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Original Research

Feasibility Analysis of Turfgrass Substrate Production Using Aquatic Silt

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Abstract

This study assessed the feasibility of using aquatic silt as a sustainable component in turfgrass substrates. Five mixtures of silt and vermiculite (0%-100%) were evaluated for their effects on the germination and seedling growth of *Festuca elata*. Results showed that while 100% silt enhanced seed germination metrics, a 25% silt addition (T2) most effectively promoted seedling growth. Higher silt proportions (>25%) significantly inhibited emergence rate, plant height, and biomass, primarily due to elevated bulk density. Correlation analysis revealed negative associations between seedling performance and bulk density, pH, and nutrient levels. Hydroponic tests with leachates indicated growth stimulation proportional to silt content, suggesting that chemical properties were not inhibitory. These findings highlight that when used moderately, aquatic silt can serve as a viable substrate component, with bulk density being the primary limiting factor.

Keywords: silt, turfgrass, green turf substrate, seed germination

Introduction

The scientific treatment and sustainable utilization of aquatic silts have garnered significant academic attention due to their extensive generation and potential environmental impacts [1, 2]. Aquatic silts, comprising river, lake, and bay silts, are classified as soft soils with natural water content exceeding the liquid limit and void ratios greater than 1.5 [3]. These silts exhibit low mechanical strength, high compressibility, and other unfavorable physical properties [4, 5]. In recent years, with the rapid development of dredging projects in China, the annual production of aquatic silts has surged [6]. For instance, in 2021 alone, major rivers in China discharged approximately 3.31×10^9 tons of silt, and the Three Gorges Reservoir recorded a silt accumulation of 7.16×10^7 tons. This growing volume poses significant environmental and logistical challenges, prompting researchers to explore diverse utilization strategies to mitigate its negative impacts [7, 8].

Among the proposed strategies, using aquatic silts to produce construction materials has been extensively

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studied [9, 10]. However, due to the inherent abundance of organic matter and plant-available nutrients in silts, their application in soil-based utilization has emerged as a promising research area [11, 12]. Despite these advantages, the widespread presence of heavy metals and other contaminants in aquatic silts limits their direct application in agriculture due to potential risks to food safety and ecosystem health [13, 14]. Consequently, utilizing aquatic silts in landscaping, particularly in developing green turf substrates, has been recognized as a safer and more practical approach.

Landscaping applications of aquatic silts in China remain in an early exploration stage, with limited studies focusing on specific plants. Previous research has demonstrated the potential of aquatic silts to enhance plant growth under specific conditions. For example, the use of silts in the cultivation of ryegrass, *Fraxinus mandshurica*, and *Salvia splendens* has shown variable success [15]. Untreated silts often fail to support stable plant growth, while processed silts – combined with amendments such as organic materials or solidifying agents – can significantly improve growth performance [16]. Similarly, a mixture of river silts and organic waste improved plant flowering and nutrient absorption [17]. These findings highlight the importance of modifying silt's physical properties, such as bulk density and porosity, to optimize their application in landscaping.

Despite these advancements, there remains a lack of systematic research evaluating the suitability of aquatic silts as turfgrass substrates. Factors such as silt composition, physical and chemical properties, and their interactions with plant growth require further investigation. Addressing these knowledge gaps is essential to ensure the sustainable utilization of silts in landscaping while minimizing environmental risks.

This study focuses on Taihu Lake silt, one of China's most abundant silt sources, as a potential component for green turf substrates. By investigating its physicochemical properties, effects on turfgrass seed germination, and subsequent seedling growth, this research aims to determine the optimal silt proportion for substrate preparation. Furthermore, this study seeks to provide a scientific basis for the broader resource utilization of aquatic silts, contributing to the development of sustainable landscaping practices and promoting the circular economy.

Materials and Methods

Experimental Materials

The Taihu Lake silt used in this study was collected from the dredging site in Wuzhong District, Suzhou, Jiangsu Province, China. The test species is turfgrass (*Festuca elata* Keng ex E.B. Alexeev), which is widely used in golf courses, sports fields, landscaping, and soil conservation. The germination rate of the turfgrass seeds was determined to be 100%, meeting the experimental requirements.

Prior to use, the Taihu Lake silt was air-dried and sieved through a 2-mm mesh. The silt had a bulk density of 1.08 $g\cdot cm^{-3}$, a near-neutral pH of 7.92, and an EC of 60.43 $\mu S\cdot cm^{-1}$. The nutrient content included total nitrogen at 1.07 $g\cdot kg^{-1}$, total phosphorus at 1.01 $g\cdot kg^{-1}$, and total potassium at 5.06 $g\cdot kg^{-1}$, with an organic matter content of 2.17%. In contrast, the vermiculite exhibited a much lower bulk density (0.20 $g\cdot cm^{-3}$), a slightly acidic pH (6.64), and a higher EC (90.50 $\mu S\cdot cm^{-1}$). Notably, vermiculite contained no detectable amounts of total nitrogen, total phosphorus, total potassium, or organic matter.

Experimental Design

Effects of Aquatic Silt on Turfgrass Seed Germination

Five experimental treatments were established by mixing aquatic silt and vermiculite at different volumetric ratios: T1 (100% vermiculite), T2 (25% silt + 75% vermiculite), T3 (50% silt + 50% vermiculite), T4 (75% silt + 25% vermiculite), and T5 (100% silt). The germination rate, germination potential, and germination index of turfgrass seeds were measured under each treatment.

Effects of Aquatic Silt on Turfgrass Seedling Growth

Five treatments were prepared using the same ratios of silt and vermiculite (T1–T5). The physicochemical properties of the substrates were analyzed. Seedlings were cultivated in seedling trays following the method described by Wang et al. [18]. In each tray, 50 holes were used, with three turfgrass seeds sown per hole. Each treatment was replicated three times, with one tray constituting a single replicate.

The trays were placed in a controlled climate chamber set at 25ºC, 80% relative humidity, 3000 lux light intensity, and a light/dark photoperiod of 16:8 hours. Each tray was watered with 1 L of clean water. On day 5 of the experiment, an additional 1 L of water was applied to each tray. After 10 days of growth, seedling emergence rate, plant height, SPAD content, root length, above-ground dry weight, and below-ground dry weight were measured.

Effects of Cultivation Substrate Leachates on Turfgrass Growth

For each treatment, 500 g of the cultivation substrate was placed in a container and thoroughly mixed with 1,000 mL of distilled water at a solid-to-liquid ratio of 1:2 (w/v). The mixture was stirred continuously for 30 minutes to facilitate the release of soluble components. Subsequently, the suspension was allowed to settle for 1 hour, after which the supernatant was collected and filtered through a 0.45 μm membrane to obtain clear leachate. A total volume of 2 L of leachate was prepared for each treatment and used in a hydroponic experiment.

The leachates were placed in hydroponic boxes, ensuring that the leachate level fully covered the germination trays. Fifty turfgrass seeds were evenly sown in the germination trays for each treatment. Three hydroponic boxes per treatment constituted one replicate, for a total of three replicates.

The hydroponic boxes were maintained in a controlled climate chamber at 25ºC, 80% relative humidity, and 3000 lux light intensity, with a 16:8-hour light/dark photoperiod. The tops of the hydroponic boxes were sealed with perforated black plastic film for the first 2 days to create a dark environment. After 2 days, the film was removed to allow light exposure. Sterile water was added every 2 days based on weight loss to maintain a consistent liquid level. After 10 days of cultivation, seedling emergence rate, plant height, SPAD content, root length, above-ground dry weight, and below-ground dry weight were recorded.

It is important to note that the primary objective of this hydroponic experiment was to assess the overall biological response of turfgrass seedlings to leachates derived from different substrate compositions. Since both aquatic silt and vermiculite used in this study originated from controlled and pre-assessed sources without known external contamination, detailed physicochemical characterization of the leachates, including heavy metal analysis, was considered beyond the scope of this investigation. This experimental design aligns with similar studies focusing on plant growth performance rather than environmental risk assessment.

Measurement of Indicators

Seed Germination

The germination rate, germination potential, and germination index of turfgrass seeds were determined following the method described by Huang et al. [19]. Ten uniform-sized turfgrass seeds were placed in a 9 cm Petri dish lined with filter paper. Each dish was treated with 10 mL of leachate from the respective treatments, while sterile water was used as the control (CK). Each treatment included three replicates, with three Petri dishes per replicate.

The Petri dishes were incubated in a controlled environment at 25ºC, 80% relative humidity, 3000 lux light intensity, and a 16:8-hour light/dark photoperiod for 7 days. Germination was monitored daily, and the number of germinated seeds was recorded. On day 5, the germination potential was calculated, while on day 7, the germination rate, root length, and germination index were measured.

$$\text{Germination rate}(\%) = \frac{\text{Number of seeds germinated at 7 days}}{\text{Total number of seeds tested}} \times 100\%$$

$$\text{Germination potential}(\%) = \frac{\text{Number of seeds germinated at 5 days}}{\text{Total number of seeds tested}} \times 100\%$$

$$\text{Germination index} = \sum \frac{\text{Germination rate}}{\text{Correspounding germination days}}$$

Seedling Growth

After 10 days of cultivation, the number of emerged seedlings was recorded for each replicate. For each treatment, 15 seedlings were randomly selected. The plant height of turfgrass seedlings was measured using a steel ruler, and SPAD content was determined with a chlorophyll meter, expressed as SPAD values. A SPAD-502 Plus chlorophyll meter (Konica Minolta, Japan) was used. Roots were rinsed with distilled water and measured for root length using a root scanner. After removing surface moisture with filter paper, the seedlings were oven-dried at 105ºC for 1 hour for initial dehydration, followed by drying at 80ºC until a constant weight was achieved. The dry weights of above-ground and below-ground parts were then determined using an electronic analytical balance.

Physicochemical Properties

The physicochemical properties of the cultivation substrates (T1–T5) were determined following the method described by Liu et al. [20]. Bulk density and total porosity were measured using the ring knife method [21], while pH and electrical conductivity (EC) were determined using an electrode method [22]. Organic matter content was measured using the dichromate oxidation method [23]. Alkaline hydrolyzable nitrogen (AN) was quantified using the alkaline diffusion method, available phosphorus (AP) was determined using the sodium bicarbonate extraction-molybdenum-antimony anti-spectrophotometric method, and available potassium (AK) was measured using the flame photometry method [24].

Results

Effects of Aquatic Silt on Turfgrass Seed Germination

From the perspective of germination potential, an increasing proportion of aquatic silt generally enhanced the germination potential. When the proportion of aquatic silt reached 100% (T5), the germination potential peaked at 86.67%, representing 52.94% and 36.85% increases relative to CK and T1, respectively. Similar trends were observed for the germination index and root length. For the germination index, T5 demonstrated

59.05% and 56.07% increases compared to CK and T1, respectively. In terms of root length, T5 exhibited improvements of 50.41% and 49.60% over CK and T1, respectively (Table 1).

Effects of Aquatic Silt on Turfgrass Seedling Growth

The growth indicators of turfgrass seedlings cultivated in substrates with different proportions of aquatic silt and vermiculite are presented in Table 2. When the proportion of aquatic silt was 25%, there were no significant differences in emergence rate, plant height, or above-ground dry weight compared to the 100% vermiculite treatment (T1). However, SPAD content, root length, and below-ground dry weight were significantly higher under this treatment than T1 ($P<0.05$). As the proportion of aquatic silt increased, the overall growth performance of turfgrass seedlings exhibited a notable decline. This trend was particularly pronounced for emergence rate and plant height. When the silt proportion reached 100% (T5), the emergence rate decreased to 30.00±3.53%, and the plant height dropped to 9.26±0.70 cm, representing reductions of 46.49% and 52.09%, respectively, compared to T1 and T2 treatments. Regarding SPAD content, a 25%-75% silt proportion provided beneficial effects; however, these effects diminished as the silt proportion increased. No significant differences were observed between T3 (50% silt) and T1 for root length. However, with further increases in silt proportion, the root length under T4 and T5 treatments was significantly lower than that of T1 ($P<0.05$).

Physicochemical Properties of Cultivation Substrates

The physicochemical properties of cultivation substrates prepared with different proportions of aquatic silt and vermiculite are presented in Table 3. Significant changes in these properties were observed as the proportion of aquatic silt increased. In terms of physical properties, the bulk density of the substrates exhibited a marked upward trend with increasing silt proportion. Under the T5 treatment (100% silt), bulk density increased by 440% compared to T1 (100% vermiculite). Conversely, the total porosity showed a significant downward trend, with T5 showing a reduction of 290.68% relative to T1. For chemical properties, the pH of the substrates increased significantly with the addition of aquatic silt. The pH under T5 was 14.49% higher than that of T1. In contrast, electrical conductivity (EC) demonstrated a declining trend, with a 50% decrease in T5 compared to T1. The contents of available nutrients, including alkaline hydrolyzable nitrogen (AN), available phosphorus (AP), and available potassium (AK), significantly increased with higher silt proportions.

Table 1. Germination of turfgrass seeds after addition of aquatic silt.

Treatments	Germination rate/%	Germination potential/%	Germination index	Root length/cm
CK	100.00	56.67±3.47d	1.05±0.06b	3.69±0.04d
T1	100.00	63.33±2.55cd	1.07±0.08b	3.71±0.03d
T2	100.00	76.67±2.55ab	1.23±0.05b	3.75±0.06d
T3	100.00	73.33±3.47bc	1.32±0.08b	4.73±0.09c
T4	100.00	83.33±4.19ab	1.59±0.06a	5.09±0.18b
T5	100.00	86.67±2.55a	1.67±0.11a	5.55±0.21a

Note: Different lowercase letters within the same row indicate significant differences at $P<0.05$.

Table 2. Characteristics of changes in the growth of turfgrass seedlings after the addition of silt.

	T1	T2	T3	T4	T5
Seedling rate/%	100.00±2.40a	100.00±2.40a	63.33±1.15b	43.33±1.15c	30.00±3.53d
Height/cm	17.31±2.13ab	19.33±1.20a	15.09±0.85bc	12.99±0.18cd	9.26±0.70d
Chlorophyll content/SPAD	10.67±0.57c	31.87±1.42a	22.87±0.54b	20.23±0.31b	8.27±0.88c
Root length/cm	7.21±0.29b	12.63±0.52a	7.24±0.57b	4.48±0.41c	4.11±0.59c
Aboveground dry weight/g	0.07±0.02a	0.09±0.01a	0.05±0.00a	0.07±0.01a	0.04±0.01b
Belowground dry weight/mg	1.73±0.00b	3.70±0.01a	2.10±0.02ab	1.37±0.05b	1.73±0.05b

Note: Different lowercase letters within the same row indicate significant differences at $P<0.05$.

Table 3. Physical and chemical properties of cultivation media.

	T1	T2	T3	T4	T5
Bulk density/(g·cm^{-3})	0.20±0.01e	0.44±0.02d	0.64±0.01c	0.83±0.02b	1.08±0.01a
Total porosity/%	131.27±0.98a	104.90±0.45b	82.43±0.21c	60.95±0.44d	33.60±0.99e
pH	6.76±0.09d	7.03±0.04c	7.25±0.00b	7.47±0.04b	7.74±0.09a
EC/(μS·cm^{-1})	0.09±0.01a	0.08±0.00ab	0.07±0.00ab	0.07±0.00ab	0.06±0.01b
AN/(mg·kg^{-1})	0.00±0.00e	76.37±1.61d	141.43±0.01c	203.66±1.57b	282.86±3.55a
AP/(mg·kg^{-1})	0.00±0.00e	10.99±0.27d	20.37±0.00c	29.33±0.26b	40.73±0.60a
AK/(mg·kg^{-1})	0.00±0.00e	64.89±5.26d	120.17±9.25c	173.04±8.14b	240.33±9.60a

Note: Different lowercase letters within the same row indicate significant differences at $P<0.05$.

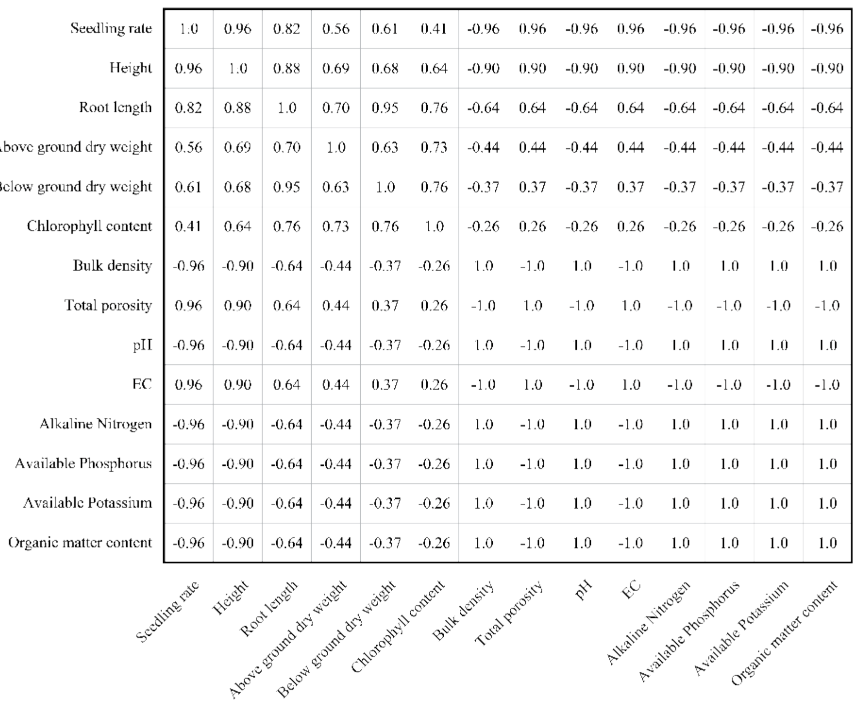
Correlation Analysis

Significant differences in the growth performance of turfgrass seedlings were observed among the treatments. To elucidate the underlying factors, a correlation analysis was conducted between seedling growth indicators and the physicochemical properties of the cultivation substrates. The results are presented in Fig. 1. The total porosity and electrical conductivity (EC) of the substrates showed positive correlations with seedling growth indicators and were significantly associated with emergence rate and plant height. In contrast, bulk density, pH, alkaline hydrolyzable nitrogen (AN), available phosphorus (AP), available potassium (AK), and organic matter content exhibited negative correlations with the growth indicators of turfgrass seedlings.

Effects of Aquatic Silt Leachates on Turfgrass Seedling Growth

Hydroponic experiments were conducted using leachates prepared from the substrates to verify the influence of the physicochemical properties of cultivation substrates on turfgrass seedling growth. The results of seedling growth indicators are shown in Fig. 2.

As the proportion of aquatic silt in the cultivation substrate increased, the leachates promoted seedling growth more effectively. Significant increases were observed in plant height (Fig. 2b), root length (Fig. 2d), above-ground dry weight (Fig. 2e), and below-ground dry weight (Fig. 2f) under higher silt proportions. Specifically, the T5 treatment (100% aquatic silt) exhibited significantly higher values for all four



	Seedling rate	Height	Root length	Above ground dry weight	Below ground dry weight	Chlorophyll content	Bulk density	Total porosity	pH	EC	Alkaline Nitrogen	Available Phosphorus	Available Potassium	Organic matter content
Seedling rate	1.0	0.96	0.82	0.56	0.61	0.41	-0.96	0.96	-0.96	0.96	-0.96	-0.96	-0.96	-0.96
Height	0.96	1.0	0.88	0.69	0.68	0.64	-0.90	0.90	-0.90	0.90	-0.90	-0.90	-0.90	-0.90
Root length	0.82	0.88	1.0	0.70	0.95	0.76	-0.64	0.64	-0.64	0.64	-0.64	-0.64	-0.64	-0.64
Above ground dry weight	0.56	0.69	0.70	1.0	0.63	0.73	-0.44	0.44	-0.44	0.44	-0.44	-0.44	-0.44	-0.44
Below ground dry weight	0.61	0.68	0.95	0.63	1.0	0.76	-0.37	0.37	-0.37	0.37	-0.37	-0.37	-0.37	-0.37
Chlorophyll content	0.41	0.64	0.76	0.73	0.76	1.0	-0.26	0.26	-0.26	0.26	-0.26	-0.26	-0.26	-0.26
Bulk density	-0.96	-0.90	-0.64	-0.44	-0.37	-0.26	1.0	-1.0	1.0	-1.0	1.0	1.0	1.0	1.0
Total porosity	0.96	0.90	0.64	0.44	0.37	0.26	-1.0	1.0	-1.0	1.0	-1.0	-1.0	-1.0	-1.0
pH	-0.96	-0.90	-0.64	-0.44	-0.37	-0.26	1.0	-1.0	1.0	-1.0	1.0	1.0	1.0	1.0
EC	0.96	0.90	0.64	0.44	0.37	0.26	-1.0	1.0	-1.0	1.0	-1.0	-1.0	-1.0	-1.0
Alkaline Nitrogen	-0.96	-0.90	-0.64	-0.44	-0.37	-0.26	1.0	-1.0	1.0	-1.0	1.0	1.0	1.0	1.0
Available Phosphorus	-0.96	-0.90	-0.64	-0.44	-0.37	-0.26	1.0	-1.0	1.0	-1.0	1.0	1.0	1.0	1.0
Available Potassium	-0.96	-0.90	-0.64	-0.44	-0.37	-0.26	1.0	-1.0	1.0	-1.0	1.0	1.0	1.0	1.0
Organic matter content	-0.96	-0.90	-0.64	-0.44	-0.37	-0.26	1.0	-1.0	1.0	-1.0	1.0	1.0	1.0	1.0

Fig. 1. Analysis of key factors influencing the growth of turfgrass seedlings.

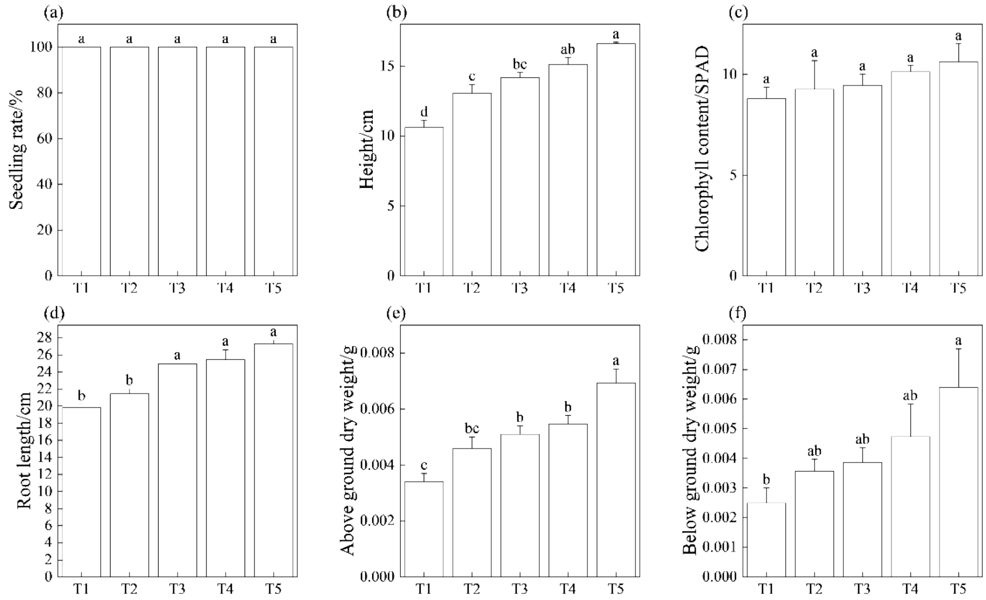


Fig. 2. Germination of turfgrass seeds under different leaching solution treatments.
Note: Different lowercase letters indicate significant differences at P<0.05.

indicators compared to T1 (100% vermiculite) (P<0.05). Compared to T1, the improvements under T5 were 56.70% for plant height, 37.69% for root length, 103.92% for above-ground dry weight, and 156. % for below-ground dry weight.

Discussion

Among various types of organic waste, aquatic silts are unique in terms of both physicochemical properties and potential for agricultural resource utilization [25]. From a physical perspective, aquatic silts typically have high bulk density and low porosity. These characteristics are unfavorable for root growth if silts are directly used as planting soils [26]. Additionally, industrial activities and human interventions contribute to the presence of harmful heavy metals in aquatic silts, limiting their application in agricultural and forestry fields [27]. According to the China agricultural industry standard NY/T 525-2021 Organic Fertilizer, silts are not listed as suitable raw materials for organic fertilizer production. This exclusion is based on safety concerns, as heavy metals and other toxic substances pose direct threats to human health [28]. Consequently, materials such as silt, fly ash, and steel slag are not permitted for organic fertilizer production. However, the national standard governing the composition and safety of organic substrates used in landscaping projects and the forestry industry standard that regulates the quality and application standards of organic substrates for forestry and ecological landscaping do not impose similar restrictions. Therefore, using aquatic silt in green turf substrates appears feasible from a regulatory standpoint.

The resource utilization of organic waste in landscaping has become a key focus, aiming to promote sustainability and reduce environmental risks. When effectively treated and transformed, organic waste can become a valuable resource for supporting plant growth while reducing reliance on non-renewable materials. For instance, compost derived from kitchen waste has been successfully used in several projects to produce green substrates, enhancing soil fertility and significantly improving the growth of turfgrass and landscaping plants. Additionally, agricultural waste, such as rice husks and straw, has been processed into organic substrates that improve soil structure and provide better plant moisture and nutrient conditions [18, 29]. After undergoing high-temperature composting, sewage sludge has also been widely applied in green substrate production, offering an economical and effective solution for urban landscaping while minimizing the environmental pollution risks associated with untreated sludge [30]. This approach not only alleviates the environmental burden of waste disposal but also prevents the release of toxic substances into ecosystems, thereby reducing potential risks to human health. Organic waste in landscaping enhances soil quality, promotes vegetation establishment, and contributes to circular economy practices. These examples further highlight the potential of organic waste as a versatile and eco-friendly material for developing sustainable green infrastructure.

This study investigated the effects of aquatic silt and vermiculite mixtures on the germination and growth of turfgrass seeds. The results showed that adding aquatic silt significantly promoted seed germination, as indicated by improved root length, germination potential, and germination index. The germination index under the 100% silt treatment (1.67) far exceeded the minimum threshold (0.65) specified in the GB/T 33891-2017 standard. However, only the 25% silt + 75% vermiculite mixture significantly enhanced growth indicators when evaluating seedling growth. Higher proportions of silt (>25%) inhibited seedling growth. The correlation analysis between seedling growth and the physicochemical properties of cultivation substrates (Fig. 1) indicated that bulk density, pH, alkaline hydrolyzable nitrogen, available phosphorus, available potassium, and organic matter content were negatively correlated with seedling growth. Table 3 shows that the maximum levels of alkaline hydrolyzable nitrogen (282.86 $mg \cdot kg^{-1}$), available phosphorus (40.73 $mg \cdot kg^{-1}$), available potassium (240.33 $mg \cdot kg^{-1}$), and organic matter (2.16%) were well below the thresholds specified in GB/T 33891-2017. Therefore, these factors are unlikely to be the primary negative influences on seedling growth. Conversely, the bulk density in substrates with more than 25% silt exceeded the standard limit of 0.5 $g \cdot cm^{-3}$ by up to 28% under the T3 treatment. Hydroponic experiments using leachates from the substrates further elucidated the role of substrate properties. Unlike the cultivation substrate experiment, where 25% silt was optimal, seedling growth indicators in hydroponic experiments improved consistently with increasing silt proportion. This discrepancy highlights that the high bulk density of substrates, rather than their chemical properties, was the primary limiting factor affecting seedling growth when aquatic silt was used.

While this study focused primarily on the agronomic performance of aquatic silt as a turfgrass substrate component, environmental safety remains a critical consideration for practical applications. Although the silt used was sourced from a site compliant with landscaping standards, it is recommended that site-specific assessments of heavy metals and other potential contaminants be conducted prior to large-scale utilization. To mitigate the risk of leachate pollution, especially in open-field landscaping projects, strategies such as installing impermeable barrier layers, incorporating biochar or zeolite to enhance adsorption capacity, and designing controlled drainage systems should be implemented. These measures can effectively prevent the migration of contaminants into surrounding soil and water bodies, ensuring that the ecological benefits of silt utilization are realized without compromising environmental safety. Future research should further explore these engineering and ecological safeguards to establish standardized protocols for sustainable silt application.

Conclusions

This study investigated the feasibility of using aquatic silt mixed with vermiculite as a cultivation substrate for turfgrass, aiming to explore its potential application in green turf substrate preparation. The results demonstrated that a 25% addition of aquatic silt to the substrate promoted turfgrass seedling growth to some extent. However, silt proportions exceeding 25% had inhibitory effects on growth. In contrast, the leachates from the substrates exhibited increasingly positive effects on seedling growth as the proportion of aquatic silt increased. The physical properties of aquatic silt, particularly bulk density, were identified as the critical factors influencing its cultivation effectiveness.

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Conflict of Interest

The authors declare no conflict of interest.

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