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A Preliminary Assessment of Utilizing Solid Waste Fractions as an Agricultural Growth Medium in Arid Soils

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***Abstract*—The fast-paced and globalized industrial/population growth has generated a vast consumerism-based culture, resulting in the rapid increase in municipal solid waste generation. Considering the case of Kuwait, the collection and disposal of waste has become a major economic and health issue for both the general public and the Kuwaiti government. Addressing and improving current waste disposal challenges, through utilizing (or recovering) basic materials from waste, will benefit society in terms of reductions in costs, pollution and associated negative health impact. The objective of this study was to assess the re-utilization prospects of waste materials (paper, cardboard and cotton) as a substrate for plant growth, consequently serving as a growing medium material, apart from naturally occurring soil. This investigation was conducted across two land plots in the Wafra region, located in Southern Kuwait. The plots were planted with *Rhanterium epapposum* and *Festuca rubra* seeds. Temperature, humidity and growth rates were measured during this study. Study results indicated that chemical composition of the growth medium is suitable for local conditions. Furthermore, the soil plot with added growth medium was found to retain moisture for prolonged periods in comparison to the plot lacking in growth medium. Field studies on grass germination and growth rates highlighted that waste-derived substrate is favorable to their development and adaptation within challenging environmental conditions. This investigation can play an important part for introducing and developing the concept of a circular economy within Kuwait, with potential to improve waste management within the country.**

***Index Terms*—Circular economy, evaporation, growth medium, moisture, soil, waste management**

I. INTRODUCTION

The rapid and globalized industrial/population growth has generated an immense consumerism culture, which resulted in the swift increase of municipal solid waste (MSW) generation. The environmental and human health impacts of MSW are well-documented within the literature [1–4]. Improper or non-regulated MSW dumping could potentially create a variety of issues, such as contaminating water sources through leachate, attracting insects and rodents, together with blocking drainage gullies, apart from increased safety hazards due to fires and increasing greenhouse gas (GHG) emissions. Consequently, managing waste / waste-streams in an appropriate manner represents a vital component for building sustainable and habitable communities, though this remains a major challenge in most nations.

Efficient and appropriate waste management is costly, and MSW management is a complex issue, affected by global economics, social awareness, technology/production, and environmental impact. According to the US Environment Protection Agency (EPA) and United Nations (UN) environment program, waste management is achieved through regulation of the generation, collection, transport, treatment and disposal (landfilling) of waste—otherwise known as Integrated Solid Waste Management (ISWM) [5, 6]. A comprehensive ISWM relies on four functional elements, adopted from the principles of pollution prevention (P2), namely: reduction, re-use, recovery, and disposal [7, 8]. Reduction and re-use seek to prevent waste from being generated through strategies, such as appropriate product design, reduced packing, and reducing use of materials. The major objective of this step is to reduce waste levels at the source, consequently minimizing disposal and environmental costs at the landfill site. Recovery involves the extraction of specific recyclable materials (e.g., metals, glass, paper) for manufacturing novel materials or products. Disposal options are used to manage MSW that cannot be prevent or recovered, with such options including landfilling or combustion. These options, however, come at a great economic cost as they require considerable capital/investments [8]. Despite this concern, landfilling is the most prevalent waste disposal option globally, due to its convenience. Notwithstanding, also due to the elevated cost of management and maintenance, many landfills are not managed properly and result in severe pollution [9].

Within rapidly developing counties (such as Kuwait and other countries in this region), expanding populations combined with rising personal income streams, typically result in a significant increase in MSW levels. The collection and disposal of waste has become a major economic and health issue, for both the public and the authorities concerned. The current disposal method in Kuwait is 'end tipping' or dumping, where this operation consists of unloading the garbage truck next to the edge of the dumpsite until ground level is reached. Once the end-of-workday is reached, the waste is covered by a layer of sand, or by sand mixed with construction/demolition waste. No liners or suitable covering systems are employed at the sites. The differing types of MSW are combined, without any guidelines or separation methods. Most of such sites have minimal fencing, with no constructed gates, resulting in illegal dumping and unauthorized entry.

MSW management in Kuwait is the responsibility of

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Kuwait Municipality (KM), a governmental agency, that sets contracts with private companies for the collection and transportation of household waste to relevant dumpsites. The MSW is deposited into three active MSW dumpsites (Jahra, Mina Abdulla, and Seventh Ring Road). Current KM objectives focus on street cleanliness, waste collection and disposal, with less attention given to MSW reduction and recovery. This waste is not segregated, however, several privatized contractors operate by recovering a degree of recyclable material from street containers, or collect materials from communal waste sources—such as household and businesses—for re-sale to local recyclers. However, no data is available regarding the amount nor the total economic value of such activities.

Trends in waste generation show an increase in the volumes of waste produced within Kuwait (Fig. 1). As of 2020, a total of 2,638,589 tonnes of MSW were generated and landfilled [10], that translates into a daily rate of approximately 1.5 kg of solid waste per capita. A study by Al-Jarallah *et al.* [11] provided a baseline for MSW generation and characteristics within Kuwait. The results of this study indicated that the organic fraction represented a major portion of the waste (44.4 %) followed by film/plastics (18%) and paper/cardboard (15%) (Fig. 2). The authors also observed significant seasonal variation in waste categories. Furthermore, Al-Yaqout *et al.* [12] assessed the public opinion regarding MSW and landfilling in Kuwait. This study concluded that <50% of respondents were aware of the negative impacts of landfills on public health and the environment. The findings also indicated that visual appearance of the landfill scored the lowest impact in public opinion, while economic concerns were considered the most important issue, from a general public perspective. Environmental impacts associated with landfills and current disposal methods, along with the life cycle assessment of MSW management, were also discussed in the literature [13–16].

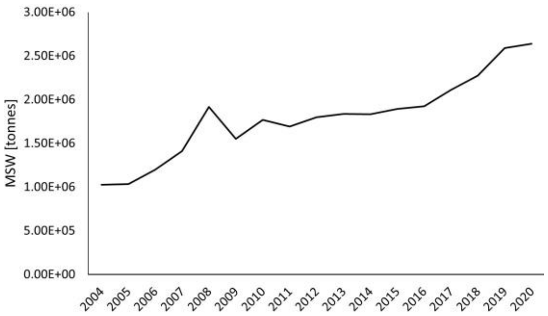

Fig. 1. Landfilled MSW (Data source: [10]).

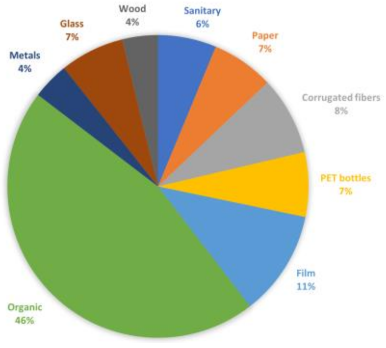

Fig. 2. MSW composition (Data source: [17]).

Addressing and improving the current issues in MSW will provide benefits to society in terms of reduction of overall costings borne by national economies, pollution reduction, and all associated health impacts. A shift towards sustainable solid waste management complements the principles of a circular economy (CE), whereby waste generation is reduced, materials are recovered, and disposal is minimized. The interconnections between solid waste management, CE and economic/environmental issues have been addressed extensively in the literature [18–22]. Circular economy is an economic system created for production and consumption, aimed at creating a model of constant restoring and regeneration for every segment of the economy. It is focused on building a closed-loop system, conversely to the linear economy, where goods serve only one purpose and end their lifespan at a disposal facility [23]. CE plays as a contrast to the traditional approach for economy and management, and was created as a response to resource depletion, growing populations, rapid civilization development and currently relevant issues that our planet is facing. The main actions that must be undertaken are: re-usage, re-manufacturing, recycling and reduction. The re-use action comprises of all aspects aiming at the conservation of raw materials, by-products of various processes, and various valuable materials, such as steel and other metals. Re-manufacture can include aspects such as the restoration of worn machines, engines or tools. Recycling is an aspect that many sectors are already gradually implementing. Packaging, products, and materials must be recycled in order to form novel sources of benefits for the economy. Reduction is aimed at all actions required to reduce the utilization or consumption of resources, such as water, electricity, and raw materials. There are promising opportunities for CE implementation within Kuwait, such as waste-to-energy and artificial growth media (artificial soil), since considerable segments of MSW are organics and paper. Organics can be separated for biogas production and composting for nutrient recovery, such as fertilizers or soil conditioners. Furthermore, paper-based waste can potentially be recycled for novel paper materials and corrugated fiber production or can be utilized as a growth medium for soils in arid regions.

The organic and paper/cardboard fractions of MSW represent approximately 60% of the annual total-mass. Currently, the utilization of paper/carboard waste in Kuwait is limited to recycling. However, a large proportion of paper waste is not utilized since it is soiled with food waste. Additionally, the organic fraction of MSW is also not being utilized and is diverted into dumpsites across the country. Consequently, the objective of the study was to assess the potential of utilizing the paper, cardboard, and textile (cotton) fractions of MSW as a growth medium (artificial soil) for plants.

II. LITERATURE REVIEW

Growth medium/media (GM/GMs), also known as “substrate” or “potting soil”, is a material in which plants grow. GMs are used to provide a rooting environment for plant stability, air storage for roots, effective water retention, and nutrient supplies [24]. Typically, GMs are most effective when combined with additives, such as fertilizers, liming materials, bio-controls and wetting agents. The range of constituents used in GMs include peat, composted organic wastes, rockwool, cotton waste, coir, cotton gin, and paper waste [24, 25]. Presently, there is a spectrum of GM products available in the market, such as rockwool and pittmoss, that are composed of waste materials (organic paper fibers). The criteria for GM selection include ecological, economic, social, and performance drivers [24, 25]. Performance drivers are essentially physical, chemical, and biological properties providing the optimal environment for root growth. Texture, shape, porosity, bulk density, and particle size distribution/arrangement are the physical properties that influence GM performance [24, 25]. Chemical properties such as nutrients, electrical conductivity, and pH are also considered when assessing GMs.

Several studies have assessed the performance of waste materials for GMs, such as paper waste [26, 27], rockwool [28], and cotton gin waste [24, 29]. Paper waste was found to act as a partial replacement for peat within industrial plant cultivations. It did not negatively influence seed emergence, though it restrained growth, while not inducing any cellular damage in plants. Results inferred that biodegradable paper was a potential mulching material to be employed for summer tomato production. Biodegradable paper mulching led to reduced soil temperature and increased moisture [30–32]. Another study found that composted paper-mill waste had long-term nitrogen retention properties when used as a soil conditioner, despite having reduced water retention capacity [27]. Studies demonstrated that cotton waste provides a good rooting medium for plant species, such as *coleus x hybrids*, *Lagerstroemia indica*, and bamboo [29]. In addition, it was suggested that adding such waste as a substrate increased water retention capacity, which is a highly useful characteristic for water-scarce terrains [33]. Hryb [34] presented the results of research selected from the biodegradable fraction of municipal waste (paper, cardboard and textiles), in terms of their utility as a soil conditioner for degraded land restoration.

III. MATERIALS AND METHODS

This study was conducted in the Southern region of Kuwait, where the localized climate is characterized as hot and arid, with temperatures reaching 51 °C, and performed during February, which is characterized by low temperatures (occasionally reaching below 0 °C) and north-westerly cold winds. During this time, dust storms are commonplace, induced by South-Easterly winds. This period was selected since it coincides with local plats' natural growth cycle, without the requirement for greenhouses.

The GM in this study was prepared using MSW fractions (cotton, waste-paper and cardboard), mixed in equal amounts by volume. The native plants employed in this study were *Rhanterium epapposum* (Native flower) and *Festuca rubra* (grass species). *Rhanterium epapposum* is a plant of the Asteraceae family, known to have a long germination period and a slow growth rate, while *Festuca rubra*, a native grass, was used in this study due its reduced germination rate when compared to *Rhanterium epapposum*. Both plants are native to the Arabian Peninsula and are considered as part of predominating forage plants for local livestock. Individual waste material constituents were shredded separately into granulation levels (<10 mm). A Trymet type T4 shredder mill was used to grind the waste into 10 mm-sized dimensions. The shredder is powered with 11 kW motor and is equipped with five fixed and three moving blades. Consequently, such granulated constituents were mixed by volume in the following proportions: 33% paper, 33% cardboard, and 33% cotton textiles (1:1:1). These proportions were selected to establish a baseline for further studies, as no previous studies were conducted in the country. Notably, waste categories were not mixed with native soil.

GM physico-chemical composition was analyzed using the methods presented in Table I. The study was conducted across two land plots (plot 1: 3.2 × 4.3 m; plot 2: 2.5 × 3.0 m) (Figs. 3 and 4). Additionally, a blank plot (native sandy soil) was used as a control for moisture measurements. Plot 1, treated with GM, was divided into the two sections and was planted with seeds of the above-mentioned plants. Consequently, an 8-cm layer of GM was applied to the plot, seeds were sown on the surface and gently pressed. The plot was covered with a 2-cm GM layer. Plot 2 was seeded with *Festuca rubra* only, and was treated with GM and dry sludge at a rate of 1.33 kg/m^2. The plot was covered with a layer of GM and sludge, seeds were sown atop, followed by a 2-cm cover layer of GM. Ambient temperature, moisture loss, and growth rates were measured throughout the duration of this study for *Festuca rubra*, across both plots. Due to its slow germination and growth rate, *Rhanterium epapposum* was used to demonstrate GM ability for growing alternative native plants. Moisture loss was measured in plot 1 (covered with GM) and compared to the blank plot (native sandy soil). All plots were watered in the evening, at 48 h intervals, with approximately 6 L/m^2 of water. The initial reading (reference point) was recorded at 150 mbar of tension. Measurements were recorded hourly for 48 h.

(a)

(b)

Fig. 3. Plot preperations prior to (a) and following (b) GM introduction and seed-sowing.

TABLE I: METHODOLOGY OF PHYSICO-CHEMICAL ASSESSMENTS FOR STUDY GM

Parameter	Methodology	Instrument
Moisture content	USEPA-3550C, ASTM D297400	Dryer
pH	USEPA -150.1	Fisher Scientific™ Accumet AB200
Specific Conductance	USEPA Method 120.1	Fisher Scientific™ Accumet AB 200
Alkalinity (Total)	APHA 2320	Burette, PH meter
TOC	USEPA METHOD 9060A	TOC-VCPH, Shimadzu™
Sulfur	ASTM D4239-17	LECO™ Truspec CHNS-628
Ca,Cu,Fe,Mg,Zn	USEPA 6010B, USEPA 3050B	ICP-OES-Perkin Elmer™, Optima™
C,H,N	ASTM D5373-14	LECO™ Truspec CHNS-628
High Heating Value	ASTM D5468-02(2007)	Parr Bomb, 6400 Calorimeter

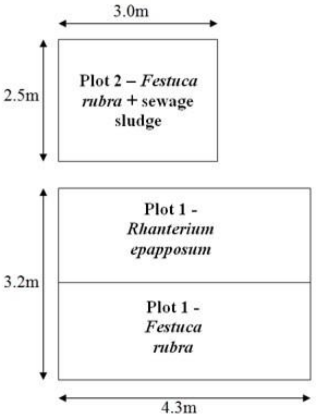

Fig. 4. Experimental plot dimensions and layouts.

IV. RESULTS AND DISCUSSION

Results describing chemical compositions for main GM constituents (paper, cardboard and cotton textiles, as well as sewage sludge from the Sulaybia Wastewater treatment Plant) are illustrated in Table II. GM pH provides an indication of acidity or alkalinity, affecting nutrient solubility and availability for plants, prior to root uptake of soil-based nutrients. Most nutrients are more soluble within acidic pH soils rather than within neutral or alkaline pH soils. The optimal pH range for such biological processes, providing adequate conditions for both plants and soil micro-organism growth, ranges between 6.1–7.2.

Salinity affects plant nutrient availability, micro-organism activity, and crop yield. Both extremely high and low electrical conductivity (EC) can negatively impact plant growth. The EC for GM components are presented in Table II. The results reveal that EC for sludge was extremely elevated, which can be detrimental to plant growth [35, 36]. Consequently, it is essential to apply sewage sludge in appropriate doses. The use of salts (chlorides and sulfur) in cotton and cardboard production caused increased EC. This increase in conductivity is also affected by calcium and magnesium levels within GM/soil.

The GM main components are rich in organic carbon, ranging from 409 mg/g (40%) in cardboard to 470 mg/g (47%) in cotton (Table II), with sludge containing 201 mg/g (20%) of organic carbon. Yost and Hartemink [37] conducted a comprehensive investigation on sandy soils, focusing on soil organic carbon. The authors found that sandy soils in arid countries are deficient in organic carbon, with concentrations as low as 0.16% on mass bases. Sulfur is another important parameter for soil, as it an essential nutrient for plant life. However, an imbalanced amount of sulfur within the soil can also be detrimental to plant growth [38]. The results demonstrated sulfur levels within paper, cardboard and textiles were in the range of 0.1–0.2%, with peak levels recorded in sewage sludge, at 1% (Table II).

Calcium de-acidifies soils, apart from playing a role in the transformation of other elements and driving soil physical characteristics [38]. Paper samples had the highest calcium content (46.5 g/kg), due to calcium additives employed as fillers and coating within pulp and paper production. Elevated copper levels (389 mg/kg) were found within sewage sludge samples, while copper levels in paper (10 mg/kg), cardboard (20 mg/kg) and cotton (39 mg/kg) were within acceptable ranges. The copper concentrations in cotton could be attributed to reduced dye fixation times, based on phthalocyanine copper complexes employed within the cotton industry. The analyzed paper, cardboard and cotton samples in this study were characterized to be acceptable for soil and plants, with zinc levels ranging between 34–139 mg/kg. Sewage sludge also typically has high zinc levels (826 mg/kg; Table II).

Total nitrogen is one of the key indicators of soil quality and fertility. Sewage sludge represented the most abundant nitrogen resource (3.12%), followed by cotton (0.89%). All other GM constituents had relatively insignificant nitrogen levels. Another important parameter is the carbon/nitrogen (C/N) ratio, which is particularly high in carboard and paper (Table II). The ideal C/N ratio for optimized microbial activity is 24:1. While the C/N value for GM developed in this study was higher than optimal, mixing the soil with GM in appropriate amounts would still improve the quality of sandy soils within Kuwait. Soil nitrogen is the essential limiting-nutrient supporting plant growth and is employed for evaluating soil nutrient content, especially within desert ecosystems [39].

Fig. 5 illustrates tensiometer readings for both GM-harboring plot 1 and native soil, during the 48-hour study. During the evening and early morning hours, evaporation rates were negligible within both plots. In comparison with native soil, the GM-harboring plot exhibited increased moisture retention, and consequently, minimized its water losses (through evaporation). This is due to the fact that water did not percolate through the sandy soil, though was absorbed and retained by the GM. This GM property allowed for prolonged moisture retention times, required for plant growth within arid soils. While water-holding capacity was not estimated in this study, a study by Hryb [34] reported a capillary water capacity of 147.8% for similar-composition GM.

The *Festuca rubra* germination and growth rate was measured for plot 1 (treated with GM) and plot 2 (GM and sludge) (Figs. 6 and 7). The reported results are the average heights of multiple measurements where the overall standard deviations for plot 1 and plot 2 are 5 mm and 4 mm, respectively. Plot 1 showed germination after nine days, reaching a maximum height of 90 mm following day-14. Conversely, plot 2 showed germination after four days, with a maximum height of 80 mm following day-13. Fig. 8 demonstrates field images of *Festuca rubra* and *Rhanterium epapposum* growth, gathered during this study.

TABLE II: PHYSICAL AND CHEMICAL COMPOSITION OF GM AND WASTEWATER SLUDGE

Parameter	Unit	Cardboard		Paper		Cotton		Sludge	
		mean	s.d	mean	s.d	mean	s.d	mean	s.d
Moisture content	%	4.52	0.57	4.26	0.23	3.29	0.25	7.08	0.43
pH	-	7.30	0.05	7.88	0.08	8.16	0.42	6.42	0.04
Specific Conductance	µmho/cm	678	10	178	8.01	529	24.95	10277	15
Total Alkalinity	mg/L	241	11	385	79	47	7.07	818	190
TOC	mg/g	409	20.91	412	31.81	471	25.70	202	66
TC	mg/g	475	23.54	441	23.33	520	21.50	236	82
Sulfur	% d.m.	0.22	0.01	0.12	0.001	0.15	0.02	1.04	0.08
Calcium	g/Kg	14.42	0.80	46.50	2.07	1.32	0.04	28	0.21
Copper	mg/Kg	20.00	2.83	10	0.98	39	2.50	389	16.88
Iron	g/Kg	0.63	0.04	0.17	0.01	0.06	0.003	14.60	1.24
Manganese	g/Kg	0.77	0.05	0.90	0.02	2.40	0.11	9.69	0.38
Zinc	mg/Kg	32	3.85	139	6.03	<DL		823	17.21
Carbon	% d.m.	40	0.29	37	0.42	41	0.42	19.60	2.7
C/N		241		848		46		6.3	
Hydrogen	% d.m.	6.5	0.7	6.3	0.46	7.1	0.47	4.0	0.7
Nitrogen	% d.m.	0.17	0.10	0.04	0.07	0.9	0.09	3.1	0.5
High Heating Value	MJ/Kg	16.57	0.11	14.23	0.14	16.53	0.04	9.4	0.8

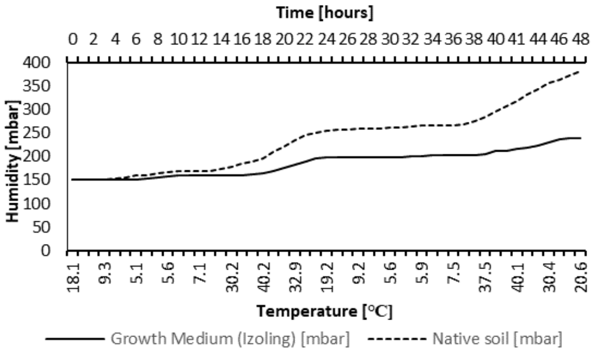

Fig. 5. Humidity loss comparison between GM (plot 1) and native soil.

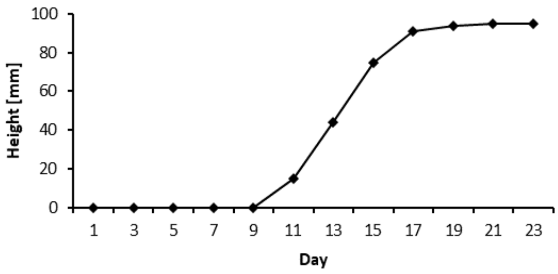

Fig. 6. Grass (*Festuca rubra)* germination and growth rate on plot 1 (day, mm).

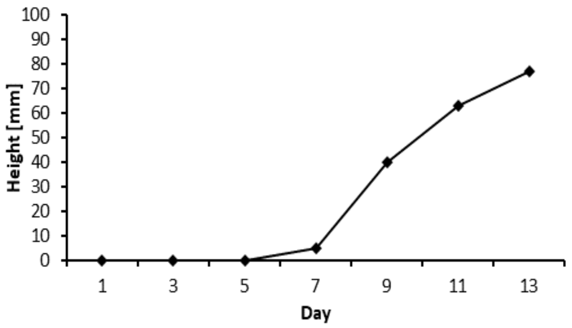

Fig. 7. Grass *(Festuca rubra)* germination and growth rate on plot 2 (day, mm).

Fig. 8. Field images of native plants: *Festuca rubra* (top); *Rhanterium epapposum* (bottom).

V. CONCLUSION

Meanwhile, as MSW quantities increase, the economic and health issues will present major international challenges. Additionally, adopting Kuwait's perspectives, biodegradable waste—such as paper and cardboard—are not utilized and are often diverted to dumpsites across the nation, becoming a source of carbon dioxide and methane emissions, thus contributing to the increase in greenhouse gases emissions. Consequently, the purpose of this study was to perform a preliminary assessment of utilizing paper-, cardboard-, and textiles (cotton)-fractions of MSW as a GM (artificial soil) for plants within arid regions. The results indicated that utilizing MSW waste components as a GM can potentially enhance water retention properties of local soils, thus reducing the high evapo-transpiration rates within arid and hot regions such as Kuwait. Additionally, GM components contain sufficient organic carbon to improve the quality of local sandy soils, which are typically carbon deficient. The results also highlighted that applying sludge provided nutrients (mainly nitrogen), which accelerated the plant growth. However, caution must be taken when applying GM with high-nitrogen content, as it might inhibit the germination process. Chemical analyses of main GM components indicated that GM has a mild alkalinity and is rich in organic carbon. Metal and mineral concentrations were within acceptable ranges. The scope of this study was to explore the potential of utilizing biodegradable fractions of municipal waste as a substrate for driving plant germination and growth within local soils and weather conditions. The study was limited by its duration and funding. Consequently, it was not possible to conduct a complete plant cycle analysis. Additionally, limitations in the quantity of allocated plots and allocated timeframe were the main factors for the limited scope of this study and within reported results. Thus, further research will be necessary for more robust analyses and results, such as pre- and post-treatment effects, water-holding capacity, and seasonal effects.

Overall, utilizing MSW components in the context for implementing a circular economy, can reduce the amount of waste being diverted to landfills and dump sites, reduce the need for novel raw materials, and enhance soil quality and properties, in the case of GMs. However, application of circular economy concepts in Kuwait is faced with regulatory and economic challenges, especially when dealing with MSW. The current objectives of the local municipality are mainly focused upon street cleanliness, waste collection and disposal, with less attention given to MSW reduction and recovery. There exists an overall lack of a clear policy or commitment towards waste management for guiding such decision-making processes. Additionally, there are no economic incentive programs for recycling or material recovery presently in-place.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Wojciech Hryb conceptualized the research idea and conducted the field experiment. Mohammad Alshawaf reviewed the research idea and wrote the manuscript. Pawel Krysztofiński analyzed the data and participated in the field experiment. All authors had approved the final version.

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