COMPETITION: Mobuoy Road Waste Remediation SBRI
Reference: SBRI_DA_313_009

SBRI End of Phase 1 Report Form

NOTE: The Authority reserves the right to amend this form and/or issue additional guidance notes on how it should be completed during the duration of the project.

This Report is the contractor's opportunity:-

- to describe the work undertaken during the project, what outputs were obtained and why these are relevant to the objectives of the Competition
- to explain and prove expenditure; and
- to develop a comprehensive report for contractor's to share with their stakeholders and those that may help further commercialisation pursuant to the terms of the contract.

The Authority may use the Report as part of the assessment for any Phase 2; it is therefore important that contractors complete the form as completely as possible.

The Report will be considered to be confidential and commercially sensitive by the Authority and its contents (other than the response to Section 5) will not be disclosed to third parties other than in accordance with the terms of the contract.

The Report must be submitted via **MobuoyRoadSBRI@sibni.org** within 14 days of the completion, or termination, date. The contractor is reminded that completion of this report is a contractual obligation and forms part of the payment terms. The report should be completed by the lead contractor, with input from any sub-contractors or project partners as appropriate. Please answer, wherever possible, on behalf of the business units, divisions, or companies which were involved in the work. If this is not possible (as a result of merger or acquisition, for example), please specify the organisation to which your answers refer.

Please answer the questions fully, but keep your answers succinct and no longer than necessary to provide a clear explanation. When describing technical solutions, please regard your audience as being someone familiar with the technology, but not an expert. The report may be done in narrative alone, however diagrams or pictures may be annexed to the Report where these aid clarity Please limit your response to a total of **ten sides of A4** plus **an additional limit of ten sides for any supporting diagrams or pictures**. (Please keep to a maximum limit of 5MB per email when submitting supporting information).
Because the true impact of an R&D project often takes several years to emerge, InnovateUK and the Authority may approach you for up to six years after project completion to follow up on the questions in this report. Your co-operation with any such follow up work is greatly valued.

1. Details

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Project Reference: [redacted]

Total Contract Cost: (£s) [redacted]

Start Date: November 2016 End Date: May 2017

2. At the outset of the project what were your aims and objectives?

The aims of this project were to examine the potential for creating soils which could be used in formation of an active hydrological and biological capping system to manage infiltration of leachate into areas of historic landfilling and to maximise evapotranspiration. Similar techniques have been used successfully in the United States (ITRC 2003) although the technology has not been widely applied in the UK. Specific engineering of soils for their water holding characteristics using organic additives is a novel approach to contaminated land management.

Specific objectives of this study were:

- To identify soils on the Mobuoy Road waste site that could be used as the basis for development of an environmental capping system.
- To identify sustainable local sources of soil amendments with necessary characteristics for improving soil water holding capacity and fertility.
- To undertake trial mixing at a cubic metre scale to assess the viability of additive mixing, and determine the physical characteristics of mixed soils regarding their potential use in landfill restoration works.
- To compare different additives and additive combinations against un-amended soils to establish the potential impact on soil water holding capacity and available water content and to identify the best proportions and combinations of additives to achieve the desired objectives within the context of environmental capping.

Initial chemical screening of soils and additives was also carried out to give an indication of their likely suitability for use within a site remediation scheme. The primary objective of this initial research was to establish the effects of amendments derived from recycled sources or waste streams on total and available water holding contents of soils. Assessment of mixed soils included determination of physical characteristics and permeability as an indication of likely interaction with landfill gas movement at the site.

3. Please provide a summary of the outputs of the project and relate these to the original objectives. How do the outputs address the requirements of this competition? What are the recommendations?

Introduction

Base soils were selected on the basis of being most representative of typical 'base soil' likely to be encountered at the site. These materials exhibit a reasonable potential grading profile for water holding capacity, being relatively evenly graded with some silt/clay component. Twelve trial mixes were scheduled based on combinations of identified soil additives. Mix proportions were established based on dry weight to enable comparison between additives, however, dry weights were converted into volumes at natural moisture content for field measurement as in practice this is the only practical way to measure and apply additives at the site scale. Mixtures were selected based on total amendments of 10% and 30% by dry weight. Whilst previous laboratory studies have shown 30% amendments by dry weight are likely to perform well, WTR and compost which have very high water contents in their field condition, volumes required at the 30% dry weight level may be difficult to implement. Amendments at the 10% dry weight level still offer practical benefits for WHC whilst being more realistic to manage in practice. In addition a control plot was established comprising base soil only which was subject to handling and mixing in exactly the same way as the amended plots.

A schedule of the trial mixes is given in Table 1 Appended.

Field trials

Field mixing trials were set up to assess the potential effects of using identified additives to engineer soils for WHC. Trials were designed at the field scale to simulate the practicalities of field mixing operations and to assess the end results likely to be realised in a site scale application of the soil engineering exercise. It was not possible, due to space available and cost and time constraints to use full size agricultural or remediation plant. It is expected that at full scale, soil mixing would be carried out by either a large excavator or bulldozer equipped with a specialist mixing bucket (allu bucket add refs.) or by mixing using a large agricultural rotavator. For establishment of the field trials soil mixing was carried out using a hand held rotavator capable of mixing soils to a depth of 0.2m. It is considered that this method provides a suitable equivalent for full scale mixing operations and uses a digging mechanism of rotary blades which is equivalent to and on the same scale as would be used within the full-sized plant. Three passes of the rotavator were made within each plot to simulate a realistic attempt at thorough mixing at the field scale.

Base soil was excavated and homogenised using a 14ton excavator and dump truck. A total of fourteen test plots were formed using a timber framework with dimensions of 1.8m x 0.9m x 0.225m to give a total volume of 0.324m^3. Base soils and selected amendments were measured by volume at field moisture content and were added to each test plot and subjected to mixing by three passes of the powered rotavator. Following mixing soils were lightly compacted to achieve a level surface. Photographs of the trial plots and mixing process are append for reference (Plates 1 and 2).

Following mixing, disturbed samples of engineered soil were obtained from each of the test plots and scheduled for geotechnical testing (particle size distribution, compaction and permeability) and standard laboratory testing for WHC, as completed on the base soils. Samples of engineered soils were also submitted for testing in accordance with BS3882 for topsoil. In addition, samples of mixed soils were subject to alternative water holding tests to examine the effects of soil structure and wetting and drying cycles following methods developed at Durham Universtity (Kerr et. al. 2016).

Test soils were left to settle in normal climatic conditions over a period of approximately 8 weeks after which time further undisturbed samples were taken from the test plots using standard 100mm diameter sampling moulds. Samples were sealed at field moisture content for further analysis of moisture content and bulk density. These samples are considered to approximately represent the field conditions of the soils following natural wetting and drying cycles and give a basis for comparison with samples remoulded in the laboratory.

Soil properties

Results of particle size distribution testing have been obtained to provide information on the mineral component of the soil; however, it is difficult to carry out conventional particle size distribution analysis on soils containing significant organic content due to difficulty caused by coagulation. Organic material is therefore removed by the laboratory prior to testing. It is not well understood at this stage how the processes used to remove organic material for these tests interact with the water treatment residual (WTR) as only a part of this material is formed of organic carbon. Compaction tests, bulk density and moisture content analyses and determination of permeability are performed on the samples with no prior processing.

The results of particle size distribution analyses for amended soils are presented in Figures 1 to 5 below, together with results of testing for the untreated soil and the control plot (A4). Due to the volume of compost contained within the 30% amendment, it was not possible to carry out a laboratory particle size distribution analysis on this material. However, in the 10% compost addition, an increase in silt and sand sized material and a significant decrease in gravel sized material is observed compared to the untreated soil.

A similar pattern is observed with amendments of WTR, being more pronounced at the 30% level. As would be expected, additions of sand and combinations including sand result in an observable increase in materials in this particle size range, together with a decrease in the proportion of gravel to compensate. The proportion of clay and sand sized material is generally not significantly affected. The co-amendment of compost and WTR resulted in a n overall increase in clay, silt and sand sized material at the expense of gravel. This is particularly notable at the 30% amendment level although less so at the 10% level.

Soil density results are summarised in Figure 6. Density values obtained from samples of soil remoulded in the laboratory and from undisturbed samples obtained from the test cells after approximately 8 weeks in-situ are presented for comparison.

Due to the nature of the compost and WTR, addition of these materials significantly reduces soil density and increases void ratio. The WTR in particular has a very high starting moisture content and low dry density. Bulk densities measured in the laboratory on remoulded samples, compacted using a standard 2.5kg rammer, are very similar to those observed in the field after 8 weeks and indicate that performance of these materials provides an appropriate analogue for field performance.

Results of permeability testing are presented in Figure 7. Testing was carried out on remoulded samples with a nominal confining pressure of $50kN/m^2$ in order to standardise the test condition for each of the samples and provide comparable results. Remoulded permeability for all the materials was found to be relatively low, being $<1x10^{-8}$ m/s. This reflects the generally well graded nature of the materials and significant proportion of clay and silt sized material present. It is however, clearly indicated that addition of both compost and WTR, either individually or as co-amendments results in a reduction in aqueous permeability of between 0.5 and 1 order of magnitude compared to the untreated soil or soils amended with sand only.

Laboratory analysis for water holding capacity was carried out under subcontract with NRM laboratories. At the time of writing, this analysis is only partially complete but available results have been reported here for completeness. Figures 8 and 9 show results of available water content (AWC) calculated in terms of water content by percentage dry weight and by volume. Results indicate an increased AWC for soils amended with compost in terms of percentage dry weight and similar performance to un-amended soils in terms of volumetric water content. Results for soils amended with WTR and sand showed a reduction in AWC by either measure based on the laboratory test.

To asses the potential for soils to support healthy plant growth, testing was carried out in accordance with BS3882:2015 for classification of topsoil. It is recognised that this is a relatively simple testing regime and that other factors may also be important in the potential for the soil to act as a growing medium; however, these tests provide an initial indication of the likelihood that soils will be suitable for cultivation. Soils have been assessed against the requirements for a multi-purpose topsoil as a starting point.

All the soils were noted to contain too high a percentage of gravel to comply with the requirement for multi-purpose topsoil. This does not however preclude the support of healthy plant growth and it is noted that addition of amendments reduces the proportion of gravel within the engineered soil.
A summary of the nutrient concentrations required together with results for each of the test soils are given in Figures 10 to 13.

None of the soils were found to contain concentrations of common phytotoxic metals (i.e. Zn, Cu & Ni) that would preclude healthy plant growth. It is noted that the WTR contains relatively high concentrations of total aluminium due to the chemical process by which it is formed in water treatment. However, leachable concentrations of aluminium from the neat WTR are comparatively low, being between 26 and 37µg/l compared to the Groundwater Framework Directive threshold of 150µg/l.

Untreated site soils were found to contain insufficient organic matter, nitrogen or phosphate to comply with the BS for topsoil. Additions of sand do not have any significant influence on the nutrient profile of the soil. Addition of WTR generally increases levels of nitrogen above the required minimum threshold required by the standard for topsoil, although has little effect on levels of phosphorus, magnesium or potassium. Additions of compost substantially increases levels of essential plant nutrients. Levels of potassium and magnesium recorded in sample B6 with 5% compost amendment showed extremely high levels of potassium and magnesium above desirable upper limits. Given the results obtained for other compost amendments, it is believed that these results are anomalous and not representative of concentrations that would be realised in practice for the material overall. The elevated results could be due to localised sampling issues. Confidence in the suitability for use of this compost is given by the fact that in bulk it complies with current requirements of the PAS-100 classification confirming suitability for re-use.

To establish water holding capacity (WHC) of the engineered soil, testing was carried out based on methods developed by Kerr et.al. (2016). An increase in total water holding capacity was observed for all soils amended with compost and WTR compared to the baseline soil. Soils amended with sand only did not show a significant change in water holding capacity. Soils amended with 30% sand were not sufficiently cohesive to form laboratory cores and no meaningful test results were therefore obtained. Highest water holding capacity was observed in soil amended with 30% compost with the 30% compost + WTR co-amended soil performing almost as well. Soils containing either 15% compost or 15% WTR in combination with 15% sand both performed well in terms of total water holding capacity. Total water holding capacity of the best performing amendments was more than twice that of un-amended soil on a volumetric basis and between 2 to 3 times greater on the basis of equivalent soil mass.

Figures 14 to 16 below show the results obtained from laboratory trials completed to date. Graphs show results averaged over three test cores for each condition. Results are presented in terms of gravimetric water content in units of g/cm^3, g/g dry weight of soil and g/g wet weight of soil for comparison. Water holding capacities show a close negative relationship with soil dry density and void ratio with lower density soils having higher water holding capacity.

Change in water content over time through the wetting and drying cycles indicates that amended soils retain water at least as well or slightly more effectively than un-amended soils, exhibiting a slightly slower drying curve. Due to time constraints, it was not possible to fully dry amended soils, however, the slope of the drying curves approaching re-wetting at approximately 940 hours indicates that further moisture would be released from these soils and that estimates of available water content based on these test results are likely to be significant underestimates. Laboratory testing of amended soils at -1500kPa indicates that minimum water contents of <0.1g/cm^3 would eventually be reached.

Amended soils were generally observed to recover well from drying, although the single amendment of WTR at 30% performed notably less well than other amendments. Co-amendments of sand and compost appear to assist re-wetting. None of the soils regained their maximum pre-drying moisture contents.

Available water contents have been calculated from minimum water contents achieved during the drying cycle and maximum water contents measured following re-wetting. This provides an estimate of the available storage capacity within the soils. Results are summarised in Figure 19 on volumetric, dry weight and wet weight bases. Based on dry mass, available water contents for best performing amended soils are more than double those of the untreated soil. On an equivalent volume basis, increases in available water content are observed within all the amended soils, except for sand only. Amendments of compost and sand with compost showed the highest overall available water contents by volume. As noted above, it is considered that the actual water holding capacities of these soils will be significantly higher than measured within this initial trial if further time is available for drying of amended soils.

Comparison of soil density measured in cores used for water holding tests and cores obtained from the field trial plots after 8 weeks is given in Figure 17. Laboratory remoulded samples tend to have slightly higher density than those recovered from the field. Relative densities across samples are consistent and indicate that the amendments are the primary factor influencing soil density. Results confirm that remoulded samples used in lab trials provide an appropriate surrogate for field conditions and allow a meaningful comparison of amendments to be made.

Discussion

Initial trials provide strong evidence that significant improvements in soil water holding capacity can be achieved by the addition of the amendments tested. In terms of pure water holding capacity, the single amendments of compost appear to show the best results, however, the co-amendment of compost and WTR at 30% also performs well.

In practical terms, addition of 30% compost on a dry weight basis results in a large volume of additives due to the comparatively low dry density of these materials. A 10% amendment by dry weight is likely to be a more practical proposition in the field. Results show that amendments at this level also have a significant positive impact on water holding capacity with increases of approximately 1.5 times by volume achievable.

Additions of sand have little effect as a single amendment but, in combination with compost or WTR, increasing the fraction of sand sized material appears to reduce the moisture content at the Permanent Wilting Point (PWP), thereby increasing the total available water content within the soil. The presence of sand also seems to improve the re-wetting behaviour of the soil.

Overall available water contents have been shown to be increased by a minimum of 20% to 33% on an equivalent volume basis, and by significantly more in terms of dry density of soil. Due to the limited time available for the laboratory water-holding trials, amended cores were not allowed to reach their minimum water contents and consequently, calculated available water contents are likely to be underestimates. Water holding capacity is negatively correlated with dry density and positively correlated with void ratio, indicating that the significant changes to the physical structure of the soil by addition of amendments are of primary importance in modifying its water holding behaviour. Initial trials show that water holding of amended soils is reduced following a severe drying episode. However, amended materials retained significantly higher water holding capacities than the un-amended soils. The ongoing behaviour of engineered soils under repeated cycles of wetting and drying is not established at this stage and further work is recommended in this area. It is, however notable that soils are unlikely to become so severely dried under field conditions, especially as the significantly higher levels of soil moisture present within amended materials provides a large buffer against such severe drying. This in turn will make the soils less vulnerable to drying induced structural changes such as cracking which can cause problems in engineered capping materials.

Initial trials indicate that amended soils can be engineered to have an available water content of $>0.4\text{Mg/m}^3$ compared with un-amended soils at approximately 0.29Mg/m^3. As an example within the specific context of the Mobuoy site, these water holding capacities have been assessed for site-specific conditions. Based on Met Office MORECS climate data for the site (2007-2015 data), the estimated annual soil moisture surplus beneath deciduous tree cover, assuming 20% runoff is approximately 495mm. Based on available water holding capacity data derived within this project, retention of this quantity of water would require a thickness of 1.2m of amended soil compared with a thickness of 1.7m of un-amended soil. Retaining moisture within a shallower layer will also place it within the effective root zone of potential surface crops for efficient use. Studies carried out on high water demand short rotation coppice willow indicate that such a crop has the potential to utilise the quantities of available stored water during the course of a growing season (Guidi et.al. 2008; Pistocchi et. al. 2009), although the potential water demand and specific design of an environmental cap in this location would need to be further investigated.

Analysis of amended soils to date confirms that amendments of compost and WTR are likely to enhance the suitability of soils for supporting healthy plant growth which would be essential to aid in removal of excess soil water stored over the winter period.

WTR is acknowledged to contain high concentrations of aluminium sulphate, although initial leachability testing indicates that mobile concentrations of aluminium are low. Aluminium toxicity to plants is usually increased in the presence of acidic soil conditions, although the exact mechanism is not well understood and is likely to vary considerably with soil and plant type (Delhaize and Ryan 1995). Amended soils have been found to be neutral or slightly alkaline which indicates that the toxicity of soil Al may be limited, however, further investigation of the potential for aluminium toxicity associated with WTR and proposed biomass willow or similar crops will be required.

Standard laboratory testing of samples at field capacity (-33kPa) and permanent wilting point (-1500kPa) indicates increases in water holding capacity on a dry weight basis due to amendment with compost and WTR. However, overall effects on a volume basis are lost using this method due to the removal of soil structure during the test process. Addition of sand reduces the moisture content at -1500kPa, so increasing total available water content, and may be beneficial as a co-amendment. Field observations indicate that sand significantly assists in mixing and integration of the soil additives and may also assist in re-wetting behaviour of the soil with little negative impact on total water holding capacity when used together with compost and WTR. Further research is required to investigate the potential influence of all three amendments used together as this combination was not fully explored within this trial.

Geotechnical analysis indicates that amendments of compost, WTR and sand can have a beneficial effect on the overall particle size distribution of the material in terms of its suitability for cultivation and water holding capacity. Increases in the proportion silt and sand sized materials, which are instrumental in favourable available water holding characteristics, is generally seen, with a concomitant reduction in gravel content.

Laboratory permeability testing has shown a decrease in permeability due to addition of both WTR and compost. In the context of use within an environmental capping system for landfill management this is a beneficial characteristic as it slows the vertical movement of soil water into the underlying wastes and improves the potential of the engineered soils to act as a barrier to gas migration, enhancing the effectiveness of any associated gas collection systems. Reduction in gas permeability is likely to be due to increased water filled porosity and reduction in soil cracking due to the altered physical properties of the soil, however, results obtained here in terms of gas permeability are based on hydraulic permeability only as an indicator and require further investigation.

Further Work

Initial trials give a clear indication that the addition or organic amendments has a significant beneficial impact on the water holding capacity of the soil, its available water content and its wetting and drying behaviour. Results indicate that a co-amendment of compost and WTR show the best performance in terms of water holding properties. This is consistent with earlier findings using laboratory mixed soils (Kerr et. Al. 2016). At this stage sample size is relatively small (n=3 observations per condition) and further trials are recommended focussing on selected amendments to repeat experiments for a larger sample size and thereby increase the level of confidence in the results obtained.

Although the mixing during the Phase 1 trials was undertaken in a way that is reasonably representative of field application, subsequent laboratory analysis has necessarily been limited to much smaller sub-samples. The potential influence of scale effects has been controlled to some extent by use of duplicate analysis, however, the next stage in advancing this technology towards viable application will be establishment of a field scale trial with in-situ monitoring of soil processes to investigate performance of soils at application scale.

At present, the potential for soils to support healthy plant growth and maximise evapotranspiration has not been fully assessed. Results obtained as part of the Phase 1 trials indicate that soils should be capable of supporting a willow or similar crop but a field scale trial established over a longer period of time, perhaps two growing seasons, will be required to further investigate how effective this element of the system is likely to be and which soils are best suited to optimising biomass growth.

Observations made during the Phase 1 trials, together with postgraduate research undertaken by the author at the University of Durham, indicate that addition of WTR imparts additional beneficial properties to engineered soils in addition to WHC. Increases in strength have been reported, which will be important in maintaining the performance of the environmental capping system over the longer term and will help to protect the environmental cap from degradation in performance as a result of compaction. This is especially important where cultivation of the surface is proposed.

The next logical progression of this project would be to establish a series of site scale test cells (lysimeters), using site-mixed soils based on the best performing amendments established from the

Phase 1 trials, to establish a working section of active hydrological and biological capping. A period of two growing seasons would enable a viable short rotation coppice willow crop to be established, allowing a comprehensive trial of the working environmental cap system to be undertaken. Field lysimeters would be constructed to carefully monitor the water balance within the soil and plant system allowing ongoing monitoring of soil moisture levels, soil water inputs and outputs and plant growth. A system similar to that recently established and studied by Guidi et.al. 2008 and Pistocchi et. al. 2009 would be proposed. In addition it would be proposed to include monitoring of soil gas permeability properties in greater detail and investigate methane oxidation potential of the capping soils to better understand the relationship between environmental capping soils and landfill gas migration.

If research into this technology proceeds to a second phase, we would hope that expertise in the use of short rotation coppice willow cultivation within remediation projects provided by the SBRI contractor AFBI could be incorporated to maximise the potential learning and performance benefits from an environmental capping solution at the Mobuoy Road site. Whilst we are now beginning to understand what can be achieved by engineering the soils for water holding capacity, the interaction with the overlying biomass component of the system will be critical to its continuing performance.

References:

Delhaise E. and Ryan P. 1995. Aluminium toxicity and tolerance in plants. *Plant Physiology* 107 pp315-321.

Guidi W., Piccioni E. and Bonari E. 2008. Evapostranspiration and crop coefficient of poplar and willow short-rotation coppice used as a vegetation filter. *Bioresource Technology* 99 pp4832-4840.

Interstate Technology and Research Council (ITRC) 2003. Technical and Regulatory Guidance for Design, Installation, and Monitoring of Alternative Final Landfill Covers.

Kerr H., Johnson K., Toll D.G. and Mansfield F. 2016. Flood Holding Capacity: a novel concept to evaluate the resilience of amended soils. http://ascelibrary.org/doi/abs/10.1061/9780784480120.041

Pistocchi C. Guidi W. Picciono E. and Bonari E. 2009. Water requirements of poplar and willow vegetation filters grown in lysimeter under Mediterranean conditions: Results of the second rotation. *Desalination* 246 pp137-146.

4. Describe any changes to the original application. What was the reason for these changes? Please include any circumstances that aided or impeded the progress of the project and the actions taken to overcome them.

The initial proposal included consideration of additional potential soil amendments including biochar and PFA. Following early discussions with the Northern Ireland Environment Agency, it was decided that PFA would not be a suitable amendment to consider due to potential environmental concerns. In addition, sources of PFA were located at a greater distance from the Mobuoy Road site than those for other additives and were therefore a less attractive option in terms of sustainability due to greater road transport requirements. Biochar was not taken forward for testing as a reliable or cost-effective supply of biochar could not be found in the vicinity of the site.

The available trials were instead directed towards expanding the combination of amendments using locally available and easily obtainable additives which would be viable and both environmentally and economically sustainable for use within a real-world application of the technology.

Initial proposals were to demonstrate water holding capacity behaviour of the amended soils using laboratory tests. However, on further research into the laboratory methods and after discussion with colleagues at the University of Durham undertaking similar research (see Kerr et.al., 2016), it became apparent that these tests, whilst available commercially, would not provide an accurate assessment of behaviour of soils at a site scale and could not take account of in-situ soil structure or the influence of soil amendments at normal soil moisture contents. It was also found that these commercial tests were very time consuming and in limited supply. With each individual test taking between 4 to 8 weeks to complete and a limited laboratory capacity, it was not possible to obtain a completed set of results within the project timeframe. Half of the final set of water holding tests remain outstanding at the time of reporting and are expected mid-June 2017. This is a useful discovery in itself, as it would have implications for verification testing which would be required as part of the implementation of an environmental capping scheme on the full scale.

Due to the limitations of the commercially available water holding tests, an alternative method developed by the Environmental Engineering group at Durham University was adopted. This method has allowed a more accurate assessment of real world water holding behaviour to be completed including consideration of soil structural effects which are of major significance in overall soil water holding behaviour. Consequently, some of the commercial laboratory testing budget was reallocated to cover laboratory time for Sirius' project team as the alternative testing has had to be carried out in-house at Durham.

5. Please provide a brief, public facing description of the project objectives, work completed and the most significant outcomes of your work. The Authority reserves the right to amend the description before publication if necessary, but will consult you about any changes.

Research has been conducted into the potential benefits of engineering soils for use in landfill capping and restoration as an alternative to traditional low permeability clay and manufactured lining materials. Focus has been placed upon the re-use of soil materials already present on the remediation site in combination with locally sourced sustainable additives such as recycled compost, clean water treatment residual and dredge arisings from the nearby Foyle Port. The objective of the research was to explore the possibility that soil could be engineered through the addition of sustainable amendments to increase its total and available water holding capacities and to enhance its suitability as a growing medium such that it could form the basis of an environmental capping system to manage infiltration and support surface vegetation such as a willow crop used for biomass fuel production.

The results of initial field mixing trials and subsequent laboratory analysis of amended soils shows that a significant increase in available water holding capacity of approximately 40% can be achieved by addition of combinations of compost, water treatment residual and dredged sand. These amendments also improved soil structure and increased soil fertility.

6. Describe the innovative aspects of the work including any new findings or techniques.

To the best of the authors knowledge, this research is the first to assess in detail the effects of soil amendments on soil properties with the aim of engineering soils for use in an environmental capping system at the site scale. Similar research on soil amendments has been undertaken at the University of Durham using laboratory prepared samples but results have not previously been replicated using actual soils mixed on site under field conditions and at natural water contents.

The use of co-amendments of compost and WTR is a novel approach that is still being investigated and appears to provide particular benefits in terms of water holding capacity and soil structure. The fact that we have been able to replicate the promising results obtained during laboratory based trials with samples mixed at the field scale using actual site soils and local additive materials provides a step forward in establishing the likely viability and effectiveness of these methods at application scale on the Mobuoy Road site.

Previous research on WTR amendments has been carried out using iron-based water treatment residual, common in water treatment works in the northeast of England. The use of aluminium-based WTR such as is obtained from the Carmoney water treatment works has not previously been trialled in this context. The positive results obtained here, which are consistent with results obtained using other sources of WTR are novel and support the use of these materials as a valuable amendment for soil engineering.

The effects of co-amendments of sand on water holding capacity together with compost and WTR have not previously been investigated and potential benefits to available water holding content and mixing efficiency of adding sand are novel findings.

No previous investigation of the effects of these soil additives on soil permeability has been identified and these findings advance understanding of the potential effects to soil permeability.

The results obtained relate specifically to materials derived from the Mobuoy Road site and its immediate environs and demonstrate the actual soil properties which can be achieved by using relatively straightforward soil engineering techniques.

7. Please give a description of how funds were spent with reference to the original budget and explain any significant variations.

The project spend has been altered to some extent to account for the difference in testing methods applied. Less commercial laboratory testing than planned was carried out, with additional budget being used to pay for water holding tests carried out by Sirius using the laboratory facilities at the University of Durham. These tests are proving to be more valuable in understanding water holding characteristics of the soils and are still ongoing, facilitated by the SBRI funding.

It was decided that biochar would not be included in the site trials due to the impracticality of using this material in a field scale application. Budget allocated for purchase of biochar was not therefore used.

Following discussions with colleagues at the University of Durham it became apparent that Field measurement of soil suction using the tensiometers originally proposed would not yield useful results. Purchase of this equipment was not therefore undertaken with resulting cost saving.

Due to the above changes, we have underspent on the project by approximately £800 as reflected in our total invoicing. The difference is primarily due to reduced commercial laboratory analysis.

In terms of the field mixing trials and other project elements, spending was as anticipated in the initial proposal.

8. Describe any potential long-term collaborations/partnerships entered into. Please list the company and the role they played in the project.

This research has primarily been conducted by the Sirius team with assistance from [redacted] at the University of Durham Department of Engineering and Computer Science. [redacted] has kindly provided advice on methods used for carrying out water holding tests and shared some of the results obtained from MSc research projects being carried out in the department.

Sirius intend that, with the permission of the Northern Ireland Environment Agency, research on the trial plots established for the Phase 1 SBRI project is continued (at no cost to the SBRI programme). This will increase the level of confidence in the findings to date and add to our understanding of the soil processes involved. It has been suggested that the mixed soils could form the basis of further MSc research projects being conducted within the research group at Durham.

It is hoped that, if this technology progresses to Phase 2, this can be undertaken in collaboration with AFBI who are conducting research into the biomass element necessary to establish a working environmental cap at the Mobuoy Site. Initial discussions with [redacted] at AFBI indicate that this would be a mutually beneficial way to proceed to the next stage.

9. Please describe how your company has gained from this project. What new business opportunities have been created? Do you expect your company to grow as a result of this project?

The project has enabled Sirius to explore the potential for developing environmental cover systems for management of contaminated land using recycled materials in the UK. The research supports the viability of this approach and provides substantial evidence to present to stakeholders and regulators in support of similar proposals at this and other sites.
We now have a better understanding of the likely changes in water holding behaviour of certain soil types when amended with compost and WTR which give sufficient confidence to propose this approach as a viable remediation option and to tailor the approach for site-specific circumstances.

It is proposed that the initial research completed here be continued to establish a higher level of confidence in the results obtained and to further understand the chemical and physical mechanisms involved in engineering soils for water holding capacity.

This approach will enable Sirius to offer environmental capping solutions as a viable, sustainable and cost effective option to clients managing contaminated land where risks to controlled waters are present. It is hoped that being able to offer this option with confidence will provide Sirius with the ability to offer a more cost effective and therefore competitive approach to contaminated land management and provide a unique service, backed up with a sufficient level of understanding, within the UK remediation marketplace.

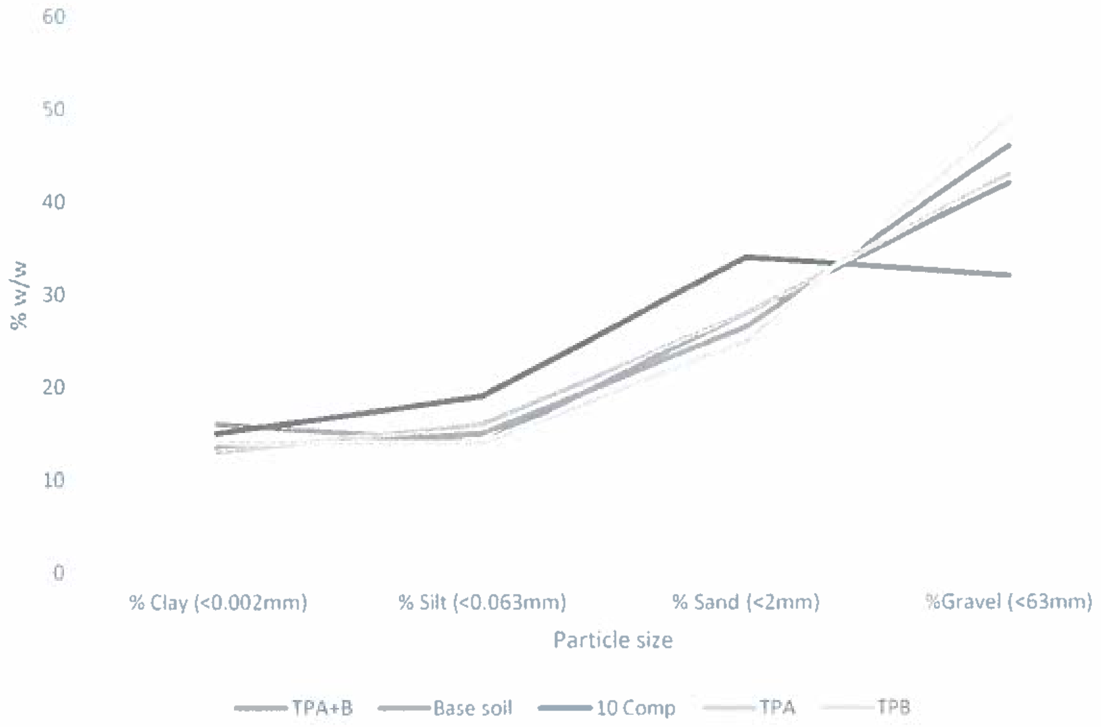
10. Describe the potential for exploiting the work. Please identify any new IP which has been filed or for which filing is anticipated.

Whilst the approaches being used are novel in their intended application, we have not identified and new techniques or products which could be filed as intellectual property. The results obtained will be used as the basis for further research and in supporting the future use of soil engineering techniques in land remediation projects. This technique will add to the range of potential solutions that we can offer to clients for management of their landfill or contaminated land liabilities.

Table 1 – Summary of trial mixes (by dry weight)

Test Plot	Abbreviation	Base soil (%)	Compost (%)	WTR(%)	Sand (%)
A-1	10 Sand	90	-	-	10
A1	15:15 Sand:WTR	70	-	15	15
A2	5:5 Comp:WTR	90	5	5	-
A3	30 WTR	70	-	30	-
A4	Base soil	100	-	-	-
A5	30 Sand	70	-	-	30
A6	10 Comp	90	10	-	-
B1	15:15 Comp:WTR	70	15	15	-
B2	5:5 Sand:WTR	90	-	5	5
B3	15:15 Sand:Comp	70	15	-	15
B4	10 WTR	90	-	10	-
B5	30 Comp	70	30	-	-
B6	5:5 Comp:Sand	90	5	-	5

Figure 1 - Particle size distribution (Compost)



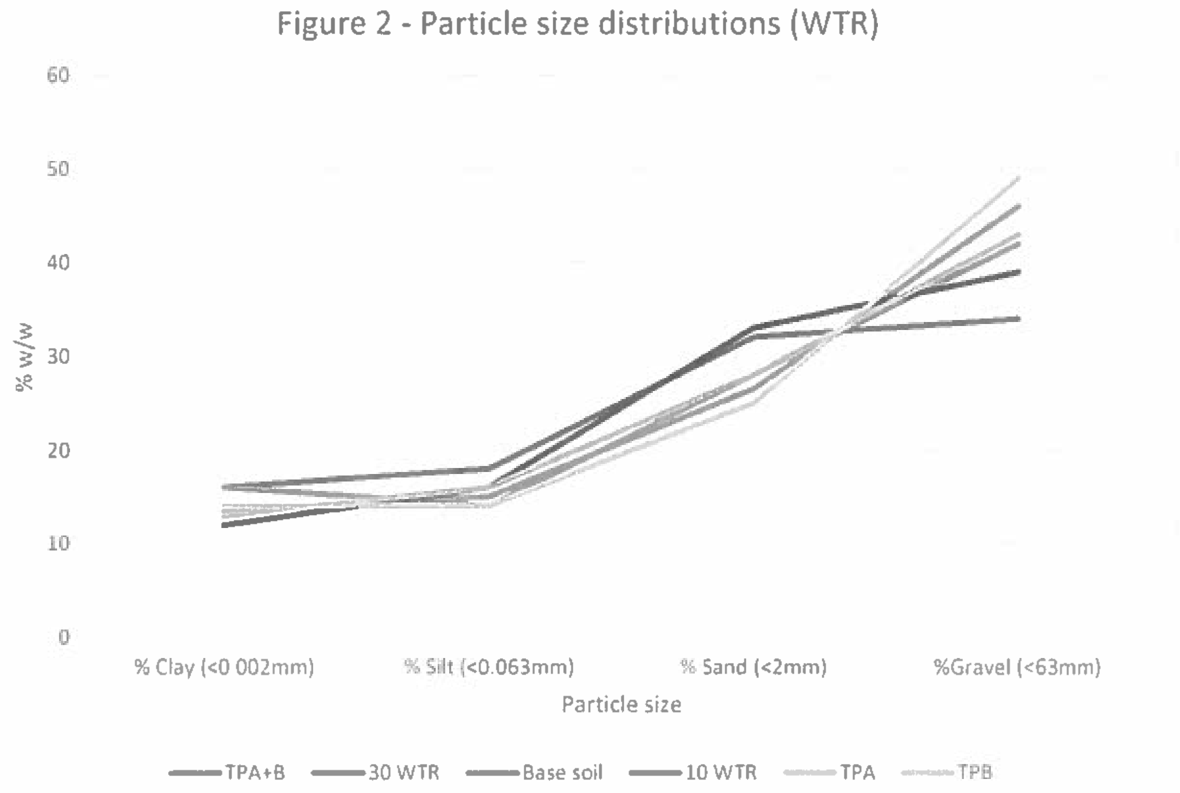


Figure 2 - Particle size distributions (WTR)
60
50
40
30
20
10
0
% w/w
% Clay (<0 002mm)
% Silt (<0.063mm)
% Sand (<2mm)
%Gravel (<63mm)
Particle size
TPA+B
30 WTR
Base soil
10 WTR
TPA
TPB

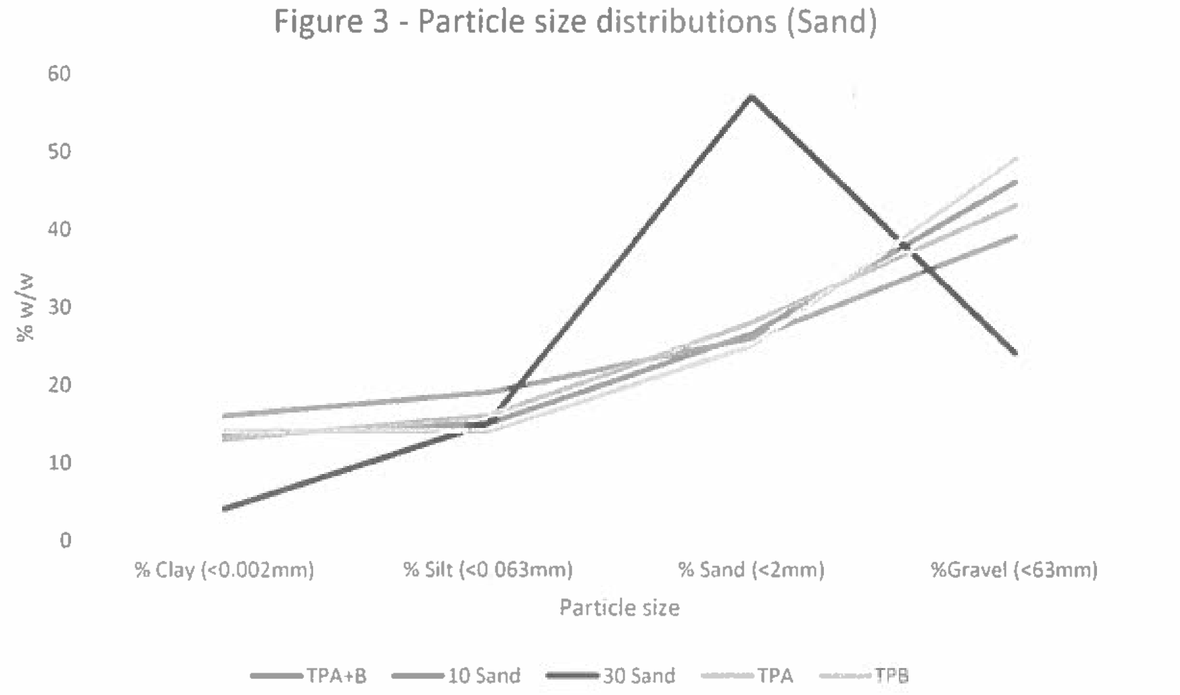


Figure 3 - Particle size distributions (Sand)
60
50
40
30
20
10
0
% w/w
% Clay (<0.002mm)
% Silt (<0 063mm)
% Sand (<2mm)
%Gravel (<63mm)
Particle size
TPA+B
10 Sand
30 Sand
TPA
TPB

Figure 4 - Particle size distributions (Combinations with sand)

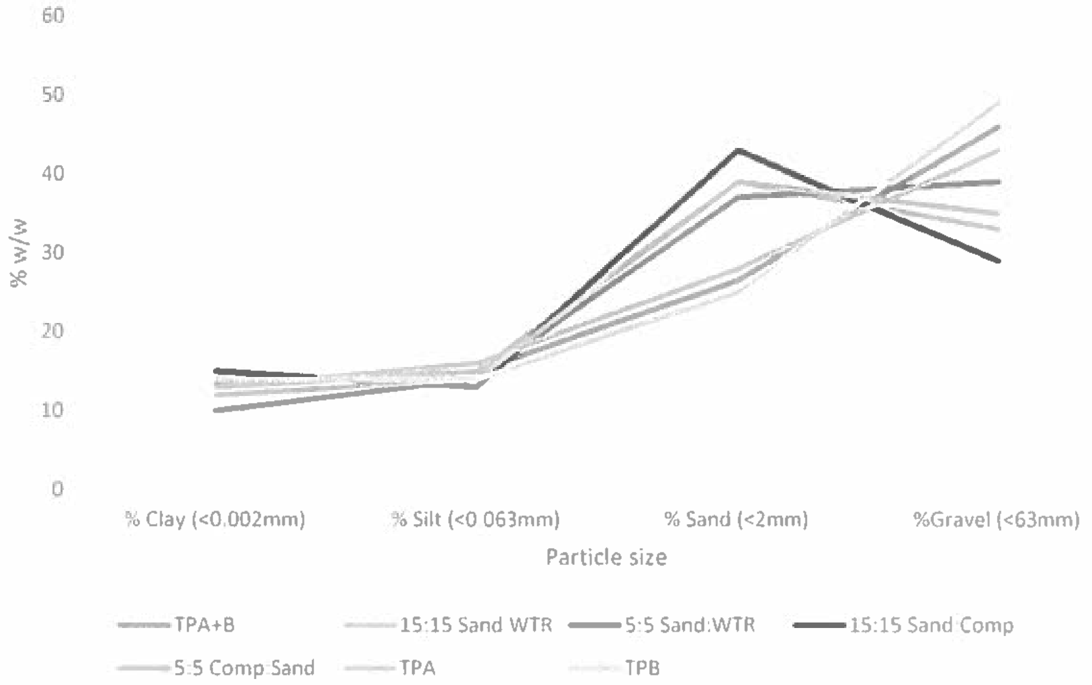


Figure 5 - Particle size distributions (Combinations of compost and WTR)

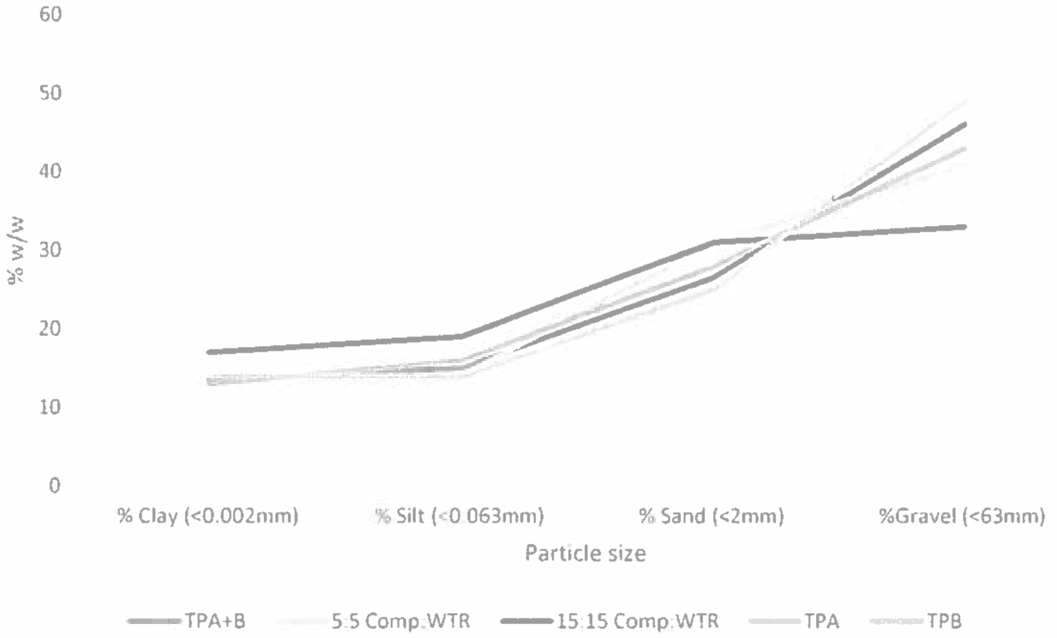


Figure 6 - Bulk density

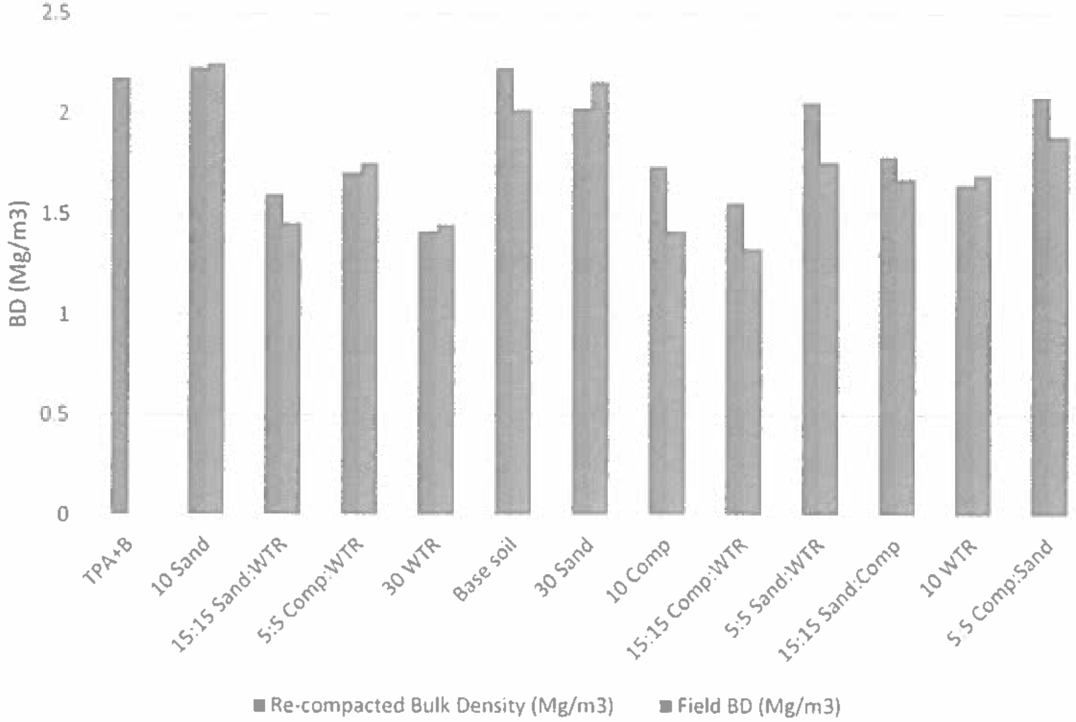


Figure 7 - Permeability

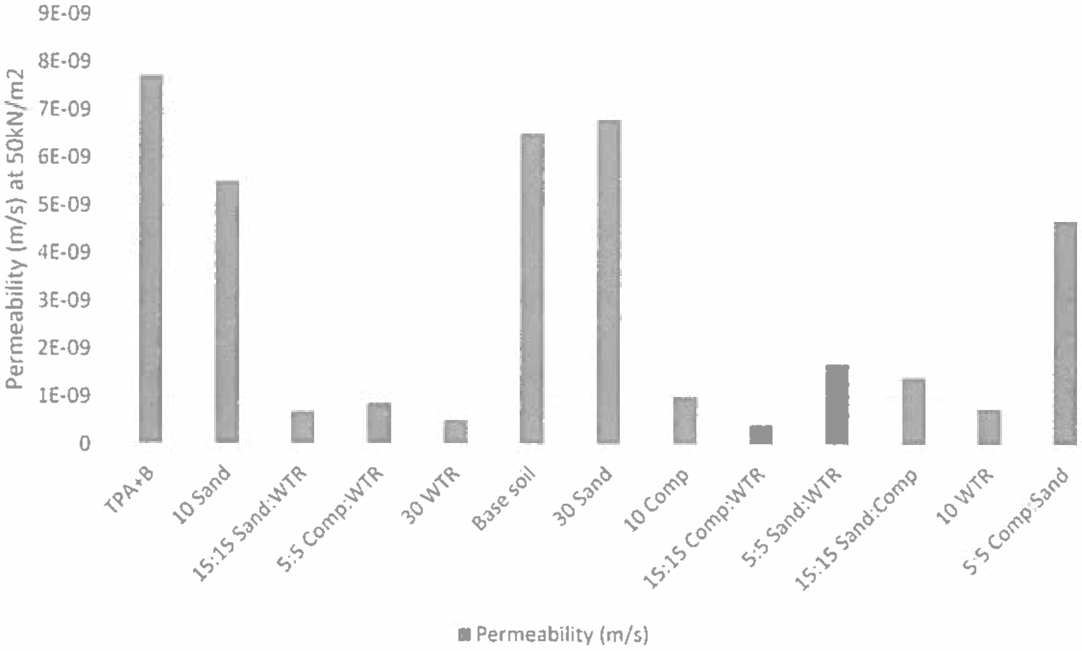


Figure 8 - Available Water Content %w/w

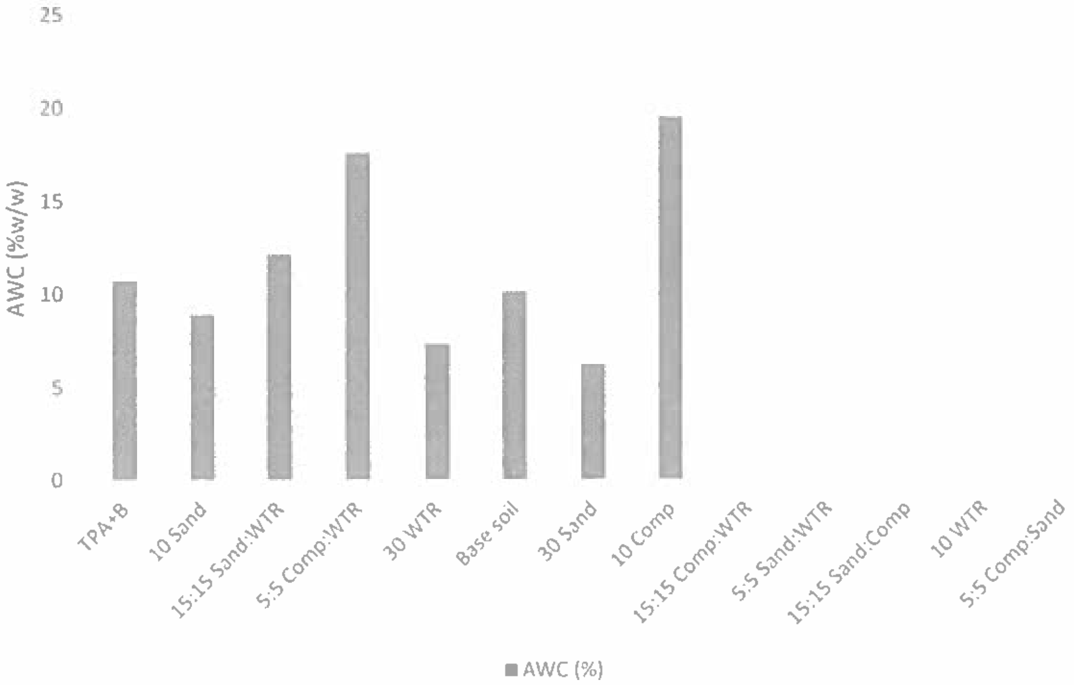


Figure 9 - Available Water Content Mg/m3

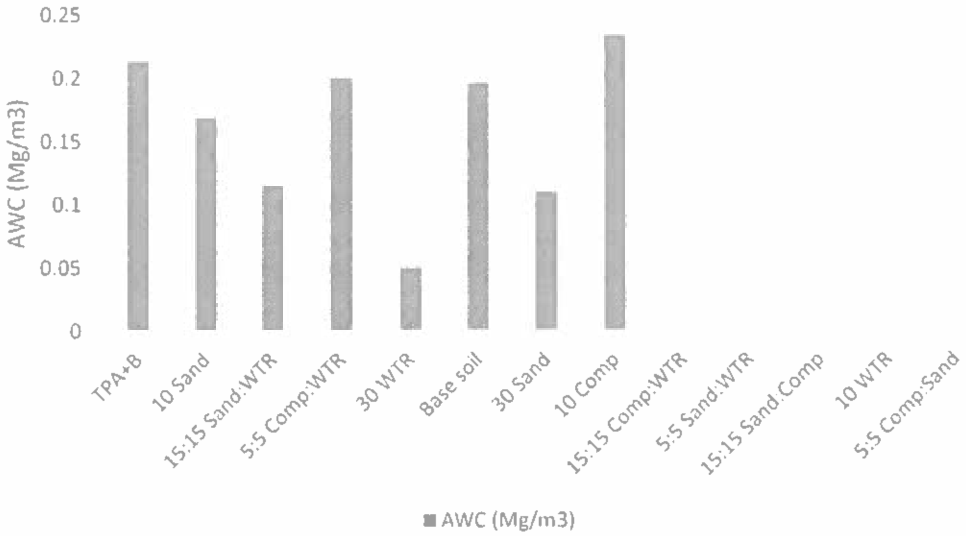


Figure 10 - Nitrogen (%)

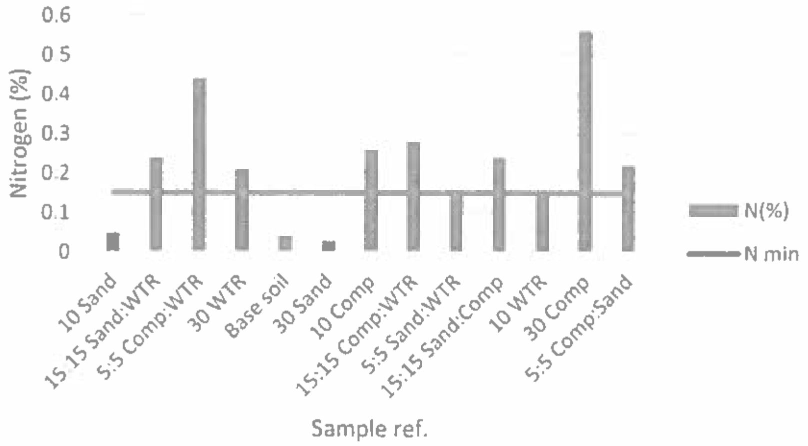


Figure 11 - Phosphorous (extractable mg/l)

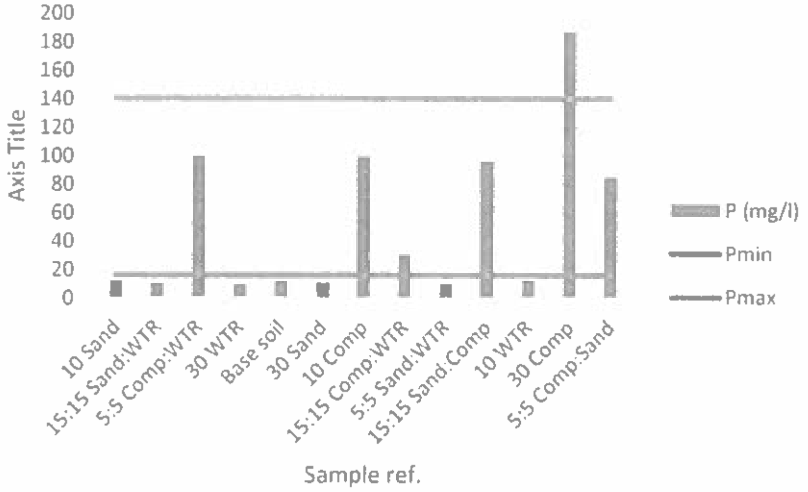
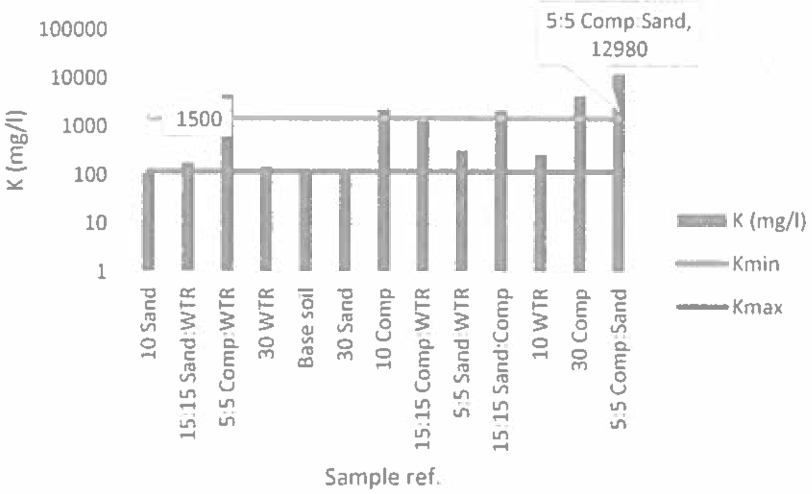


Figure 12 - Potassium (extractable mg/l)



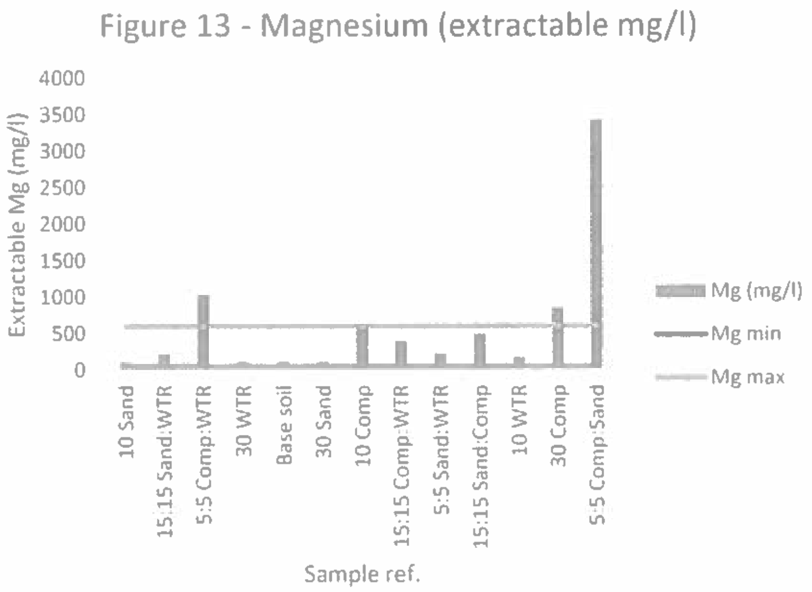


Figure 13 - Magnesium (extractable mg/l)

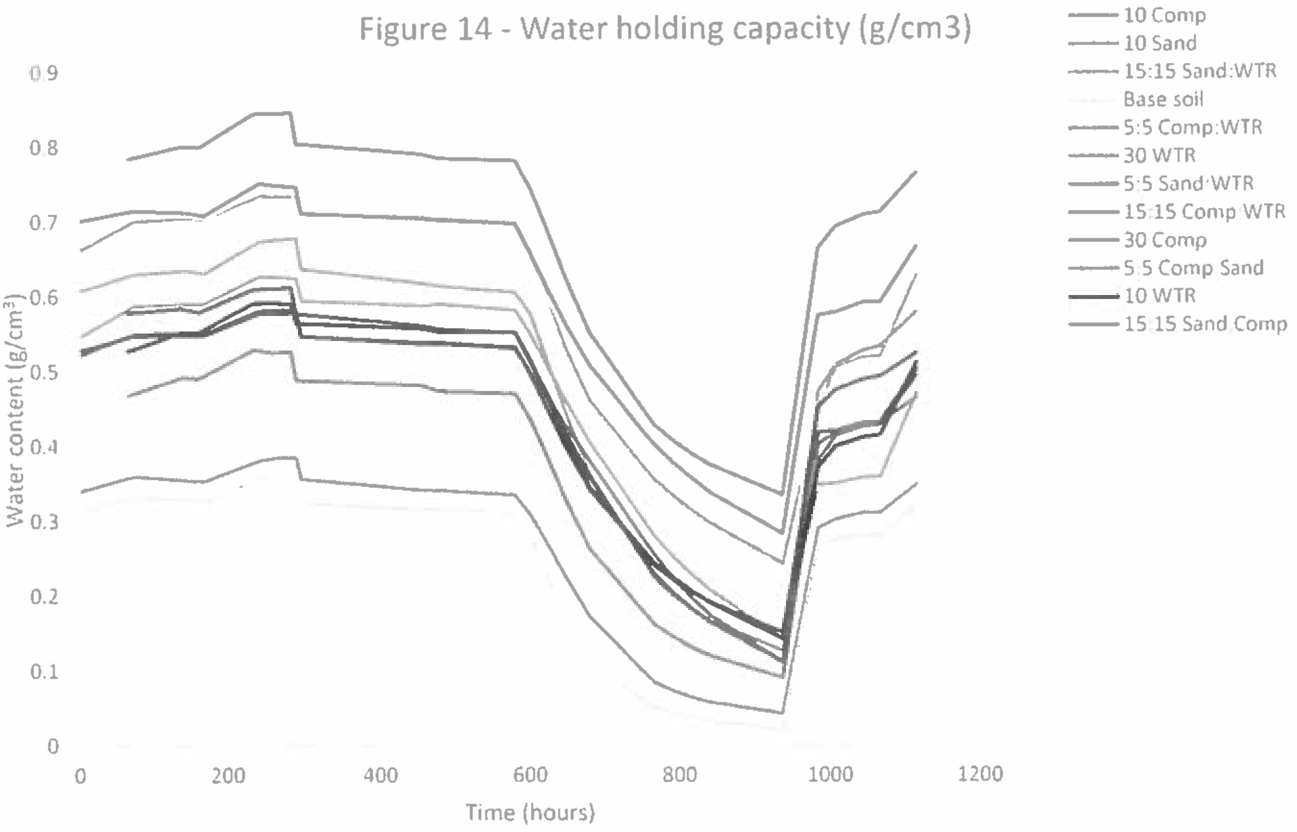


Figure 14 - Water holding capacity (g/cm3)

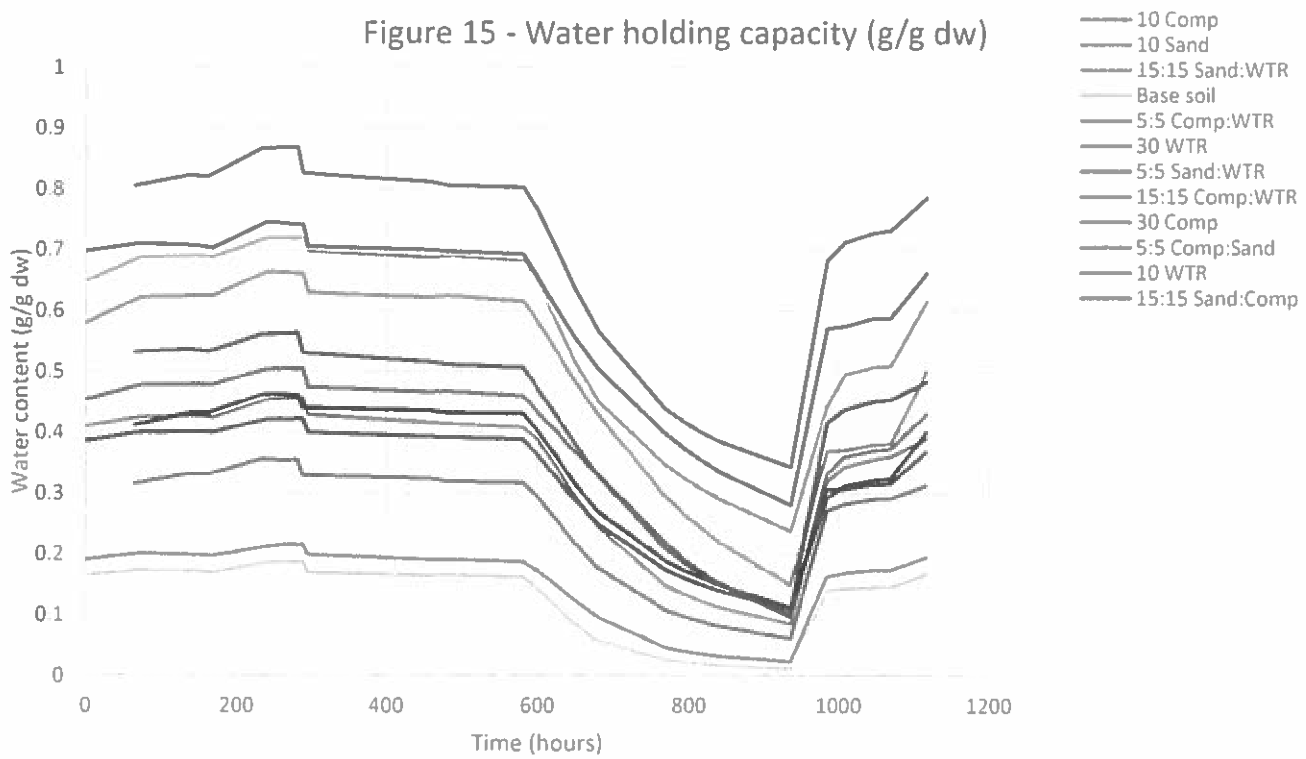


Figure 15 - Water holding capacity (g/g dw)

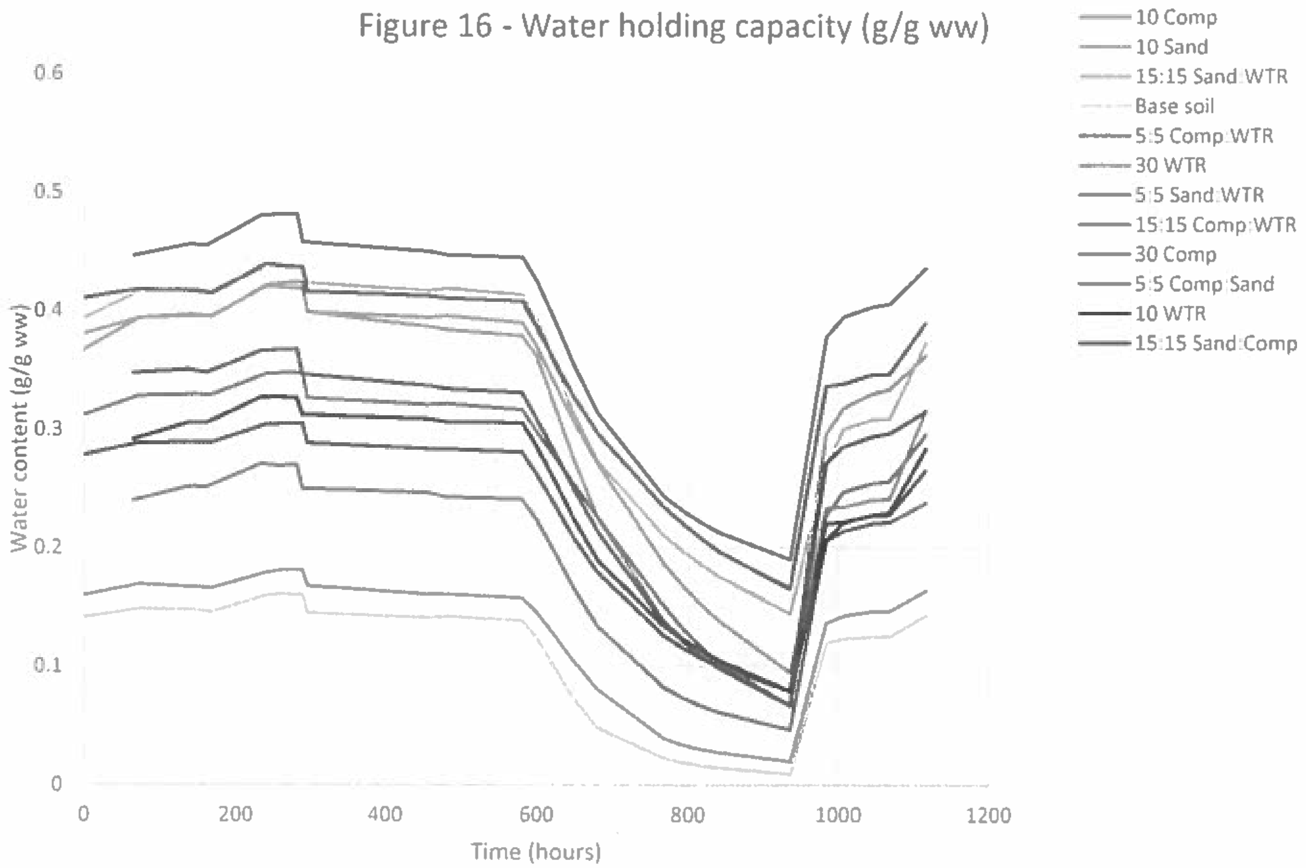


Figure 16 - Water holding capacity (g/g ww)

Figure 17 - Available Water Content results

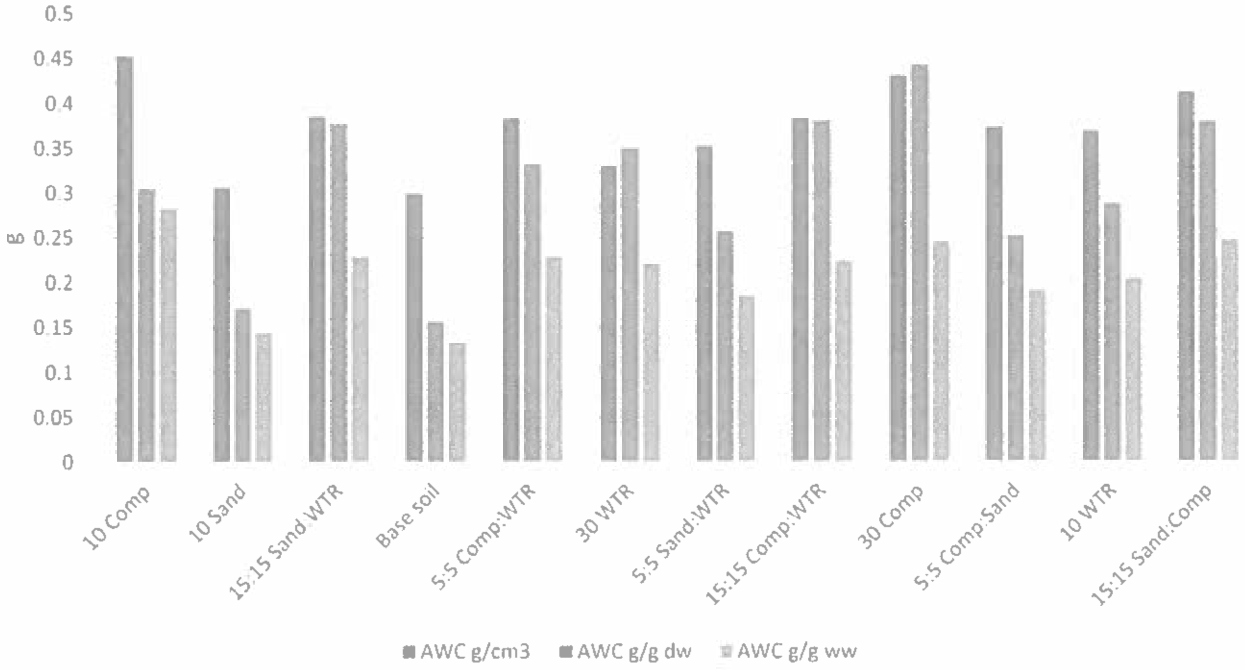


Plate 1 – Mixing of field test plots.

Plate 2 – Completed test plots

Plate 3 – Weighing of core samples for Water Holding Capacity