 1st Harvest g/pot.	0.79	1.61	1.33	1.98	1.85
Dry Weight 2nd	0.50	0.85	0.90	2.02	1.62

Harvest g/pot.

Table 3 Interpretation of Results from Figure 5: Potential Impacts of Application Waters from Test Models as Irrigation Water on Soil Structure

	Stone Base	Permavoid Base	Control Stone Base	Control Permavoid Base
SAR	1.3	1.09	1.64	1.75
EC	0.3	0.34	0.23	0.24
Arrow Colour (Chart)	Red	Blue	Black	Orange
Soil Structure	Stable	Stable	Depends on soil Type	Depends on Soil Type

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Figure Captions

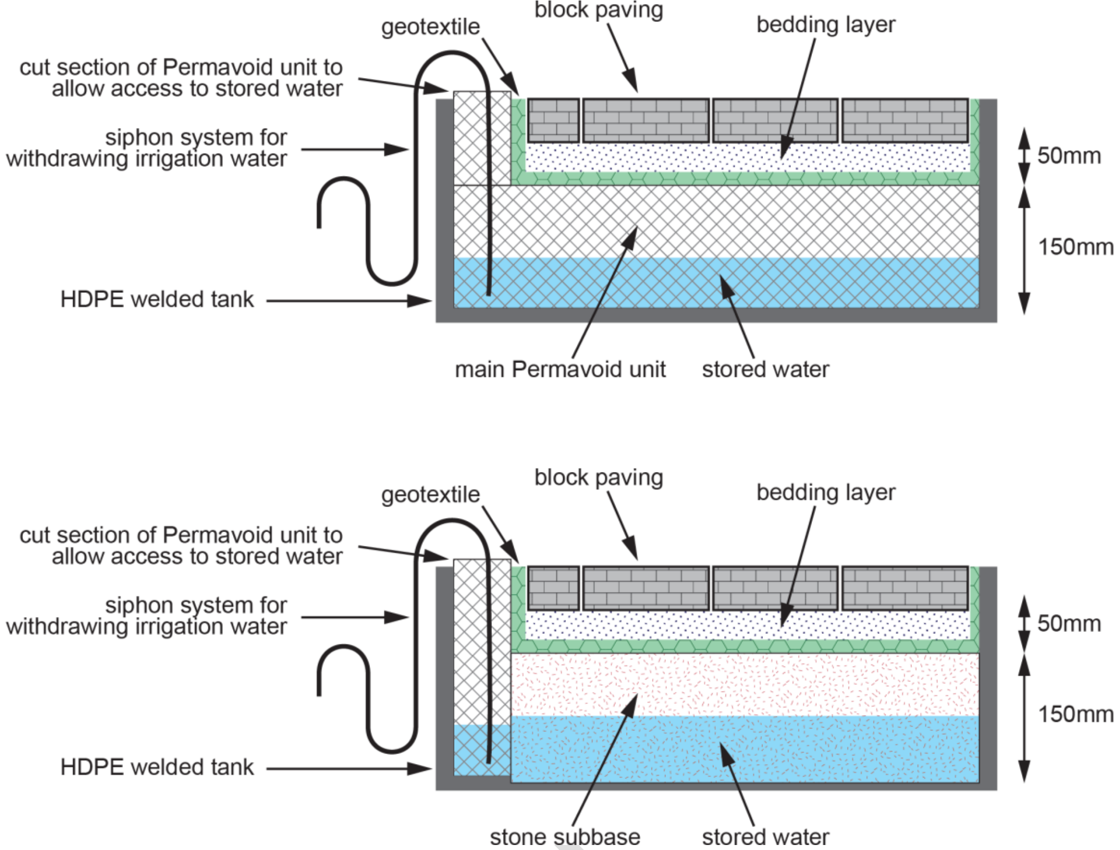

Figure 1 Schematics of the Rig Model Types:Top-Permavoid Bottom–Stone Sub-base

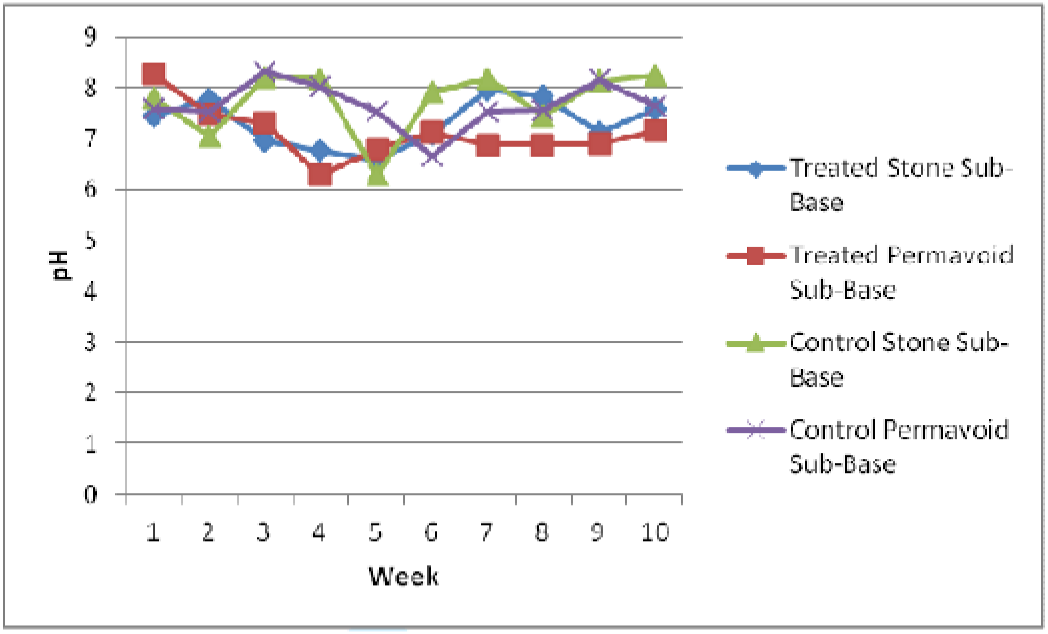

Figure 2 Weekly measurements of pH in irrigation waters (median)

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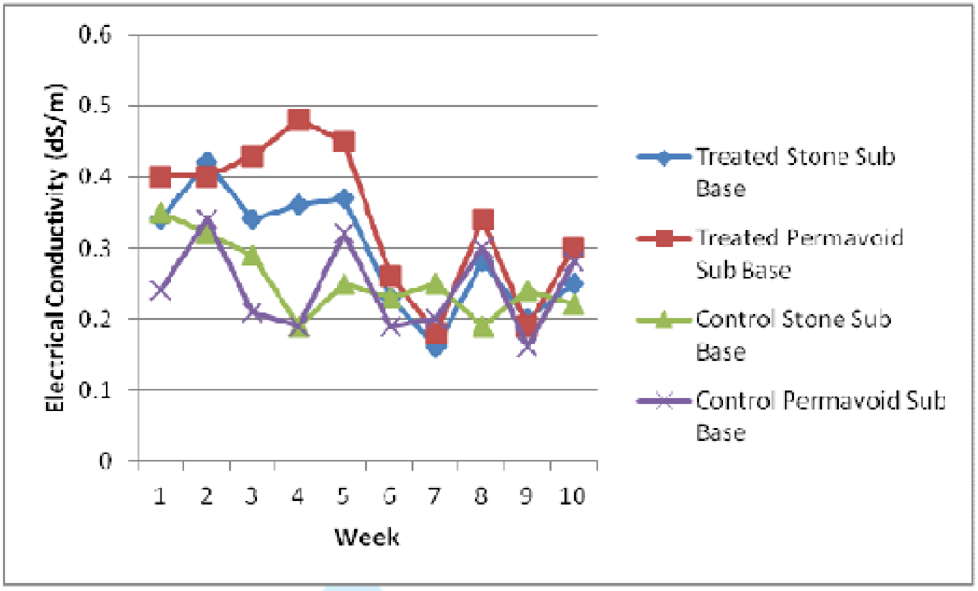

Figure 3 Weekly measurements of electrical conductivity in irrigation water (mean)

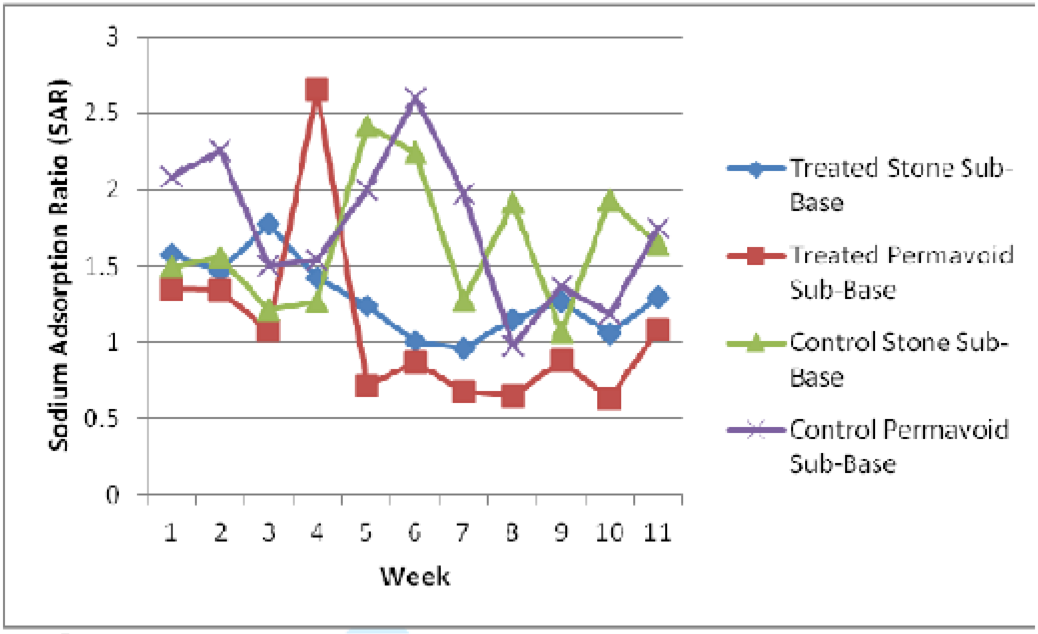

Figure 4 Weekly measurement of sodium absorption ratio in irrigation waters (mean)

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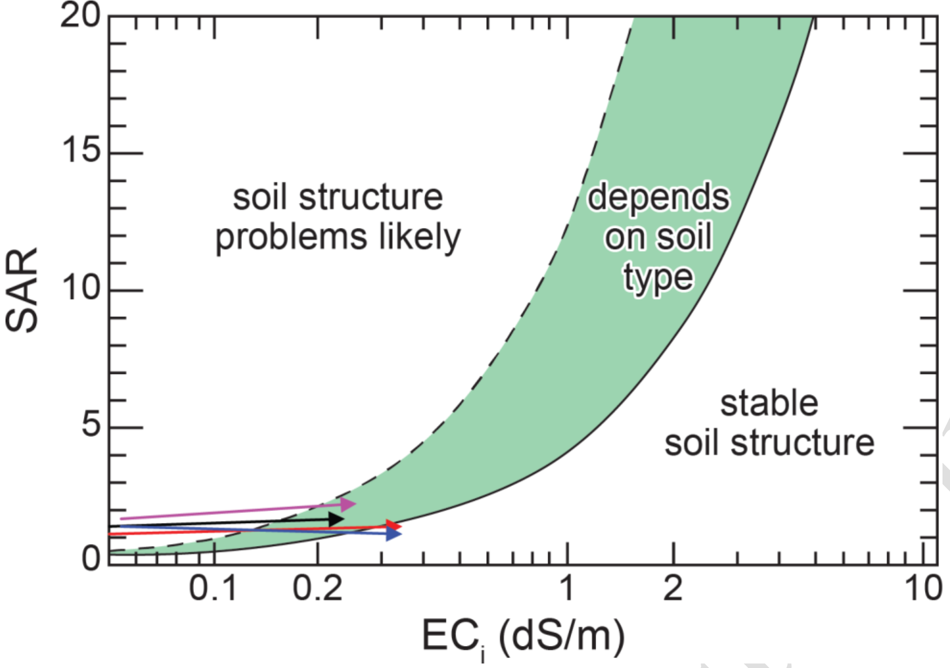

Figure 5 Effects of EC and SAR of Water from Test Models on Soil Structure

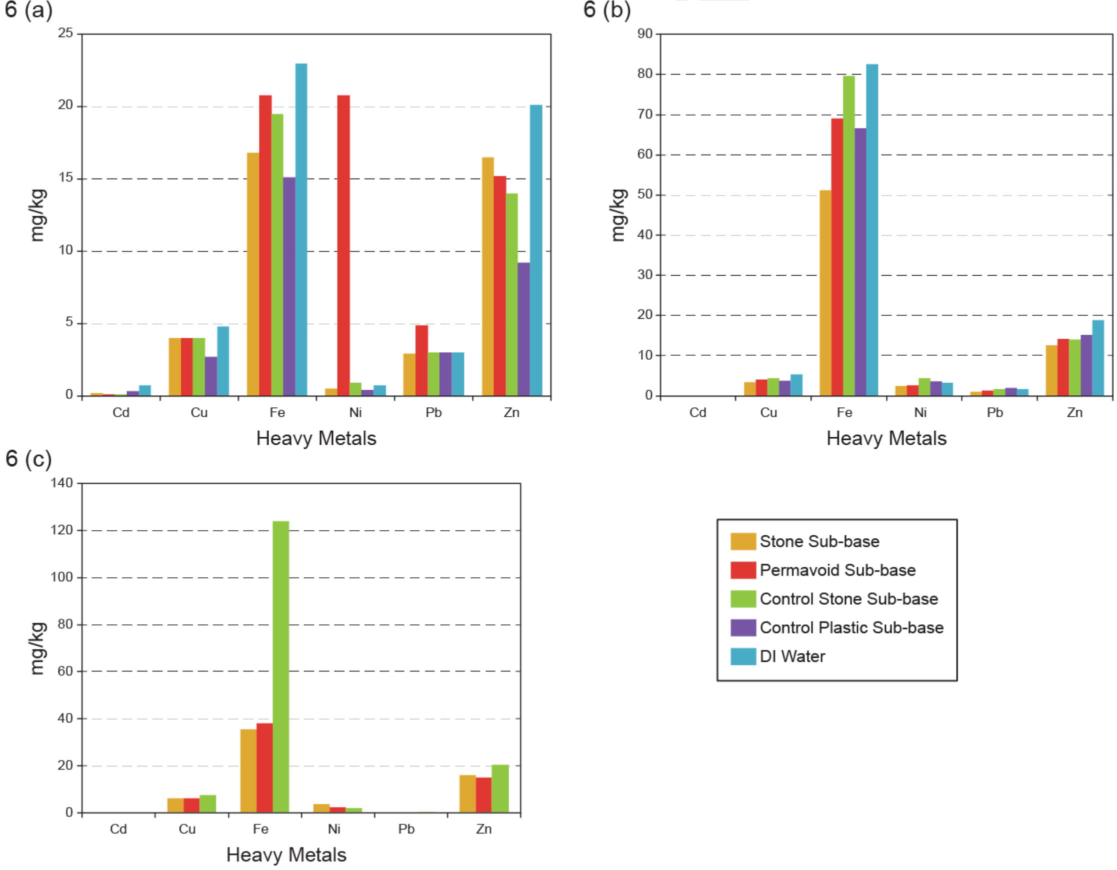

Figure 6 ((a) Metals in Tomato Stem; 6 (b) Metals in Tomato Leaves; 6 (c) Metals in Tomato Fruit

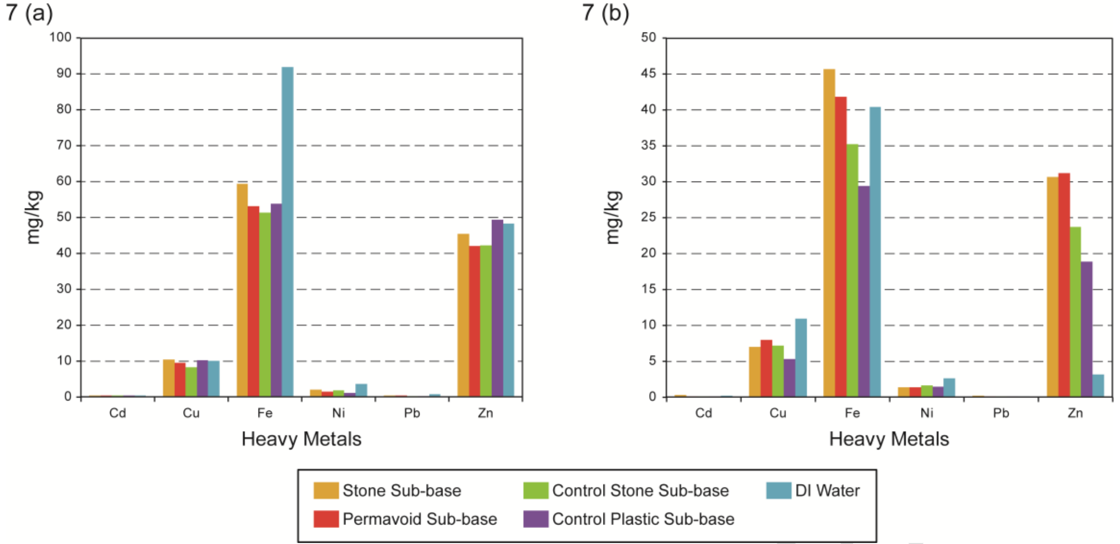

Figure 7 (a) Metals in Rye Grass (1st harvest); 7 (b) Metals in Rye Grass (2nd harvest)

Figure 8 Tomato and Ryegrass Irrigated with Waters recycled in PPS Models 10 Weeks Post Planting