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# Assessment of marine dredged materials taken from Turkey's ports/harbors in landscaping

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## ABSTRACT

This paper presents the technical usability of marine dredged material (DM) as a manufactured topsoil (MT) in the municipality's landscaping works. In the first part of this study, the physico-chemical and toxicological properties and leaching potentials of DMs taken from two sampling points (Istanbul Ambarlı Port and Mersin Erdemli Fishery Harbor) from Marmara and Mediterranean Sea of Turkey were determined and compared pursuant to the National Legislation. In the second part, various improvement studies such as screening, desalination (washing), dewatering, organic amelioration via peat and sheep manure and pH adjustment were carried out on DM samples in order to transform DMs into an alternative natural soil in compliance with the British Standard BS 3882:2015. A total of five different MT mixtures were prepared; then, soil quality and soil nutrient characteristics were examined. Finally, grass seeds were planted into topsoil mixtures, and plant growth performances were followed for 3 months. The results of this study showed that improved DMs can be beneficially used as an alternative MT in order to cultivate grass in municipality's landscaping applications.

*Keywords:* Beneficial use; Desalination; Dredged material; Organic amelioration; pH adjustment; Topsoil

## 1. Introduction

Dredging is a necessity to excavate or take away sediments from the bottom of marine/fresh waterways in maintaining navigation and developing new ports/harbors [1,2]. Each year, considerable amounts of dredged materials (DMs) are generated around the world, i.e., more than 50 million tons in France [3,4], about 400 million m$^3$ in USA, 40 million m$^3$ in Netherlands [5], 40–50 million m$^3$ in Germany [6], and about 3 million m$^3$ in Turkey.

The management of DMs is a global problem [7]. Traditional options such as dumping at sea cause a physical, chemical and/or biological risk to aquatic nature [8] while upland disposal of DMs is high-priced, needed large spaces and monitoring [9–11]. Therefore, beneficial use alternatives are introduced around the world in order to explore efficient long-term solutions by utilizing DM as a resource for three main purposes [12]: (a) engineering uses, i.e., land improvement, land reclamation, beach nourishment,

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coastal protection, landfill daily cover/liner and capping material; (b) environmental enhancement involving wetland creation/enhancement, sediment cell maintenance; and (c) agricultural/product uses such as manufactured topsoil (MT), construction fill materials, bricks, ceramics, blocks, tiles, lightweight aggregates, and road sub-base [2,7,13–22].

DMs can be transformed into MT mixtures, and application studies of MT instead of highly demanded natural soil in urban landscaping have also gained importance despite MTs' variable characteristics [23]. MT mixtures are mineral-based materials generally comprising high amounts of sandy particles. However, several organic waste-based products (wastepaper, yard waste, wood chips, etc.), biosolids (sewage sludge or animal manure) or peat, which takes place by the accumulation of partially decayed vegetation, are blended with the sandy DM materials of concern in order to enhance the organic matter content of MT. On the other hand, different organic materials show diverse effects on the topsoil mixtures' quality in terms of soil structure, biological processes, nutrient supply-availability and erosion resistance, respectively [24,25]. This composting process ensures the degradation of complex organic matters and allows producing a rich soil [26].

The assessment of technical usability of DMs in landscaping applications should be done pursuant to the national topsoil requirements. Unfortunately, there is no Turkish Standard regarding the topsoil specifications. However, British Standard BS 3882:2015 (latest version) can also be used for this purpose. It is observed that the salinity, pH and organic matter are the most critical parameters for the production of MT due to the fact that marine DMs possess high pH value, high saline content and low organic matter content. Besides, both dewatering and desalination process should be carried out in order to estimate the time for achieving the intended salinity and handling properties. Organic content analysis should be performed in order to investigate the degree of organic improvement for rising plant's seasonal growth while pH analysis should be conducted in order to increase the availability of nutrients for the plant growth [17].

Several laboratory-scale investigations for the production of MT using marine DM have been undertaken up till now. Some of them are as follows: the work on the usability of DM as MT was realized in the University of Strathclyde in Glasgow/Scotland. The full-scale soil factory with a production capacity of 2,000 tons of topsoil per week (£ 5.20/ton topsoil selling price) was established in Clyde/Glasgow [27,28]. In the United States, some national projects were performed in order to produce topsoil for environmental applications. MT of interest obtained from DM has been used in recreational fields in Pearl Harbor, Hawaii, as well as in landscaping applications throughout the city of Toledo, Ohio. In addition, topsoil prepared with DM taken from New York/New Jersey Harbor was assessed in growing wetland plants [13]. Joo et al. [29] focused on the salt-tolerant turf grass re-vegetation on the reclaimed sea sand dredged from the Yellow Sea in order to utilize it at the new Incheon International Airport (The Republic of Korea). Sheehan et al. [17] aimed to investigate the technical feasibility of MT production by mixing DM taken from the Port of Waterford (Ireland) together with household organic waste study conducted by Kim and Pradhan [30] in South Korea also assessed the mechanical and germination characteristics of dredged soil ameliorated with organic matter (humic acid) and stabilizer (slag cement).

A 3-year national research project named "(111G036) Marine Dredging Applications and Environmental Management of Dredged Materials (DIPTAR)" was managed on 01.10.2013–01.10.2016 in order to develop sustainable approach across Turkey for the integrated environmental management of DMs for the first time within the context of dumping at sea, upland disposal and beneficial use. Besides, it is intended to supply sufficient data and knowledge for Ministry of Environment and Urbanization in order to prepare the National Legislation of DM management, which will entry into force at the end of 2016 [31].

As previously denoted, there are several examples and/or practices about the utilization of DMs in various beneficial use areas in worldwide [13,17–22,27,28]. However, beneficial use applications of DMs, especially as MT in landscaping applications, are very insufficient in Turkey, where dumping at sea has been chosen as the most preferred option so far today, followed by upland disposal in low ratios. As it is clearly known, finding new soil supply like DM for plant growth is required when considering the danger of extinction of natural resources at present.

Thus, the objective of this study is to investigate the technical usability of marine DMs from Turkey's Istanbul Ambarlı Port and Mersin Erdemli Fishery Harbor together with local peat and sheep manure in the production of MT for municipality's landscaping applications. Hence, it has a predominant emphasis in inspiring other national beneficial use attempts in Turkey. Furthermore, previous studies have investigated the usage of DM together with the sewage sludge, composts of biowaste, green manure, lime, gypsum and clay minerals as geotechnical soil structure promoter and organic additive for the production of MT [24–26]. In this study, peat and sheep manure were chosen as additives in order to improve the physical structure and organic content of DM in topsoil manufacture.

## 2. Materials and methods

### 2.1. Materials

#### 2.1.1. Dredged materials

DM samples were taken from İstanbul Ambarlı Port (DM-1) and Mersin Erdemli Fishery Harbor (DM-2), which are well known for their broad loading-discharge and fishing activities, with bucket ladder dredger and excavator prior to beneficial use applications, respectively. These sampling points are located in the shores of Turkey, Marmara Sea and Mediterranean Sea, and given in Fig. 1.

#### 2.1.2. Natural soil, peat and sheep manure

Natural soil used as a control specimen was taken from TUBITAK MAM Agriculture Department. Peat was purchased from peat facility in Yeniçağ/Bolu in a pure form in 10-L packages while sheep manure was obtained locally from Gebze-Pelitli Village/Kocaeli in order to ameliorate the organic contents and to improve the physical structures of MTs.

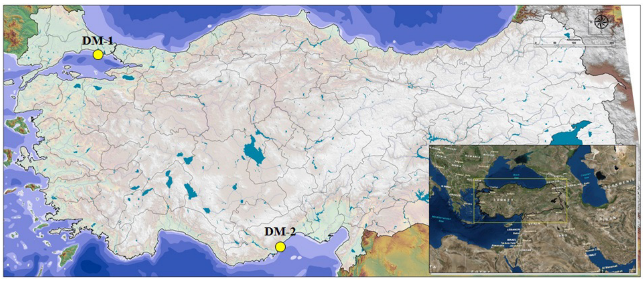

Fig. 1. The sampling points in the shores of Turkey (source: TUBITAK MAM Environment and Cleaner Production Institute Geographic Information System Group).

#### 2.1.3. Grass seed

High-quality lawn seed mixture composed of 20% *Lolium perenne* Stravinsky, 30% *Lolium perenne* TROYA, 35% *Festuca rubra* CORAIL and 15% *Poa pratensis* EVORA was chosen as landscaping grass for both control and MT samples.

### 2.2. Methods

TUBITAK MAM Environment and Cleaner Production Institute laboratories have an international accreditation certificate given by German Accreditation Council DAR/DAP (Deutscher Akkreditierungsrat) since December 17, 2002 and by Turkish Accreditation Agency TURKAK in accordance with TS EN ISO/IEC 17025:2012 standard since July 16, 2010, respectively. In addition, "Measurement and Analysis of Environmental Qualification Certificate" was taken from the Republic of Turkey Ministry of Environment and Urbanization on February 21, 2011. Entire studies conducted within the context of this research were carried out in the above-accredited laboratories.

On the other hand, all physico-chemical, mineralogical and toxicological properties of DMs should be identified pursuant to "The Turkish Waste Management Regulation (AYY)" [32] prior to the selection of beneficial use application, which is obligatory in Turkish Legislation. Besides, leaching potentials of DMs should also be determined in compliance with "The Regulation on the Landfilling of Waste (ADDDY)" [33].

#### 2.2.1. Physico-chemical, mineralogical and toxicological characteristics of DMs

DMs were dried at 105°C for the determination of water/solid content while organic/inorganic matter content was obtained by ignition at 550°C. The pH and electrical conductivity (EC) values were measured with WTW Inolab multimeter. The particle size distributions of DMs were determined through Retsch AS 200 model vibratory sieve shaker (wet sieve analysis) having different sieves (2 mm, 200 μm and 63 μm sized) and hydrometer test. Heavy metal contents of DMs were obtained by PerkinElmer inductively coupled plasma optical emission spectroscopy (ICP-OES) 8300 DV while Dionex ICS-1000 ion chromatography was used for the measurement of anion concentrations. In addition, Fourier transform infrared spectroscopy (FT-IR) and headspace gas chromatography-mass spectrometry (GC-MS) were utilized for the determination of (volatile) organic compounds. Concentrations of dioxins/furans (PCDD/Fs), polyaromatic hydrocarbons (PAHs), total pesticides and tributyltin compounds were measured by chromatographic techniques via GC-high resolution mass spectrometry, GC-MS and liquid chromatography-mass spectrometry-mass spectrometry, respectively. LECO-AC350 bomb calorimeter and LECO Truspec elemental analyzer were used to obtain high heating value (HHV) and total sulfur content. The amounts of total nitrogen, total phosphorus and oil-grease were determined pursuant to the Standard Methods [34]. Quantitative phase-mineralogical analysis of specimens were performed on Shimadzu XRD-2 6000 X-ray diffractometer (XRD), using Cu k$\alpha$ radiation ($\lambda$ = 1.5405Å).

Acute toxicity tests on fish and rat were undertaken in order to identify the ecotoxicological properties of DMs. Ecotoxicity analysis of 24-h extracted DM elutriates (Liquid/Solid: 10 L/kg) was performed using ToxAlert 100 toxicity equipment and bioluminescence bacteria in accordance with ISO/EN/DIN 11348 standard. One to ten diluted aqueous solutions of DMs were subjected to 92/69/EEC Method C.1: "Acute Toxicity for Fish". Acute oral toxicity of DM samples were performed by "OECD TG 423: Acute Toxic Class Method" on laboratory test rat and assessed according to the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (GHS) Part 3 Health Hazards Part 3.1.

#### 2.2.2. Leaching properties of DMs

For the identification of landfill classes, the leach abilities of DMs were examined in accordance with the TS EN 12457–4:2004 [35]. Leaching test was performed for 24 h with a liquid-to-solid ratio of 10, and leachate samples were filtered through Millipore AP40 glass fiber filter. Polychlorinated biphenyls (PCBs); benzene, toluene, ethyl benzene, xylene (BTEX); total organic carbon (TOC); and hydrocarbons were analyzed on the solid matrix while the concentrations of metals, anions, phenol index, dissolved organic carbon (DOC) and total dissolved solids (TDS) were investigated in the leachates, respectively. The contents of TOC and DOC were carried out via TOC-V CPH Shimadzu equipment whereas TDS content was determined gravimetrically.

#### 2.2.3. Soil quality analysis of natural soil, peat, sheep manure and MT samples

The water/solid content was measured with PMB 53 Moisture Analyzer. WTW Inolab multimeter was used in order to determine pH and EC values in dried DM samples by preparing aqueous solutions of solid-to-water weight ratio of 1:5. Both specific gravity and porosity of samples under investigation were obtained according to the TS 3526:1980. The identification of soil textures was carried out with Bouyoucos Hydrometer test method. The contents of TOC, total nitrogen and total phosphorus were specified in compliance with the related Standard Methods [34]. Available macronutrients (Ca, Mg, Na, K) were determined by treating dried DM samples with ammonium acetate solution pursuant to TS 8341:1990 while available micronutrients (Fe, Cu, Zn, Mn, Al) were specified by extracting dried DM samples via diethylenetriaminepentaacetic acid with regard to TS ISO 14870/T1:2009; then, aqueous solutions were measured via PerkinElmer ICP-OES 8300 DV. The content of $CaCO_3$ was obtained with respect to ISO 10693:2014.

### *2.2.4. Plant nutrient concentrations of grass grown in MT samples*

The concentrations of available macronutrients (N, P, K, Ca, Mg and S) and micronutrients (Fe, Cu, Zn, Mn) were also measured on the grasses grown in MT mixtures. Harvested grass samples were dried at 40°C until constant weight. For the identification of nutrient contents (K, Mg, Ca, Fe, Zn, Mn and Cu), dried grass samples were digested in acidic medium ($HNO_3$ + HCl) in Microwave Digestion Device (EPA 3052:1996), and eluates were analyzed using PerkinElmer ICP-OES 8300 DV. Gerhardt Vapodest 50 device and distillation equipment were utilized for total nitrogen analysis (ISO 11261:1996). The amount of sulfur was measured in accordance with ASTM D 4239–05. The content of total phosphorus was determined by using HACH LANGE 3800 spectrophotometer via wet digestion method. All the analysis of samples under investigation were performed with three replicates, and average values were presented with 95% confidence limits.

## 3. Results and discussion

### *3.1. Evaluation of physico-chemical, mineralogical and toxicological characteristics of DMs*

The physico-chemical and toxicological analysis results of DMs in compliance with the “AYY-Appendix 3B: Hazardous waste thresholds limits” [32] are presented in Table 1 together with the standard deviations. DMs are (dark) grey in color and have moderate water content. They show slightly saline and high alkaline nature. They have low organic matter content (1.18%–2.26%), as well as low oil-grease content (<180.0 mg/kg) and low HHV (~10.0 kcal/kg); therefore, they demonstrate inorganic character. Specific gravities of DMs are changed from 2.54 to 2.64 g/cm$^3$, which are almost similar to the specific gravity of silica sand (2.65 g/cm$^3$). DM samples include moderate total nitrogen (113.6–354.5 mg/kg) and total phosphorus (320.0–397.0 mg/kg) contents [36].

Table 1 also illustrates the grain size distributions of DM samples. It is found that DMs are mainly composed of fine and coarse sand with very low contents of silt and clay. DM-1

Table 1
Physico-chemical and toxicological properties of DMs

| Parameters | DM-1 | DM-2 | Methods |
|---|---|---|---|
| Physical properties | | | |
| Color | Dark gray | Gray | Visual |
| Odor | Slightly smelling | Slightly smelling | Sensory |
| Water content (%w) | 26.15 ± 0.34 | 30.59 ± 0.39 | TS 9546 EN 12880:2002 |
| Solid content (%w) | 73.85 ± 0.96 | 69.41 ± 0.90 | |
| pH (aqueous solution (aq.sol.)) | 9.38 ± 0.06 | 8.89 ± 0.06 | TS EN 12176:2009 |
| EC (mS/cm) (aq.sol.) | 2.28 ± 0.05 | 3.48 ± 0.08 | TS ISO 11265:1996 |
| Specific gravity (g/cm$^3$) | 2.64 ± 0.03 | 2.54 ± 0.03 | TS EN 1097-6:2002 |
| Chemical properties | | | |
| Organic matter content (%w) | 2.26 ± 0.01 | 1.18 ± 0.01 | TS 8336:2008 |
| Inorganic matter content (%w) | 71.59 ± 0.47 | 68.23 ± 0.44 | |
| HHV (kcal/kg) (dry basis) | 8.0 ± 2.0 | 12.0 ± 2.0 | ASTM D 5865-13 |
| Total S (%) | 0.06 ± 0.01 | 0.07 ± 0.01 | ASTM D4239-05 |
| Oil-grease (mg/kg) | <180 | <180 | SM-5220 F |
| TOC (mg/kg) | <1,884 | <1,884 | SM-5310 B |
| Total N (mg/kg) | 113.6 ± 3.9 | 354.5 ± 12.1 | SM-4500 N |
| Total P (mg/kg) | 397 ± 10 | 320 ± 8 | SM-4500 P |
| Toxicological properties | | | |
| Ecotoxicity | No toxic effect on marine bacterium *Vibrio fischeri* | | ISO/EN/DIN 11348 |
| Acute toxicity (fish) | No acute risk for fishes | | 92/69/EEC Method C.1. |
| Acute toxicity (rat) | Category 5-GHS 5 or unclassified ($LD_{50}$ > 5,000 mg/kg b.w.) | | OECD TG 423 |
| Sieve analysis | Loamy sand | Sand | |
| Gravel (>2 mm) (%) | 0.95 ± 0.03 | 0.74 ± 0.02 | Wet sieve analysis and hydrometer test (in-house method) |
| Coarse sand (2 mm–200 μm) (%) | 22.87 ± 0.36 | 38.14 ± 0.59 | |
| Fine sand (200 μm–63 μm) (%) | 62.43 ± 0.98 | 58.18 ± 0.91 | |
| Silt (63–2 μm) (%) | 6.83 ± 0.22 | 2.74 ± 0.09 | |
| Clay (<2 μm) (%) | 6.91 ± 0.22 | 0.20 ± 0.01 | |

is a loamy sand soil while DM-2 is a sandy soil in accordance with BS 3882:2015.

In the context of toxicological characteristics, it is observed that DM samples have no toxic effect on marine bacteria *Vibrio fischeri*. Furthermore, there are no acute risk for fishes and rat ($LD_{50}$ > 5,000 mg/kg b.w.), but chronic effects were not considered in this study.

According to the FT-IR analysis performed in hexane-extracted organic phase of DM samples, there are no any appreciable peaks observed on FT-IR spectra. Besides, no considerable volatile organic compounds were found in headspace GC-MS analysis. As it can be seen, FT-IR and GC-MS analysis results confirmed the low organic content of DM-1 and DM-2. On the other hand, analysis results for persistent organic pollutants (POPs) of PCDD/F, PAH, PCB and total pesticides were determined as 0.032–0.049 ng/kg I-TEQ, 0.098–0.114 mg/kg, <0.1–0.5 mg/kg and <0.005 mg/kg, respectively. POPs are classified as Carc. Cat. 3: R40 (H7), Carc. Cat. 1 and 2: R45 (H7), Repr. Cat. 1 and 2: R61 (H10), Xn: R20/21/22 (H5), Xi: R36/37/38 (H4), and N: R50/53 (H14) giving thresholds of 1%, 0.1%, 0.5%, 25%, 20%, and 0.25% (w/w), respectively [32,37]. Considering the potential worst case for these threshold levels of POPs, it is seen that POPs' concentrations are below the threshold limits and DM samples indicate non-hazardous character in terms of organic matter content in compliance with the AYY-Appendix 3B hazardous waste threshold limits.

Detailed information about the chemical compositions of DMs in terms of weight percentages is presented in Table 2 with the combination of risk phrases and dangerous/hazardous properties. Mineralogical analysis results demonstrate that quartz, feldspar, illite and calcite are dominant minerals found in DM-1 while calcite, quartz and feldspar minerals are commonly presented in DM-2. Hematite ($Fe_2O_3$) and forsterite ($Mg_2SiO_4$) minerals in DM samples are H4-irritant (Xi) having a risk code of R36/37/38 (irritating to eyes, respiratory system and skin). However, the AYY-Appendix 3B: hazardous waste threshold limit for R36/37/38 is 20%; therefore, contents of these minerals do not exceed the limit value [32]. It is observed that DM samples also indicate non-hazardous character in terms of inorganic matter content. Due to the risk code of R48/20 (harmful: serious health damage by prolonged exposure via inhalation) for quartz and R37/38–41 (irritating to respiratory system and skin, risk of serious damage to eyes) for calcite, a dust mask/respirator and eye/face protection should be worn in case of contacting with DMs.

On the other hand, heavy metal levels of DMs should not exceed the national limit values in urban landscaping applications; otherwise, DMs must be treated prior to beneficial use as indicated in other studies [38,39]. Heavy metal analysis results of DMs obtained by ICP-OES are reported in Table 3 together with standard deviations, AYY-Appendix 3B limit values, categories of danger classes, risk phrases and hazards. It is seen that all DMs under investigation possess very low heavy metal contents that do not lead to any environmental hazard pursuant to AYY limits. Thus, it is clear that DM samples indicate non-hazardous character in terms of organic and inorganic matter content.

Consequently, characterization results presented that both DMs can be defined as "non-hazardous waste" with a waste code of 17 05 06 (dredging spoil other than 17 05 05). Except remediation purposes for the significant contamination, waste materials originated from dredging works would usually be classified as non-hazardous according to the chemical criteria of the European Waste Catalogue [40,41]. As it is known, DMs are bulk materials taken by dredgers from ports/harbors that differ from sedimentary materials where sediments are generally the deposited layers of top 5 cm across the seabed. Even if some degree of contamination is observed in the sediment layer caused by intensive port/harbor activities, the dilution of this kind of

Table 2
Chemical compositions of DMs

| Chemical composition, % | Methods | DM-1 | DM-2 | Category of danger, risk phrase(s) and hazards | AYY-App.3B hazardous waste threshold limit values |
|---|---|---|---|---|---|
| Quartz, $SiO_2$ | XRD Rietveld analysis (in-house method) | 40.4 | 16.2 | Xn, T: R48/20 (–) | 25% |
| Illite, $(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$ | | 16.8 | 4.7 | – | – |
| Feldspar | | 25.5 | 11.4 | – | – |
| Calcite, $CaCO_3$ | | 13.7 | 44.8 | Xi: R41 (H4) | 10% |
| | | | | Xi: R37/38 (H4) | 20% |
| Hematite, $Fe_2O_3$ | | 2.1 | 4.5 | Xi: R36/37/38 (H4) | 20% |
| Calcium iron oxide chloride, $CaFeClO_2$ | | ND | 2.2 | – | – |
| Forsterite, $Mg_2SiO_4$ | | ND | 1.9 | Xn: R20 (H5) | 25% |
| | | | | Xi: R36/37/38 (H4) | 20% |
| Lizardite, $Mg_3Si_2O_5(OH)_4$ | | ND | 9.8 | – | – |
| Diopside, $CaMg(SiO_3)_2$ | | ND | 4.5 | – | – |
| Carnallite, $KMgCl_3 \cdot 6(H_2O)$ | | 1.5 | ND | – | – |

Note: ND – not detected.

Table 3
Heavy metals analysis results of DMs

| Heavy metals | Methods | DM-1 | DM-2 | Category of danger, risk phrase(s) and hazards | AYY-App.3B hazardous waste threshold limit values |
|---|---|---|---|---|---|
| Pb | ISO 11885 | 0.00118 ± 0.00007 (%) | 0.00354 ± 0.00021 (%) | (–): R33 (–) | – |
| | | | | Repr. Cat. 1 and 2: R61 (H10) | 0.5% |
| | | 11.8 ± 0.7 (mg/kg) | 35.4 ± 2.1 (mg/kg) | Repr. Cat. 3: R62 (H10) | 5% |
| | | | | Xn: R20/22 (H5) | 25% |
| | | | | T+: R26/27/28 (H6) | 0.1% |
| | | | | N: R50/53 (H14) | 0.25% |
| Cd | ISO 11885 | <0.000010 (%) | 0.000017 ± 0.000001 (%) | T+: R26 (H6) | 0.1% |
| | | | | Carc. Cat 1 and 2: R45 (H7) | 0.1% |
| | | <0.10 (mg/kg) | 0.17 ± 0.01 (mg/kg) | Repr. Cat. 3: R62, R63 (H10) | 5% |
| | | | | Muta. Cat. 3: R68 (H11) | 1% |
| | | | | Xn, T: R48/23/25 (–) | 3% |
| | | | | N: R50/53 (H14) | 0.25% |
| Cr | ISO 11885 | 0.0085 ± 0.0003 (%) | 0.0111 ± 0.0004 (%) | F: R11 (H3A) | - |
| | | | | Carc. Cat. 3: R40 (H7) | 1% |
| | | 85 ± 3 (mg/kg) | 111 ± 4 (mg/kg) | N: R52 (H14) | 25% |
| Cu | ISO 11885 | 0.0015 ± 0.0001 (%) | 0.0046 ± 0.0004 (%) | F: R11 (H3A) | - |
| | | | | N: R52 (H14) | 25% |
| | | 15 ± 1 (mg/kg) | 46 ± 4 (mg/kg) | Xi: R36/37/38 (H4) | 20% |
| Ni | ISO 11885 | 0.0037 ± 0.0002 (%) | 0.0055 ± 0.0004 (%) | Carc. Cat. 3: R40 (H7) | 1% |
| | | | | Xi: R43 (H13) | 1% |
| | | 37 ± 2 (mg/kg) | 55 ± 4 (mg/kg) | Xn, T: R48/23 (-) | 3% |
| | | | | N: R52/53 (H14) | 25% |
| Zn | ISO 11885 | 0.0042 ± 0.0002 (%) | 0.0077 ± 0.0004 (%) | F: R15, R17 (H3A) | 0.3% |
| | | 42 ± 2 (mg/kg) | 77 ± 4 (mg/kg) | N: R50/53 (H14) | 0.25% |
| Hg | EPA 7473 | 0.0000030 ± 0.0000005 (%) | 0.0000090 ± 0.0000013 (%) | T+: R26 (H6) | 0.1% |
| | | | | Repr. Cat. 1 and 2: R61 (H10) | 0.5% |
| | | 0.030 ± 0.005 (mg/kg) | 0.090 ± 0.013 (mg/kg) | Xn, T: R48/23 (-) | 3% |
| | | | | N: R50/53 (H14) | 0.25% |
| As | ISO 11885 | 0.00080 ± 0.00007 (%) | 0.00130 ± 0.00011 (%) | T: R23/25 (H6) | 3% |
| | | 8.04 ± 0.68 (mg/kg) | 12.96 ± 1.11 (mg/kg) | N: R50/53 (H14) | 0.25% |

contamination within the huge amounts of DMs will be possible. The non-hazardous characteristics of all representative 15 DM samples determined in the context of national DIPTAR project confirmed this non-polluting features of DM samples even though they were dredged from different ports/harbors across Turkey having intensive anthropogenic activities [31].

### 3.2. Environmental effects of DMs

The leachabilities of DM-1 and DM-2 samples were identified in Table 4 with the standard deviations in compliance with the principles of "TS EN 12457–4:2004 [35] leaching test" and "ADDDY-Appendix 2 criteria" [33]. The eluate concentrations of $Cl^-$, $SO_4^{2-}$ and TDS were found above the limits of Class III (inert waste) landfilling criteria. It is clear that high $Cl^-$, $SO_4^{2-}$ and TDS contents for the materials originated from marine environment are acceptable [42].

### 3.3. Physico-chemical characteristics of natural soil, peat and sheep manure

At present, the mixture of natural soil, peat and sheep manure has been widely used in urban landscaping applications in Turkey. Thus, physico-chemical properties of natural soil, peat and sheep manure with respect to the "soil quality" were also determined and are pointed out in Table 5. Natural soil was used as control sample while peat and sheep manure were preferred as soil conditioner and organic improver in MT mixtures. It is clear that peat and sheep manure are rich in terms of organic content, macronutrients and micronutrients.

### 3.4. Preparation and assessment of MT samples

Due to the fact that raw DMs showed moderate water content, slightly saline and high alkaline nature, low total nitrogen, low organic matter content and high C/N ratio pursuant to

Table 4
Leachabilities of DMs and "ADDDY-Appendix 2" quality criteria

| Parameters | DM-1 | DM-2 | Inert waste (Class III) | Nonhazardous waste (Class II) | Hazardous waste (Class I) | Methods |
|---|---|---|---|---|---|---|
| Leachate (Liquid/Solid = 10 L/kg) | | | | | | |
| As (mg/L) | 0.013 | 0.003 | 0.05 | 0.2 | 2.5 | EPA 6020A:2007 |
| Ba (mg/L) | 0.047 ± 0.004 | 0.018 ± 0.002 | 2 | 10 | 30 | |
| Cd (mg/L) | <0.00010 | <0.0010 | 0.004 | 0.1 | 0.5 | |
| Cr (mg/L) | <0.001 | <0.001 | 0.05 | 1 | 7 | |
| Cu (mg/L) | 0.0080 ± 0.0007 | 0.0080 ± 0.0007 | 0.2 | 5 | 10 | |
| Hg (mg/L) | <0.00013 | <0.00013 | 0.001 | 0.02 | 0.2 | SM-3112 |
| Mo (mg/L) | 0.0060 ± 0.0003 | 0.0070 ± 0.0004 | 0.05 | 1 | 3 | EPA 6020A |
| Ni (mg/L) | 0.0017 ± 0.0002 | 0.0050 ± 0.0006 | 0.04 | 1 | 4 | |
| Pb (mg/L) | 0.0011 ± 0.0002 | 0.0008 ± 0.0001 | 0.05 | 1 | 5 | |
| Sb (mg/L) | 0.0025 ± 0.0006 | 0.0008 ± 0.0002 | 0.006 | 0.07 | 0.5 | |
| Se (mg/L) | 0.0028 ± 0.0006 | 0.0011 ± 0.0003 | 0.01 | 0.05 | 0.7 | |
| Zn (mg/L) | <0.005 | 0.0070 ± 0.0004 | 0.4 | 5 | 20 | |
| $Cl^-$ (mg/L) | 601 ± 33 | 1,000 ± 54 | 80 | 1,500 | 2,500 | SM-4110B |
| $F^-$ (mg/L) | 0.20 ± 0.01 | 0.97 ± 0.05 | 1 | 15 | 50 | |
| $SO_4^{2-}$ (mg/L) | 103.0 ± 1.1 | 155.4 ± 1.7 | 100 | 2,000 | 5,000 | |
| DOC (mg/L) | <0.5 | 1.5 ± 0.1 | 50 | 80 | 100 | SM-5310B |
| TDS (mg/L) | 1,204 ± 23 | 2,006 ± 24 | 400 | 6,000 | 10,000 | SM-2540C |
| Phenol (mg/L) | <0.07 | <0.07 | 0.1 | – | – | SM-5530D |
| Solid matrix | | | | | | |
| TOC (mg/kg) | <1,884 | <1,884 | 30,000 | 50,000 (5%) | 60,000 | SM-5310B |
| BTEX (mg/kg) | <0.5 | <0.5 | 6 | – | – | EPA 8015C |
| PCBs (mg/kg) | <0.10 | 0.49 ± 0.04 | 1 | – | – | ISO 10382 |
| Hydrocarbons (mg/kg) | 79.3 ± 1.1 | <65.0 | 500 | – | – | BS EN 14039:2004 |
| LOI (%) | <2.30 | 4.11 ± 0.06 | – | – | 100,000 | TS EN 12879:2003 |

"BS 3882:2015-Topsoil specifications", they are inadequate for plant growth; thus, DMs require significant pre-treatment procedure for MT production. First, debris greater than 5 mm was removed by screening, and both DM samples were split into two portions before desalination in order to observe the effect of salinity on plant growth. One portion of DMs was subjected to washing procedure at 170 rpm for 5 min. with KIKI-WERK HS 501 horizontal shaker in order to reduce EC value below 2 mS/cm, which is appropriate level for plant germination. Washed DMs were filtered using a Buchner funnel; thus, dewatered. Another portion of DMs was left as saline for comparison. Then, physical properties and organic contents of both washed/unwashed DMs were ameliorated through addition of peat and sheep manure. Compositions of MT samples representing the current mixture ratios used for landscaping in Turkey are illustrated in Table 6. A control mixture (without DMs) was also prepared by blending peat and sheep manure together with natural soil in order to compare the plant growth performances. Each mixture was prepared as a total of 1,800 mL in (9.5 × 20.0 cm) rectangular prism-shaped pots. Because of high alkaline characteristics of DMs, the pH levels of topsoil mixtures were reduced by the addition of 30 g $FeSO_4.2H_2O$ to each pot in order to provide the target neutral pH range (6.50–7.50) for potential nutrient availability. Similar processes were also used for the topsoil production by Sheehan et al. [17].

The soil quality analysis results of the entire MT samples are pointed out in Table 7. Based on BS 3882:2015 topsoil specifications, it is observed that the soil textures of MT samples are generally sandy loam and loamy sand. Besides, all MTs have neutral pH (6.50–7.50), and their organic contents are quite high (10%–16%) due to the addition of sheep manure. They are rich in terms of macronutrients and micronutrients in order to sustain plant growth, while total nitrogen and total phosphorus concentrations are also too high. It is seen that solid contents of MT samples are in the range of 49.58%–62.32%. In addition, MT mixtures with washed DMs have low EC values (0–2 mS/cm [salt-free]), whereas MT mixtures containing unwashed DMs are slightly salty (EC 2–4 mS/cm). It is clear that EC is a signal for the amount of dissolved salts where these salts can cause a decrease in plant germination and growth [43].

### *3.5. Plant growth trials*

1.0 g of high-quality lawn seed mixture was planted into each pot of 2.5 cm below the soil surface, and the plants were irrigated with the same volume (50 mL) of tap water periodically. Grass growth performances were monitored daily on the basis of the following parameters: number of germinated seeds, germination rate (%), average and total

Table 5
Soil quality analysis results for natural soil, peat and sheep manure

| | Natural soil | Peat | Sheep manure | Methods |
|---|---|---|---|---|
| Physical properties | | | | |
| Color | Brick red | Brown | Dark brown | Visual |
| Water content (w%) | 5.05 ± 0.07 | 30.32 ± 0.39 | 60.34 ± 3.20 | TS 9546 EN 12280:2002 |
| pH (aq.sol.) | 7.88 ± 0.06 | 7.35 ± 0.05 | 7.63 ± 0.06 | TS ISO 10390:2013 |
| EC (mS/cm) (aq.sol.) | 0.35 ± 0.01 | 3.66 ± 0.08 | 1.83 ± 0.04 | TS ISO 11265:1996 |
| Specific gravity (g/cm$^3$) | 2.50 ± 0.03 | 1.33 ± 0.02 | 0.85 ± 0.01 | TS 3526:1980 |
| Porosity (%) | 59.20 ± 1.26 | 61.65 ± 1.31 | 54.12 ± 1.15 | |
| Soil texture | Sandy loam | Clay | Clay | ASTM D422-63:2007 |
| Sand (%) | 74.05 ± 2.38 | 24.47 ± 0.38 | 30.45 ± 0.49 | |
| Silt (%) | 10.98 ± 0.17 | 11.36 ± 0.18 | 8.12 ± 0.13 | |
| Clay (%) | 14.97 ± 0.24 | 64.17 ± 2.07 | 61.43 ± 1.98 | |
| Chemical properties | | | | |
| Organic matter content (w%) | 2.61 ± 0.02 | 37.68 ± 0.24 | 28.70 ± 0.19 | TS 8336:2008 |
| LOI (%) | 3.37 ± 0.01 | 26.95 ± 0.08 | 21.37 ± 0.06 | TS EN 12879:2003 |
| TOC (mg/kg) | 7,690 ± 500 | 19,167 ± 1,246 | 211,496 ± 13,747 | SM-5310 B |
| Total N (mg/kg) | 687 ± 17 | 10,700 ± 266 | 24,234 ± 603 | SM-4500 N |
| Total P (mg/kg) | 481 ± 13 | 2,253 ± 59 | 5,543 ± 145 | SM-4500 P |
| Lime content (%) | 1.19 ± 0.03 | 1.36 ± 0.04 | 1.29 ± 0.03 | TS EN ISO 10693:2014 |
| Available macronutrients | | | | |
| Ca (mg/kg) | 24,760 ± 644 | 7,661 ± 199 | 9,121 ± 237 | TS 8341:1990 |
| Mg (mg/kg) | 216 ± 4 | 519 ± 10 | 1,805 ± 36 | |
| Na (mg/kg) | 61 ± 2 | 320 ± 8 | 175 ± 5 | |
| K (mg/kg) | 225 ± 6 | 1,865 ± 50 | 1,582 ± 43 | |
| Available micronutrients | | | | |
| Fe (mg/kg) | 1.800 ± 0.027 | 25.420 ± 0.386 | 6.589 ± 0.100 | TS ISO 14870/T1:2009 |
| Cu (mg/kg) | 0.246 ± 0.021 | 0.617 ± 0.052 | 0.641 ± 0.054 | |
| Zn (mg/kg) | 1.117 ± 0.064 | 4.292 ± 0.124 | 17.650 ± 1.008 | |
| Mn (mg/kg) | 1.307 ± 0.020 | 0.525 ± 0.008 | 4.735 ± 0.071 | |
| Al (mg/kg) | 0.288 ± 0.008 | 0.220 ± 0.007 | <0.050 | |

Table 6
Compositions of MT samples

| Sample codes | Mixture compositions (v/v) |
|---|---|
| Control | Natural soil 33% + peat 33% + sheep manure 33% |
| Mixture – X1 | DM-1 (unwashed) 33% + peat 33% + sheep manure 33% |
| Mixture – X2 | DM-1 (washed) 33% + peat 33% + sheep manure 33% |
| Mixture – Y1 | DM-2 (unwashed) 33% + peat 33% + sheep manure 33% |
| Mixture – Y2 | DM-2 (washed) 33% + peat 33% + sheep manure 33% |

growth height (cm/d) and grass health (visual and by photography). Germination was occurred within 2–3 weeks, and grasses were harvested 5 cm above the soil surface at once a month. Average and total harvest height (cm), biomass production (kg/m$^2$) and leaf color are also recorded at each harvest. Plant growth trials conducted in this study are presented in Fig. 2.

Plant growth performances was monitored during 90 d, and a total of three harvests were carried out for each mixture. The germination success rates for all MT samples are illustrated in Fig. 3.

It is observed that control sample has a maximum seed germination rate of 92.5% as expected. Mixture – Y2 and Mixture – X2 comprising washed DMs have better germination rates (74.8% and 66.4%) than those of Mixture – Y1 and Mixture – X1 (48.3% and 53.5%) having unwashed DMs. It is a known fact that salt existence in the soil can increase the osmotic potential of soil and decrease the plant product efficiency since it becomes much more difficult for plants to uptake water and nutrients from saline soils [43]. These results are also compatible with Sheehan et al. [17].

Fig. 4 demonstrates the average and total height of grasses in MT samples after each harvest under investigation. It is seen that total and average harvest heights of entire MT mixtures increase dramatically in the second harvest while growth heights decrease partially in the third

Table 7
Soil quality analysis results for MT samples

| Parameters | | Methods | Control | Mixture | | | | References for limit values |
|---|---|---|---|---|---|---|---|---|
| | | | | X1 | X2 | Y1 | Y2 | |
| Solid content (%w) | | TS 9546 EN 12880:2002 | 62.32 (0.81) | 56.95 (0.74) | 57.80 (0.75) | 49.58 (0.64) | 52.79 (0.69) | – |
| pH (aq.sol.) | | TS ISO 10390:2013 | 7.22 (0.05) | 7.36 (0.05) | 7.39 (0.05) | 7.42 (0.05) | 7.45 (0.05) | [44] |
| EC (mS/cm) (aq.sol.) | | TS ISO 11265: 1996 | 1.43 (0.03) | 2.89 (0.07) | 1.98 (0.05) | 3.36 (0.08) | 1.95 (0.05) | [45] |
| Saturation (%) | | TS 8333:1990 | 31.27 (0.70) | 43.16 (0.99) | 39.12 (0.90) | 38.22 (0.87) | 42.09 (0.97) | – |
| Total salt (%) | | TS 8333:1990 | 0.034 (0.001) | 0.062 (0.002) | 0.063 (0.002) | 0.114 (0.003) | 0.060 (0.002) | [44] |
| Soil texture | | ASTM D422-63: 2007 | Sandy loam | Sandy loam | Sandy loam | Loamy sand | Loamy sand | [46] |
| Sand (%) | | | 67.80 (1.06) | 72.43 (1.14) | 73.89 (1.16) | 84.67 (1.33) | 84.91 (1.33) | |
| Silt (%) | | | 24.09 (0.78) | 21.69 (0.70) | 22.45 (0.72) | 7.45 (0.24) | 8.22 (0.26) | |
| Clay (%) | | | 8.04 (0.26) | 6.82 (0.22) | 3.66 (0.12) | 7.88 (0.25) | 6.87 (0.22) | |
| Porosity (%) | | FAO (2010) | 60.13 (1.27) | 50.50 (1.07) | 50.50 (1.07) | 49.57 (1.05) | 54.39 (1.15) | – |
| Organic content (%) | | TS 8336:2008 | 15.41 (0.10) | 15.17 (0.10) | 10.73 (0.07) | 13.6 (0.09)) | 15.22 (0.10) | [47] |
| Total N (mg/kg) | | ISO 11261:1996 | 5,891 (147) | 5,841 (145) | 5,236 (130) | 5,914 (147) | 5,882 (146) | [48] |
| Total P (mg/kg) | | Olsen Method (1982) | 1,784 (46) | 2,305 (59) | 1,365 (35) | 2,147 (55) | 2,053 (53) | |
| Available potassium ($K_2O$ kg/da) | | TS 8341:1990 | 377 (8) | 468 (10) | 318 (7) | 590 (12) | 446 (9) | [47] |
| Available phosphorus ($P_2O_5$ kg/da) | | TS 8340:1990 | 1,513 (49) | 1,537 (40) | 1,276 (33) | 1,654 (43) | 1,328 (35) | |
| Available macronutrients | Ca (mg/kg) | TS 8341:1990 | 13,160 (210) | 8,217 (131) | 6,553 (105) | 7,865 (126) | 8,256 (132) | [48] |
| | Mg (mg/kg) | | 2,007 (40) | 2,159 (43) | 2,796 (55) | 1,915 (38) | 2,175 (44) | |
| | Na (mg/kg) | | 582 (13) | 2,109 (47) | 2,852 (63) | 2,040 (45) | 2,047 (45) | |
| | K (mg/kg) | | 2,514 (68) | 4,447 (120) | 5,910 (160) | 3,255 (88) | 3,956 (107) | |
| Available micronutrients | Fe (mg/kg) | TS ISO 14870/T1:2009 | 44.51 (0.68) | 77.46 (1.18) | 82.99 (1.26) | 59.98 (0.91) | 69.09 (1.05) | [49] |
| | Cu (mg/kg) | | 1.825 (0.151) | 4.928 (0.419) | 4.532 (0.382) | 4.193 (0.353) | 4.907 (0.415) | [50] |
| | Zn (mg/kg) | | 11.51 (0.66) | 32.36 (1.85) | 34.02 (1.94) | 32.04 (1.82) | 42.12 (2.41) | [51] |
| | Mn (mg/kg) | | 47.76 (0.76) | 98.50 (1.58) | 104.50 (1.68) | 87.97 (1.41) | 128.11 (2.05) | |
| | Al (mg/kg) | | 0.071 (0.002) | 0.114 (0.003) | 0.105 (0.003) | 0.162 (0.005) | 0.126 (0.004) | |

harvest. Furthermore, it is not surprising that lower EC values (0–2 mS/cm; salt-free) provide easier uptake of plant nutrients and water from the root zone where MT mixtures having lower EC values (X2, Y2) showed better performances than those of X1 and Y1 in terms of average and total harvest height. In addition, MT mixtures having soil texture of sandy loam (X2, X1) also exhibited better plant growth rather than those mixtures of Y2 and Y1 having loamy sand texture. This result is also consistent with Woodard [52].

Total biomass productions of MT samples, measured as sum of three harvests, are illustrated in Fig. 5. It is seen that the washed mixtures of X2 and Y2 achieved 16.0% and 8.0% greater biomass than those of unwashed mixtures of X1 and Y1, respectively. In addition, mixtures of X samples have performed better biomass production than those of Y mixtures. It is observed that there is a close relationship between the biomass production results and the total/average harvest heights of MT samples. Total biomass production results for MT mixtures are also in agreement with Sheehan et al. [17].

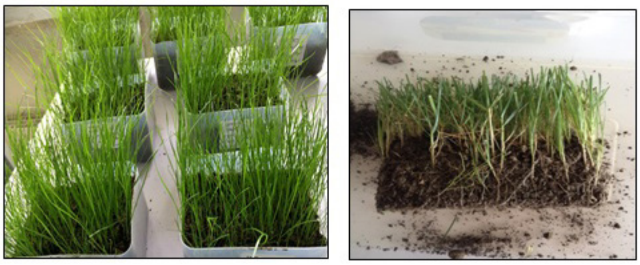

Fig. 2. Grasses grown under this study.

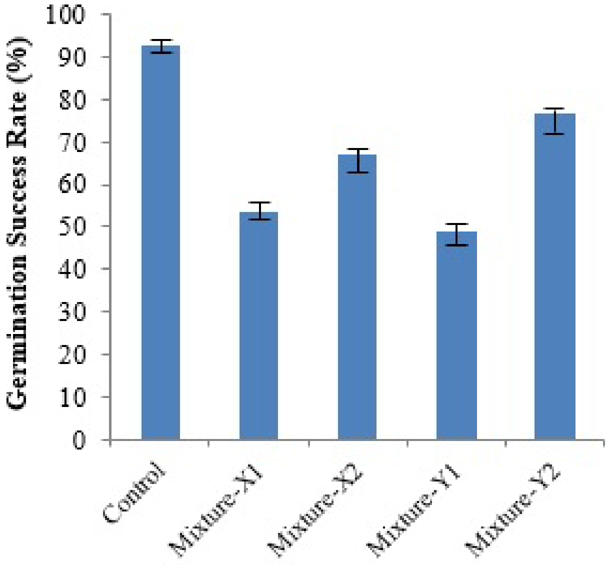

Fig. 3. Seed germination rates (%) for MT samples.

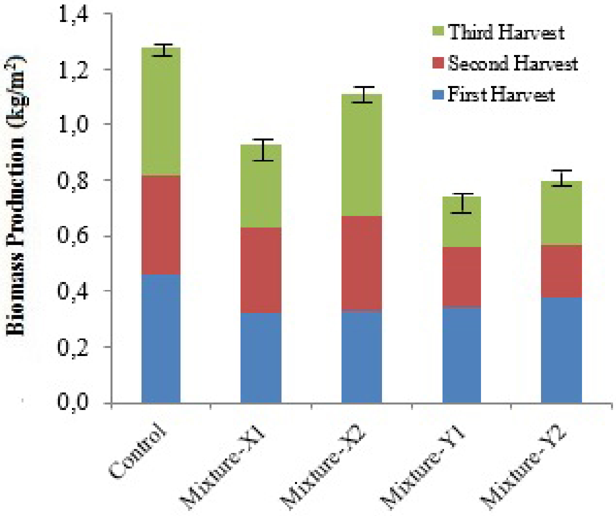

Fig. 5. Total biomass production of MT samples.

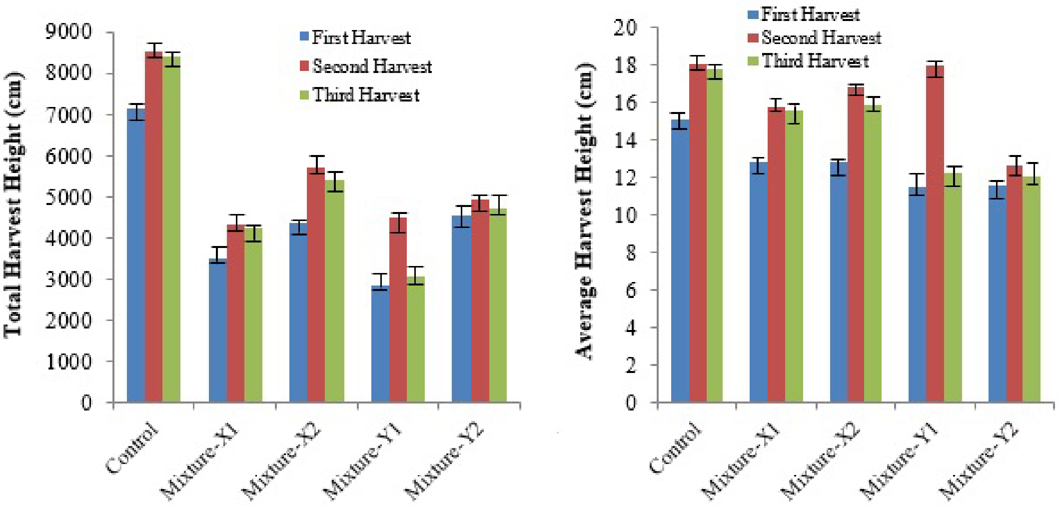

Fig. 4. Average and total height (cm) of grasses after each harvest in MT samples.

Table 8
Nutrient concentrations in the harvested grass

| Parameter | Methods | Control | Mixture | | | | Sufficiency range | References for sufficiency range |
|---|---|---|---|---|---|---|---|---|
| | | | X1 | X2 | Y1 | Y2 | | |
| First harvest | | | | | | | | |
| N (%) | TS 8337 ISO 11261:1996 | 4.06 ± 0.10 | 2.93 ± 0.07 | 3.94 ± 0.10 | 2.86 ± 0.07 | 3.75 ± 0.09 | 1%–5% | [53] |
| P (%) | Wet digestion method | 0.26 ± 0.02 | 0.14 ± 0.01 | 0.30 ± 0.03 | 0.14 ± 0.01 | 0.28 ± 0.02 | 0.1%–0.5% | |
| K (%) | EPA 3052:1996 | 3.27 ± 0.09 | 1.92 ± 0.05 | 3.09 ± 0.09 | 2.11 ± 0.06 | 3.21 ± 0.09 | 2%–4% | [54] |
| Ca (%) | | 0.94 ± 0.12 | 0.66 ± 0.08 | 0.82 ± 0.10 | 0.78 ± 0.10 | 0.84 ± 0.10 | 0.4%–0.8% | |
| Mg (%) | | 0.27 ± 0.04 | 0.18 ± 0.02 | 0.24 ± 0.03 | 0.20 ± 0.02 | 0.21 ± 0.03 | 0.1%–0.4% | [53] |
| S (%) | ASTM D 4239-05 | 0.36 ± 0.04 | 0.11 ± 0.01 | 0.28 ± 0.04 | 0.14 ± 0.01 | 0.26 ± 0.03 | 0.1%–0.4% | |
| Fe (ppm) | EPA 3052:1996 | 168.7 ± 2.5 | 96.7 ± 1.1 | 149.2 ± 2.2 | 116.6 ± 1.7 | 146.8 ± 2.2 | 50–250 ppm | [55] |
| Cu (ppm) | | 16.39 ± 0.28 | 11.69 ± 0.20 | 22.03 ± 0.37 | 6.78 ± 0.11 | 13.17 ± 0.22 | 5–20 ppm | [53] |
| Mn (ppm) | | 26.87 ± 0.40 | 17.95 ± 0.27 | 19.74 ± 0.30 | 18.87 ± 0.28 | 24.15 ± 0.36 | 25–300 ppm | |
| Zn (ppm) | | 71.49 ± 1.14 | 42.80 ± 0.68 | 59.11 ± 0.95 | 35.44 ± 0.57 | 52.18 ± 0.83 | 25–150 ppm | |
| N/S ratio | Calculation | 11.28 | 26.64 | 13.59 | 20.43 | 14.42 | 10–15 | [55] |
| N/K ratio | | 1.24 | 1.52 | 1.28 | 1.36 | 1.17 | 1.2–2.2 | |
| Second harvest | | | | | | | | |
| N (%) | TS 8337 ISO 11261:1996 | 4.19 ± 0.10 | 2.77 ± 0.07 | 4.58 ± 0.11 | 2.71 ± 0.07 | 4.14± 0.10 | 1%–5% | [53] |
| P (%) | Wet digestion method | 0.28 ± 0.02 | 0.17 ± 0.01 | 0.36 ± 0.03 | 0.15 ± 0.01 | 0.37 ± 0.03 | 0.1%–0.5% | |
| K (%) | EPA 3052:1996 | 3.18 ± 0.09 | 2.04 ± 0.06 | 3.12 ± 0.09 | 2.19 ± 0.06 | 2.98 ± 0.08 | 2%–4% | [54] |
| Ca (%) | | 0.86 ± 0.11 | 0.74 ± 0.09 | 0.86 ± 0.11 | 0.77 ± 0.10 | 0.87 ± 0.11 | 0.4%–0.8% | |
| Mg (%) | | 0.32 ± 0.03 | 0.23 ± 0.03 | 0.27 ± 0.04 | 0.20 ± 0.02 | 0.24 ± 0.03 | 0.1%–0.4% | [53] |
| S (%) | ASTM D 4239-05 | 0.37 ± 0.04 | 0.13 ± 0.01 | 0.31 ± 0.04 | 0.15 ± 0.01 | 0.34 ± 0.04 | 0.1%–0.4% | |
| Fe (ppm) | EPA 3052:1996 | 162.3 ± 2.4 | 105.5 ± 1.6 | 154.2 ± 2.3 | 128.9 ± 1.9 | 148.1 ± 2.2 | 50–250 ppm | [55] |
| Cu (ppm) | | 15.27 ± 0.26 | 10.01 ± 0.17 | 19.84 ± 0.34 | 7.59 ± 0.13 | 12.53 ± 0.21 | 5–20 ppm | [53] |
| Mn (ppm) | | 28.49 ± 0.43 | 16.18 ± 0.24 | 19.78 ± 0.30 | 16.91 ± 0.25 | 20.49 ± 0.31 | 25–300 ppm | |
| Zn (ppm) | | 66.49 ± 1.06 | 44.80 ± 0.72 | 58.63 ± | 43.68 ± 0.94 | 47.14 ± 0.75 | 25–150 ppm | |
| N/S ratio | Calculation | 11.32 | 21.31 | 14.77 | 18.06 | 12.18 | 10–15 | [55] |
| N/K ratio | | 1.32 | 1.36 | 1.47 | 1.24 | 1.39 | 1.2–2.2 | |
| Third harvest | | | | | | | | |
| N (%) | TS 8337 ISO 11261:1996 | 3.79 ± 0.09 | 2.79 ± 0.07 | 3.69 ± 0.09 | 2.43 ± 0.06 | 3.92 ± 0.10 | 1%–5% | [53] |
| P (%) | Wet digestion method | 0.23 ± 0.02 | 0.11 ± 0.01 | 0.29 ± 0.03 | 0.19 ± 0.01 | 0.32 ± 0.03 | 0.1%–0.5% | |
| K (%) | EPA 3052:1996 | 3.10 ± 0.09 | 1.98 ± 0.05 | 3.01 ± 0.08 | 2.09 ± 0.06 | 3.07 ± 0.09 | 2%–4% | [54] |
| Ca (%) | | 0.84 ± 0.10 | 0.69 ± 0.09 | 0.80 ± 0.10 | 0.77 ± 0.10 | 0.90 ± 0.11 | 0.4%–0.8% | |
| Mg (%) | | 0.31 ± 0.04 | 0.22 ± 0.03 | 0.28 ± 0.04 | 0.17 ± 0.02 | 0.20 ± 0.02 | 0.1%–0.4% | [53] |
| S (%) | ASTM D 4239-05 | 0.33 ± 0.04 | 0.10 ± 0.01 | 0.32 ± 0.04 | 0.12 ± 0.01 | 0.30 ± 0.04 | 0.1%–0.4% | |
| Fe (ppm) | EPA 3052:1996 | 153.5 ± 2.3 | 101.9 ± 1.5 | 138.6 ± 2.1 | 112.2 ± 1.7 | 157.3 ± 2,4 | 50–250 ppm | [55] |
| Cu (ppm) | | 15.91 ± 0.27 | 9.66 ± 0.16 | 19.15 ± 0.33 | 7.67 ± 0.13 | 12.04 ± 0.20 | 5–20 ppm | [53] |
| Mn (ppm) | | 33.15 ± 0.50 | 22.18 ± 0.33 | 26.78 ± 0.40 | 18.07 ± 0.27 | 19.92 ± 0.30 | 25–300 ppm | |
| Zn (ppm) | | 48.92 ± 0.78 | 35.60 ± 0.57 | 40.76 ± 0.65 | 37.61 ± 0.60 | 42.32 ± 0.68 | 25–150 ppm | |
| N/S ratio | Calculation | 11.48 | 27.90 | 11.53 | 20.25 | 13.07 | 10–15 | [55] |
| N/K ratio | | 1.22 | 1.41 | 1.23 | 1.16 | 1.28 | 1.2–2.2 | |

Table 9
Ranking of plant growth performances in MT samples

| Sample codes | Germination rate (%) | Total growth height (cm) | Average growth height (cm) | Biomass production (kg/m$^2$) | Overall ranking |
|---|---|---|---|---|---|
| Control | 1 | 1 | 1 | 1 | 1 |
| Mixture – X1 | 4 | 4 | 3 | 2 | 3 |
| Mixture – X2 | 3 | 2 | 2 | 3 | 2 |
| Mixture – Y1 | 5 | 5 | 4 | 5 | 5 |
| Mixture – Y2 | 2 | 3 | 5 | 4 | 4 |

The analysis results of the available plant nutrients obtained for entire MT samples at each harvest are pointed out in Table 8 together with the standard deviations and the sufficiency ranges of related macronutrients and micronutrients.

Sufficiency range of a plant is the range of nutrient amount in order to maximize the plant growth and to satisfy the nutritional plant requirements [56]. As it can be seen from Table 8, the concentrations of macronutrients and micronutrients of the harvested grasses have been found between plant's sufficiency ranges in all cases except Mn and Ca concentrations. The Ca concentrations of grasses harvested from X1 and Y1 mixtures are close to the upper limit level of Ca, while Ca concentrations of grasses harvested from X2 and Y2 mixtures are above the limit (toxicity range) of Ca in terms of sufficiency range. Besides, it is found that Mn concentrations of grasses collected from mixtures comprising washed and unwashed DMs are below the sufficiency range of Mn at all harvests. It is clear that the excess of macroelements such as Ca inhibits the uptake of microelements (i.e., deficiency of Mn) required for the plant growth. Furthermore, grasses harvested from X2 and Y2 mixtures are richer in terms of macronutrients and micronutrients than those of X1 and Y1 mixtures at all harvests. Although sulfur contents of harvested grasses were found to be in the sufficiency range, N/S ratio, which is >18 [55], indicates the sulfur deficiency for the grasses of X1 and Y1 mixtures.

Before each harvest, plant/leaf color is compared with the scale ranging from 1 to 5 where 1: decay, light yellow, 2: light yellow green, 3: light green, 4: green and 5: dark green [57]. Plants having green color are mainly provided by nitrogen and phosphorus elements taken from soil. The desired color for grasses/plants grown in the context of the environmental landscaping is the value of 4 (green). Also, this value represents the normal growing of grasses/plants [57].

Considering the plant growth performances, efficiency ranking was made between MT samples by giving equal scores for each performance indicator of interest. The ranking scores for all MT samples are summarized in Table 9.

As it can be clearly seen, efficiency ranking of plant growth performances may be listed as follows: Mixture – X2 comprising washed DM-1 showed the best plant growth performance among MT samples. Due to the higher salt content resulting from the unwashed DM-2, Mixture – Y1 demonstrated the worst plant growth performance among MT samples. Topsoil mixtures having washed DMs were found to be better than those of having unwashed DMs.

## 4. Conclusions

The following outcomes are obtained from this study:

- AYY-Appendix 3B: Hazardous waste threshold limits exhibited that both DMs can be defined as "non-hazardous waste" with a waste code of 17 05 06 (dredging spoil other than 17 05 05).
- According to the TS EN 12457–4:2004 [35] leaching test results of DMs, eluate concentrations of $Cl^-$, $SO_4^{2-}$ and TDS were found suitable to dispose DMs at Class II (non-hazardous waste) landfill.
- In all cases, MT samples comprising washed DMs (X2, Y2) showed better plant growth performances (seed germination rate, average and total harvest height and biomass production) than those of unwashed DMs (X1, Y1).
- Plant growth habits of MT mixtures having soil texture of sandy loam (X1, X2) were better than those of having loamy sand (Y1, Y2).
- Salts found in the soil's root zone can increase the osmotic pressure; thus, they decrease the plant productivity due to the lack of water and nutrients uptake by roots.
- The concentrations of macronutrients and micronutrients have been found between plant's sufficiency ranges in all cases except Mn and Ca concentrations, where excess Ca inhibited Mn uptake by roots. Grasses harvested from mixtures of X2 and Y2 are richer in terms of macronutrients and micronutrients rather than X1 and Y1 mixtures at all harvests.
- No substantial differences were observed between topsoil samples of control mixture and X2 mixture in terms of plant growth performances.
- It can be clearly stated that 70% ± 5% of DMs can be used for the MT application across Turkey as suggested in this work when considering the 15 sampling points (ports/harbors) of DIPTAR project representing Turkey's shores, DM amounts generated from these ports/harbors, the related characterization results and the required pre-treatment processes of these DMs under investigation.
- The outcomes of this study showed that DM sample can be efficiently and beneficially used as topsoil with no adverse environmental effect; however, several pre-treatment techniques such as desalination, dewatering, organic amelioration and pH adjustment should be performed on DM samples before utilization in municipality's landscaping applications for grass growth.

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## References

[1] R. Zentar, D. Wang, N.E. Abriak, M. Benzerzour, W. Chen, Utilization of siliceous-aluminous fly ash and cement for solidification of marine sediments, Constr. Build. Mater., 35 (2012) 856–863.
[2] *H. Cho*, *J.* Shim, J Park, Performance evaluation of solidification/stabilization of dredged sediment using alkali-activated slag, Desal. Wat. Treat., 57 (2016) 10159–10168.
[3] R. Boutin, Improvement of Knowledge about the Outputs of Dredging Products as Mud in Sea: Phenomena Short Term-Close Field, Lyon, France, 1999.
[4] C. Alzieu, Dredging and Marine Environment, State of the Art, IFREMER, Plouzané, 1999.
[5] J. Vermeulen, S.G. Van Dijk, J.T.C. Grotenhuis, W.H. Rulkens, Quantification of physical properties of dredged sediments during physical ripening, Geoderma, 129 (2005) 147–166.
[6] A. Netzband, A.L. Hakstege, K. Hamer, Treatment and Confined Disposal of Dredged Material – Part 2: Dutch-German Exchange on Dredged Material, Germany, 2002.
[7] V. Dubois, N.E Abriak, R. Zentar, G. Ballivy, The use of marine sediments as a pavement base material, Waste Manage., 29 (2009) 774–782.
[8] OSPAR Commission, Oslo-Paris Commission, JAMP Assessment of the Environmental Impact of Dumping of Wastes at Sea, Biodiversity Series, London, UK, 2009, p. 433.
[9] LIFE, Methods for Management and Re-use of Polluted Sediments, European Project Realized by in vivo, France, 2002 (in French).
[10] P. Grégoire, Conceptual Model for Help with Multi-criterion Decision-taking in the Framework of the Negotiated Choice for a Marine Dredging Scenario, France, 2004, p. 281 (in French).
[11] F. Agostini, F. Skoczylas, Z. Lafhaj, About a possible valorisation in cementicious materials of polluted sediments after treatment, Cem. Concr. Compos., 29 (2007) 270–278.
[12] J. Lukens, National Coastal Program Dredging Policies. An Analysis of State, Territory & Commonwealth Policies Related to Dredging & Dredged Material Management, Vol. I/II, OCRM/CPD Coastal Management Program Policy Series, Technical Document 00–02, 2000.
[13] P.R. Krause, K.A. McDonnell, The Beneficial Reuse of Dredged Material for Upland Disposal, HLA Project No. 48881, California, 2000.
[14] J.P. Ulbricht, Contaminated Sediments: Raw Materials for Bricks, Symposium Dragage, Dunkerque, France, 2002.
[15] J. Riordan, J.P. Murphy, J.R. Harrington, Construction and Demolition Waste and Dredge Material as Landfill Liner in Ireland, 1st Middle European Conference on Landfill Technology, The Hungarian Academy of Sciences, Budapest, 2008.
[16] Port of Baltimore, Up for Grabs-innovative Solutions Are Being Found for Dredged Material, The Port of Baltimore Magazine, Maryland, June/August Issue, 2009.
[17] C. Sheehan, J.R. Harrington, J.D. Murphy, A technical assessment of topsoil production from dredged material, Resour. Conserv. Recycl., 54 (2010) 1377–1385.
[18] D.J. Yozzo, P. Wilber, R.J. Will, Beneficial use of dredged material for habitat creation, enhancement, and restoration in New York-New Jersey Harbor, J. Environ. Manage., 73 (2004) 39–52.
[19] K. Reine, D. Clarke, C. Dickerson, Fishery resource utilization of a restored estuarine borrow pit: a beneficial use of dredged material case study, Mar. Pollut. Bull., 73 (2013) 115–128.
[20] J. Limeira, M. Etxeberria, L. Agulló, D. Molina, Mechanical and durability properties of concrete made with dredged marine sand, Constr. Build. Mater., 25 (2011) 4165–4174.
[21] I. Said, A. Missaoui, Z. Lafhaj, Reuse of Tunisian marine sediments in paving blocks: factory scale experiment, J. Clean. Prod., 102 (2015) 66–77.
[22] V. Cappuyns, V. Deweirt, S. Rousseau, Dredged sediments as a resource for brick production: possibilities and barriers from a consumers' perspective, Waste Manage., 38 (2015) 372–380.
[23] T.K. Haraldsen, P.A. Pedersen, Mixtures of crushed rock, forest soils, and sewage sludge used as soils for grassed green areas, Urban For. Urban Greening, 2 (2003) 41–51.
[24] C.Y. Jim, Edaphic properties and horticultural applications of some common growing media, Commun. Soil Sci. Plant Anal., 27 (1996) 2049–2064.
[25] A. Boen, T.K. Haraldsen, Fertilizer effects of increasing loads of composts and biosolids in urban greening, Urban For. Urban Greening, 10 (2011) 231–238.
[26] R.B. Davidov, G. Harman, S. Landess, W. Muir, D. Scott, P. Swensen, P. Petzrick, Innovative Reuse of Dredged Material, Report to the Executive Committee of Maryland's Dredged Material Management Program, USA, 2007.
[27] J.F. Riddell, G. Fleming, P.G. Smith, The use of dredged material as a topsoil, Terra et Aqua, 39 (1989) 11–19.
[28] B.R. Thomas, M.S. De Silva, Topsoil from Dredgings: A Solution for Land Reclamation in the Coastal Zone, Davies MCR, Land reclamation: an End to Dereliction? London, UK, 1991.
[29] Y.K. Joo, S.K. Lee, Y.S. Jung, N.E. Christians, Turfgrass revegetation on amended sea sand dredged from the Yellow Sea, Comm. Soil Sci. Plant Anal., 39 (2008) 1571–1582.
[30] Y.T. Kim, B. Pradhan, Mechanical and germination characteristics of stabilized organic soils, Mar. Georesour. Geotechnol., 34 (2016) 681–688.
[31] TÜBİTAK MAM, Marine Dredging Applications and Environmental Management of Dredged Materials (DIPTAR) Project (111G036), Project Final Report, TÜBİTAK KAMAG 1007 Project, Kocaeli, 2016.
[32] Turkish Regulation, The Waste Management Regulation (AYY), Official Gazette No.: 29314, The Ministry of Environment and Urbanization, Ankara, 2015 (in Turkish).
[33] Turkish Regulation, The Regulation on the Landfilling of Waste (ADDDY), Official Gazette No.: 27533, The Ministry of Environment and Urbanization, Ankara, 2010 (in Turkish).
[34] Standard Methods, Standard Methods for the Examination of Water and Wastewater, APHA/AWWA/Water Environment Federation, Washington, D.C., 2012.
[35] TS EN 12457–4, Turkish Standard, Characterization of Waste, Leaching-Compliance Test for Leaching of Granular Waste Materials and Sludges – Part 4: One Stage Batch Test at a Liquid to Solid Ratio of 10 L/kg for Materials with Particle Size below 10 mm (without or with Size Reduction), Turkish Standards Institute, Ankara, Turkey, 2004.
[36] R.A. Jones, G.F. Lee, The Significance of Dredging and Dredged Material Disposal as a Source of Nitrogen and Phosphorus for Estuarine Waters, Estuaries and Nutrients, Humana Press, Clifton, 1981, pp. 517–530.
[37] Environment Agency, Hazardous Waste: Interpretation of the Definition and Classification of Hazardous Waste, Technical Guidance WM2, UK, 2011.
[38] N. Krachai, M. Hadjel, Characterization and treatment of contaminated marine sediments for reuse, Desal. Wat. Treat., 52 (2014) 2309–2314.
[39] M.H. Lin, C.H. Lee, Y.C. Lin, K.H. Yang, Potentially toxic trace elements accumulating in marine sediment and bivalves in the outfall area of a desalination plant, Desal. Wat. Treat., 25 (2011) 106–112.
[40] H. Köthe, P. Boer, Dutch-German Exchange (DGE) on Dredged Material – Part 1: Dredged Material and Legislation, The Hague and Bonn, 2003.
[41] S.T. Casper, Regulatory Frameworks for Sediment Management, Sustainable Management of Sediment Resources: Sediment Management at the River Basin Scale, 2008, pp. 55–81.

[42] J.W. Lloyd, J.A. Heathcote, Natural Inorganic Hydrochemistry in Relation to Groundwater, Clarendon Press, Oxford, 1985.

[43] D.A. Horneck, J.W. Ellsworth, B.G. Hopkins, D.M. Sullivan, R.G. Stevens, Managing Salt-Affected Soils for Crop Production, PNW 601-E, Oregon State University, a Pacific Northwest Extension Publication, USA, 2007.

[44] L.A. Richards, Diagnosis and Improvement of Saline and Alkali Soils, U.S. Salinity Laboratory, U.S. Department of Agriculture, Agriculture Handbook No. 60, Washington, D.C., 1954.

[45] I.P. Abrol, J.S.P. Yadav, F.I. Massoud, Salt-Affected Soils and Their Management, FAO Soils Bulletin, 39, Food and Agriculture Organization of the United Nations, Rome, Italy, 1988.

[46] BS 3882, British Standard, Specification for Topsoil, British Standards Institute, UK, 2015.

[47] N. Ulgen, N. Yurtsever, Turkey Fertilizer and Fertilization Guide, Soil and Fertilizer Research Institute Publications, Ankara, 1995 (In Turkish).

[48] M. Sillanpää, Micronutrient Assessment at the Country Level: An International Study, FAO Soils Bulletin 63, FAO/Finnish International Development Agency, Rome, Italy, 1990.

[49] W.L. Lindsay, W.A. Norvell, Development of a DTPA test for zinc, iron, manganese, and copper, Soil Sci. Soc. Am. J., 42 (1978) 421–428.

[50] F.H. Follet, Zn, Fe, Mn and Cu in Colorado Soils, Colorado State University, Colorado, USA, 1969.

[51] Hill Laboratories, Aluminium Soil Test Interpretation, Technical Notes, New Zealand, 2014.

[52] H.J. Woodard, Plant growth on soils mixed with dredged lake sediment, J. Environ. Sci. Health., Part A, 34 (1999) 1229–1252.

[53] A. Pagani, J.E. Sawyer, A.P. Mallarino, Specific Nutrient Management: 1. Overview of Soil Fertility, Plant Nutrition and Nutrition Management, Natural Resources Conservation Service, Washington, D.C., 2014.

[54] Midwest Laboratories, Agronomy Handbook, Soil and Plant Analysis Resource Handbook, Midwest Laboratories Inc., Omaha, 1990.

[55] H.A. Mills, J.B. Jones, Plant Analysis Handbook II: A Practical Sampling, Preparation, Analysis and Interpretation Guide, Micro-Macro Publishing, USA, 1996.

[56] A. McCauley, C. Jones, J. Jacobsen, Plant Nutrient Functions and Deficiency and Toxicity Symptoms, Nutrient Management Module No. 9, Montana State University, USA, 2011.

[57] T.K. Haraldsen, E. Brod, T. Krogstad, Optimising the organic components of topsoil mixtures for urban grassland, Urban For. Urban Greening, 13 (2014) 821–830.