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Effects of Five Domestic and Imported Soil Organic Amendments on Weekly Seedling Emergence, Early Establishment Potential, Vertical Shoot Growth in a Stoloniferous-type Turfgrass (*Agrostis stolonifera*L.) in South Korea

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ABSTRACT
Due to limited supplies and importing costs, it is one of the goals ofthe Korean turf industry to replace overseas peat with local organic soil amendments. The experiment was initiated in creeping bentgrass (CB) to assess both local and overseas soil organic amendments (SOAs) on the early-stage growth characteristics, to recommend a reasonable mixing ratio for each amendment, and to provide the preliminary basic data for rootzone mixes on CB establishment. Twenty-five treatments were prepared with SOA plus sand at 10% to 50% (v/v).Significant differences were observed in early-stage growth characteristics. Seedling emergence,establishment vigor, and shoot growth were variable with the type of SOAs and their mixing rate in rootzone mixtures. At the termination of the study,the establishment vigor was shown from 20.70% in SOAS 20 to 92.30% in SOAB 10. Imported SOAB and domestic SOAE were rated as the most effective one, reaching more than 90% of establishment vigor at SOAB 10and 80% at SOAE 20 only in 2 WAS (weeks after seeding). Domestic SOAG was also a good amendment, yielding a maximum vigor of about 80% at SOAG 10 in 3 WAS. However, the SOAS amendmentshowed poor performance below 40% in establishing CB turf until 8WAS.Significant variations were also measured in CB shoot growth, being 5.17 cm in SOAG 20 to 16.67 cm in SOAS 50 with differences of 11.50 cm in plant height among treatments. In particular, greater differences in plant height resulted from SOAS treatments.Commonly, the best rootzone mixing rate to sand may be variable with the kind of SOAs. Regarding seedling emergence and establishment vigor, reasonable mixing rates are regarded as 10% (v/v), except for SOAP and SOAE. Proper rates for SOAP and SOAE were 30% (v/v) and 20% (v/v), respectively. Considering overall responses, both local SOAE and overseas SOAB are regarded as the most useful amendments for the early growing stage of CB establishment. However, the local SOAS amendmentwould be considered for low-maintenance turfs like rough and utility areas because of greater shoot growth.Repeated studies and field performance experiments are necessary to decide reasonable SOA and ratio for domestic sports turf application as a high-priced, importing peat substitute.

Keywords:Establishment vigor,Creeping bentgrass, Rootzone mixture, Seedling emergence, Top growth

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I. INTRODUCTION

Golf courses are notusually closed for sufficient time for turfgrass recovery or some cultural practices.Putting greens are subjected to regular irrigation, repeated mowing, and intense traffic [19, 31].Under these circumstances,maintaining high-quality greens becomes a real challenge for golf course superintendents.If greens are not appropriately established, they easily become compacted,resulting in poor growth, unacceptable quality, and undesirableplaying conditions [5].

Turfgrasses for putting greens must have specific characteristics such as a low growth habit, high shoot density, and strong tolerance to low-cut mowing of 5 mm [47]. In this view, creeping bentgrass (CB, *Agrostis stolonifera*L.) is the most commonspecies ofgreens, extensively used for the cool and transitional climate [9, 13].

Most green turfs are commonly established in the sand to resolve soil compaction[38].In the case of establishing CB in sand, organic amendments are integrated into rootzone mixes for sand greens. This application is useful in soil physical and chemical properties, leading to improved drainage, moisture retention, and nutrient holding capacity[30, 36, 44].Other benefits are also greater germination rate, better seedling survival, and higher turfquality.

Puustjarvi and Robertson[39]indicated two types of soil amendments are categorized by the raw materials used, being organic or inorganic amendments. Soil quality can be improved by organic materials[14, 25]. Several investigations [8, 10, 12, 14, 26, 33, 35, 39]demonstrated that it furnishes favorable environmental conditions that relate to increased beneficial microorganisms, disease suppression, enhanced turf growth and visual quality, and fertilizer and organic matter substitute.Soil amendments are useful for soil structure, aeration, nutrient availability, and ecosystem sustainability [23, 42].They also help to create better soil-water-air relationships. As a role of nutrient source, it is a good component, necessary for plant growth in turfgrass soil systems [15, 44].

In the turf industry, a standard organic amendment is a sphagnum peat around the world.It is a major organic source in golf course construction.However, Liu et al. [34] &Waltz Jr. and McCarty [46] statedthat peat is a nonrenewable resource in restricted supply.It is also lost within a few years as it decomposes with time after establishment[44]. Due to importing costs from overseas countries of Canada and the USA, it is also high-priced here in Korea. In addition, it is difficult to secure peat at a proper time for the construction schedule due to frequent, irregular delaysduring the plant quarantine process.The domesticnecessity for peat substitutes has been increased for years.One of the possible options is to use composted materials from locally available organic sources. However, local amendments are not used extensively in sports turf areas, due to limited information on the turf performance. Consequently, practical testsare necessary for domestic amendments.Moreover, their comparisons should be made with overseas standard organic soilamendments in the turf industry of Korea.

Koh et al. [30] reported organic amendments from local sawdust and animal manure improved turf quality and root growth of Korean lawngrass (*Zoysia japonica*Steud.) and Kentucky bluegrass (*Poa pratensis* L.). In studies by Kim, local amendments affected the turf growth and quality of perennial ryegrass (*Loliumperenne* L.)[16] and Kentucky bluegrass [17]. Several domestic investigators [12, 18, 20, 24, 26, 27, 28, 29, 30, 32] demonstrated turfgrass growth responses in rootzone mixtures of sand, nutrients, andorganic soil amendments.However, these studies were carried out with only one amendment or rootzone mixture with only overseas peat.A little information is available in comparison of local soil amendments with importing standard peats for turfgrass establishment21, 22, 24].

This experiment was initiated to assess both local and overseas soil amendments on the early-stage growth characteristics, to rate the performance for rootzone mixtures, to recommend reasonable mixing ratio for each amendment for a further field study, andto provide the preliminary basic data for rootzone mixes on CB establishment.

II. MATERIALS AND METHODS

2.1 Treatments and Rootzone Mixtures

The experiment was conducted with creeping bentgrass (*Agrostis stolonifera* L.) in the spring at Sahmyook University, Seoul, Korea. Treatments were made up of 25 rootzone mixtures of soil organic amendment (SOA) and sand. Two overseas and three local soil amendments were prepared as organic material sources for rootzone mixes, being SOAB (Berger Peat, Les Tourbières Berger Ltee, Quebec, Canada), SOAP (Premier Peat, Premier Tech Horticulture, Quebec, Canada), SOAG (G1-Soil, Nature & Environment Co. Ltd., Seoul, Korea), SOAS (Supersoil, Jookjoo Fertilizers, Iljuk, Kyounggi, Korea) and SOAE (Eco-Peat, Nature & Environment Co. Ltd., Seoul, Korea).

Basically, these materials were peat-type amendments except for SOAG and SOAS which were compost-type ones.Three peat-type amendments such as SOAB, SOAP and SOAE had organic matter content of 90 to 95%. The other compost-type amendments werelower than others, being 66.5% for SOAG and 77.8% for SOAS, respectively. Other chemical properties are as follows: SOAB is pH 3.78, EC 0.115 dS/m and CEC 124.6 me/100g;SOAP pH 3.60, EC 0.171 dS/m and CEC 127.6 me/100g; SOAG pH 6.13, EC 2.100 dS/m and CEC 38.3 me/100g; SOAS pH 6.41, EC 4.590 dS/m and CEC 81.9 me/100g; and SOAE pH 5.40, EC 3.830 dS/m and CEC 74.8 me/100g.

We prepared treatments with these five soil amendments at five volume percentages (10, 20, 30, 40, and 50%, v/v), being a total of 25 soil mixtures in the study. When preparing rootzone mixtures in a pot, the rest of the soil was sand for each treatment. We used sand acceptable for USGA green specifications in Table 1 [43].The pot size is 0.2 m x 0.2 m x 0.07 m.The experimental design was made up of a randomized complete block design with six replications.

Table 1. The particle size analysis of pure silica sand used for 25 treatment rootzone mixtures in the study.

	Particle size distribution (%)							
Particle	Gravel	Very coarse	Coarse	Medium	Fine	Very fine	Silt	Clay
size (mm)	2.0 -3.4	1.0 -2.0	0.5 -1.0	0.25 -0.5	0.15 -0.25	0.05 -0.15	0.002 -0.05	< 0.002
Criteria for USGA Spec.†	≤3%	≤7%	≥60%		≤20%	≤5%	≤5%	≤3%
Silica sand	1.00	1.30	92.00		2.75	1.30	0.75	0.03

†USGA: United States Golf Association.

CB seeds were obtained from Jacklin Seed Company (Post Falls, ID, USA). A preliminary germination test was carried out to good germination of the cultivar. Seeds were tested with 4 replications under a controlled incubator. Alternative conditions were applied, consisting of 8-hr light at 25℃ and 16-hr dark at 15℃[42]. The cultivar 'Penncross' was selected after a month's test, based on an over 90% germination rate. This cultivar has been widely used for golf course greens in South Korea as well as in cool-temperate regions [2, 41]. The seeds were sown at a rate of $10g \cdot m^{-2}$.

Creeping bentgrass turf was grown in a greenhouse environment with 15 to 30℃. Irrigation practice was done as needed to avoid drought stress. We did not mow turf during the study. Fungicide application was applied on a curative basis.

2.2 Data Collection and Analysis

We collected dataon early-stage growth characteristics such as seedling emergence, establishment vigor, and shoot growth.Weekly evaluation was made on seedling emergencefor two months. The emergence was rated as percentage of ground coverwhen the seedlings reached to over 1 cm out of soil surface. The establishment vigor was decided as the final turfgrass ground coverat the end of the study. Shoot growth was measured as plant height with six subsamples for each replication.Statistical analyses were performed by ANOVA procedure of the SAS System (SAS Institute, Inc., Cary, NC, USA). Duncan's multiple range test at $P \leq 0.05$ was used to compare means among treatments[40].

III. RESULTS AND DISCUSSION

3.1 Turfgrass establishment vigor

Statistically significant differences were found in seedling emergence, establishment vigor, and shoot growth during the early establishment stage. Results were variable with the type of SOAs and rootzone mixing ratio. The establishment vigor is explained in Figure 1. At the termination of the study,overall establishment vigor was shown between 20.70 and 92.30%. The SOABplots (Treatments 1 to 5) had an establishment vigor of 63.00 to 92.30%. The greatest vigor of 92.30% was observed from plots in SOAB 10. However, the lowest value of63.00% was also associated with the SOAB 40 mixture. Treatments 6 to 10 with SOAP mixtures had a range of 35.30 to 60.00% in establishment vigor. The highest was 60.00%, which was related tothe SOAP 30. But the lowest was 35.30% from plots in SOAP 50 mixture. In plots of SOAG mixtures (Treatments 11 to 15), the vigor varied between 49.30and 79.70%. The greatest vigor of 79.70% was from the SOAG 10, whereas the lowest was 49.30% from the SOAG 40. From the SOAS plots (Treatments 16 to 20), the establishment vigor ranged from 20.70 to 35.00%.The SOAS 10 mixture produced the greatest vigor of 35.00%.The lowest values were 20.70 and 21.70% from the SOAS 20 and SOAS 30 mixture, respectively. Treatments 21 to 25 with SOAE produced 44.70 to 86.30% in establishment vigor. The highest rating was 86.30% from plots in the SOAE 20 mixture. But the lowest vigor was 44.70% which was associated with SOAE 50.

These results indicated the CB establishment vigor differed with SOAs and rootzone mixing rate. Furthermore, the establishment trend was weekly observed as seedling emergence by WAS (weeks after seeding.The pattern was highly variable according to the SOA typewith time after seeding (Figure 2).Among the five SOAs tested, overseas SOABand domestic SOAE were rated as the most effective one, reaching more than 90% of establishment vigor at SOAB 10and 80% at SOAE 20 only in 2 WAS.Domestic SOAG was also a good amendment, yielding a maximum vigor of about80% at SOAG 10 in 3 WAS.However, the SOAS amendmentshowed poor performance below 40% in establishing CB turf until 8WAS.Most of theSOAPplots had an intermediate rate of establishment vigor, making between 50 and 60% in 8 WAS.

For the top rootzone mixture, the proper rate changed with SOAat the experiment.Generally, a rate between 10 and30% could be recommended for fast establishment vigor.Higher rates of over 40% led to very poor establishment.Glasgow et al. [11]reportedorganic compost materials are favorable in turfgrass establishment by improvingwater-holding capacity and nutrient retention.This conclusion is supported by the investigation of Magni et al. [37]. They concluded hydrophilic nature can explain the better moisture retention from the compost-amended soil.However, too much peat caused the soil properties of the rootzone mixture to become unfavorable for turf growth[6].In a study with Kentucky bluegrass, Kim [21]reported the establishment vigor decreased as the mixing rate increased from 0 to 50% when mixing soil organic amendment and sand. Organic materials in root zonesbeyond a certain level can cause macropore's blockage to worsen some soil physical properties such as aeration, drainage, and moisture retention.This turns out to decreased rooting and increased disease[1].

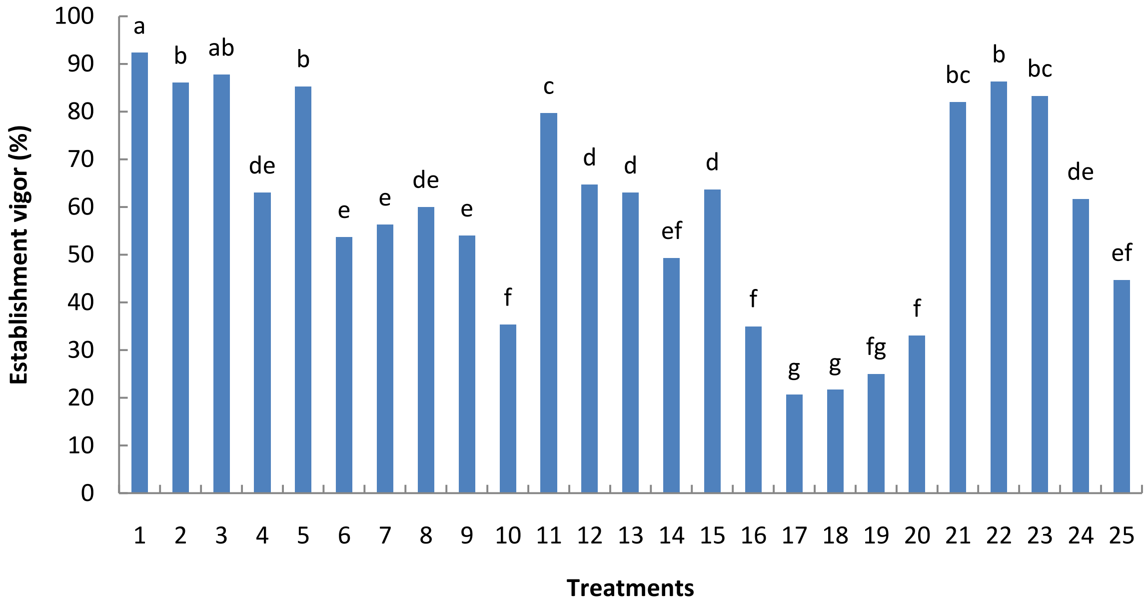

Figure 1. The establishment vigor of creeping bentgrass affected by five domestic and overseas soil soil amendments. The soil amendments were SOAB (Berger Peat, Canada; Treatments 1~5), SOAP (Premier Peat, Canada; Treatments 6~10), SOAG (G1-Soil, Korea; Treatments 11~15), and SOAS (Supersoil, Korea; Treatments 16~20) and SOAE (Eco-Peat, Korea; Treatments 21~25). Twenty-five rootzone mixtures were prepared with these amendments at five volume percentages (10, 20, 30, 40 and 50%, v/v). In each rootzone treatment mixtures, the remaining portion was filled with silica sand acceptable for USGA green recommendation. Bars with different letters are significantly different based on Duncan's multiple range test at $P \leq 0.05$.

3.2 Shoot growth

Significant variations were measured in CB shoot growth, being 5.17 to 16.67 cm with differences of 11.50 cm in plant height among treatments (Figure 3). The SOAB mixturesranged between 7.17 and 8.83 cm in plant height.The shortest height was related toSOAB 10, being 7.17 cm.Treatments amended with SOAP showed 6.33 to 7.50 cm in plant height. Evaluation ofthe SOAGmixtures indicated plant height ranged from 5.17 to6.33 cm. No significant variations were found among SOAP and SOAGrootzone treatments. However, there were statistically significant differences among the SOAS plots. It was greatly variable from 8.00 to 16.67 cm.The SOAS50 mixture had the greatest height of 16.67 cm.The second greatest value was 15.17 cm from SOAS30.But the shortest was 8.00 cm, being measured with SOAS 10. Both SOAS 20 and SOAS 40 mixtures demonstrated a similar height of 13.17 and 13.33 cm, respectively.SOAE treatmentsproduced 6.17 to 7.17 cm in height. No significant differences were also found among ratios for SOAE.

This data showed that shoot growth was greatly variable in CB, depending on the type of SOAs and their mixing rates.Generally, optimum rates were considered as 20 to 50% for vigorous shoot growth.Among the five SOAs evaluated, the SOAS amendment produced much greater shoot growth, showing over 13 cm in plant height from most SOASmixtures. Concerning other SOAs, however, there was not much difference in shoot growth, being 5 to 9 cm in plant height.

Genetically, CB is more inclined to horizontal growth because of a stoloniferous type of growth habit [19, 47]. This leads to shorter plant height when compared with bunch-type species of tall fescue (*Festuca arundinacea*Schreb.) and perennial ryegrass (*Loliumperenne* L.).However, this study indicated that the shoot growth orientation of CB is also affected by SOAs.In other words, it might grow more vertically according to the kind of SOAs used.Thisinterpretation was confirmed from the study with a Kentucky bluegrass of rhizomatous-type growth habit [21]. Consequently, it is practically needed to regard a specific SOA for a turf establishment purpose.For example, the higher plant height is more useful for a rough area, while the lower plant height is much more suitable for high-density areaslike tees and fairways [5].

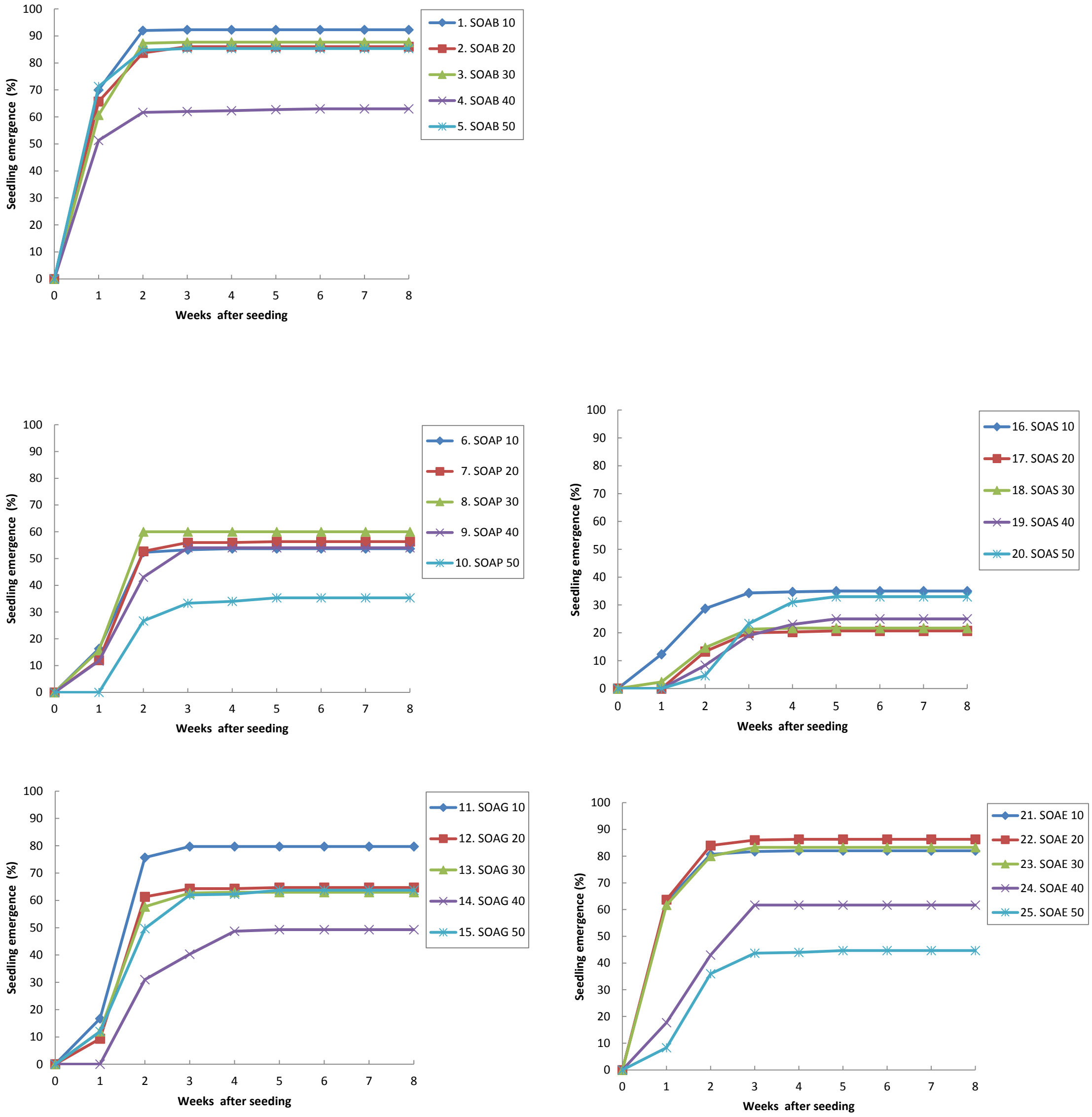

Figure 2. Seedling emergence variation in weeks after seeding of creeping bentgrass affected by five domestic and overseas soil soil amendments. The soil amendments were SOAB (Berger Peat, Canada; Treatments 1~5), SOAP (Premier Peat, Canada; Treatments 6~10), SOAG (G1-Soil, Korea; Treatments 11~15), and SOAS (Supersoil, Korea; Treatments 16~20) and SOAE (Eco-Peat, Korea; Treatments 21~25). Twenty-five rootzone mixtures were prepared with these amendments at five volume percentages (10, 20, 30, 40 and 50%, v/v). In each rootzone treatment mixtures, the remaining portion was filled with silica sand acceptable for USGA green recommendation. Bars with different letters are significantly different based on Duncan's multiple range test at $P \leq 0.05$.

Our data indicated that fast establishment was not necessarilyassociated with a higher SOA mixing rate.In particular, as for the SOAP and SOAE mixtures (Figure 1), we found that the highest mixing rate of 50% significantly led to a poorer establishment vigor not only in CB but also in Kentucky bluegrass [21].This can be clarified by the fact that optimum mixing rate enhances soil moisture and nutrient retention, resulting in good growth.However, its excessive mixing could alter soil physical and chemical balance in the rootzone mixtureresulting inpoor turf growth.As mentioned previously, Adams and Saxon [1] concluded organic materials exceeding a certain level can cause the blockage of macroporesto impair aeration, drainage, and water retention.Thereby, it might increase disease and reduce rooting.Soil amendment effects could differin mixed soil and mixture ratio and method[45].Acommon mixing rate for peat was considered as 5 to 20%(v/v), but excessive mixing turned out poor growth by altering physical and chemical properties of rootzone mix[6].

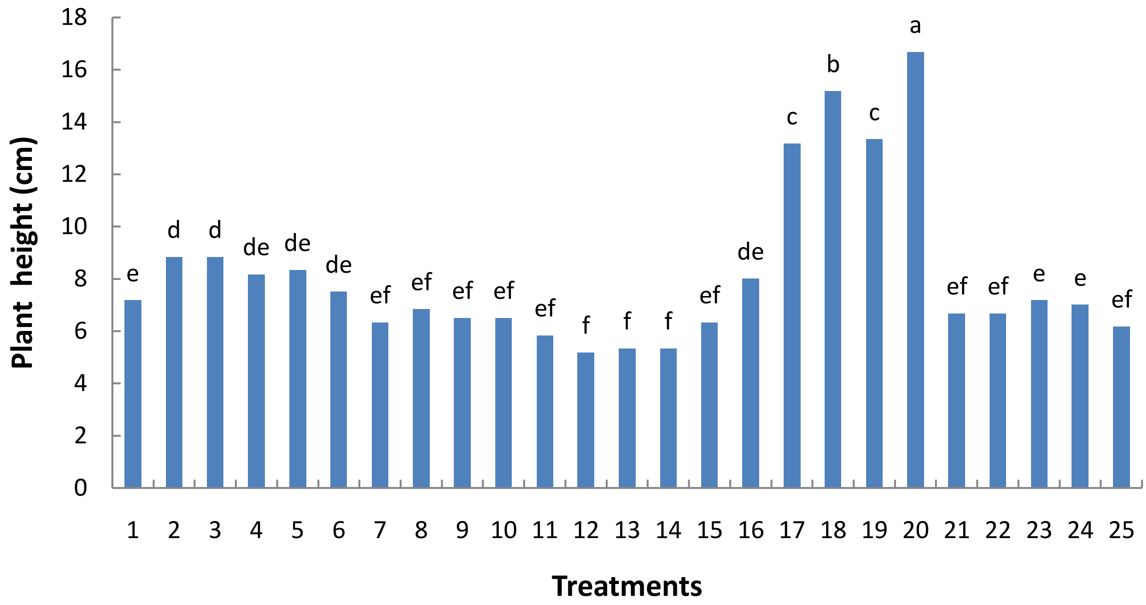

Figure 3. The shoot growth of creeping bentgrassaffected by five domestic and overseas soil soil amendments. The soil amendments were SOAB (Berger Peat, Canada; Treatments 1~5), SOAP (Premier Peat, Canada; Treatments 6~10), SOAG (G1-Soil, Korea; Treatments 11~15), and SOAS (Supersoil, Korea; Treatments 16~20) and SOAE (Eco-Peat, Korea; Treatments 21~25). Twenty-five rootzone mixtures were prepared with these amendments at five volume percentages (10, 20, 30, 40 and 50%, v/v). In each rootzone treatment mixtures, the remaining portion was filled with silica sand acceptable for USGA green recommendation. Bars with different letters are significantly different based on Duncan's multiple range test at $P \leq 0.05$.

At this experiment,local SOAs such as SOAE and SOAG may perform as well as imported peat. Also, we found differences in best growth responses according to SOAs and their rates. This conclusion is also supported by other studies.Under greenhouse conditions, Liu et al. [34] reported with warm-season turfgrasses increased clipping yields three times and enhanced quality in rootzone sand mixed by 15% (v/v) with organic compost materials.Some data with cool-season grass demonstrated that turfgrass growth and quality were influenced by soil amendment in perennial ryegrass[16] and Kentucky bluegrass [17].

Best rootzone mixing rate to sand may be variable with the kind of SOAs as summarized in Table 2. In regards of seedling emergence and establishment vigor, reasonable mixing rates are regarded as 10% (v/v) in our study except for SOAP and SOAE (Table 2). Proper rates for SOAP and SOAE were 30% (v/v) and 20% (v/v), respectively. The optimum rate for shoot growth isgenerally 30 to 50% (v/v), but it isvariable depending on SOAs. Further study is required in field conditions.Several authors demonstrated variable threshold levelsoforganic matter content in rootzone mixture. Carrow[7] reported the suitable content of organic matter as 4-5%(w/w)in sand-based root zones.Adams and Saxon [1], however, recommended the organic matter contents over 12%(w/w)for improving rootzone performance.

For organic matter levels, these conclusions were based on a weight basis.It would be variable as compared with a volume-to-volume basis, turning out potentially higher rates in mixtures.Jacobsen and McIntyre [15]indicated the organic materials from peat moss, composted pine bark, and coconut are successful for rootzone mixtures. They recommended the mixing amount is generally 10 to 15% (v/v). According to an on-site recommendation on a volume basis by Alkire[3], incorporation of organic matter with 10-20% should be applied to amend the sand in rootzone mixture of golf course turf.Recommendations for high performance, sand-based rootzones of sports fields suggest that proportions of peat in a rootzone blend should provide an organic matter content of 0.3 to 2.0% by weight which are usually similar to 15 to 20% by volume [4].

Table 2. Overall summary of turf performance and optimum rate for rootzone mixtures on creeping bentgrass according to soil organic amendment in the study.

Soil organic amendment†	Turf performance‡			Reasonable mixing rates (%, v/v)	
	Establishment vigor	Shoot growth	Overall rating	Establishment vigor	Shoot growth
SOAB	+++++	+++	+++++	10	20, 30
SOAP	++	++	+++	30	10
SOAG	+++	+	+++	10	10, 50
SOAS	+	+++++	+	10	30, 50
SOAE	++++	++	++++	20	30, 40

†SOAB: Berger Peat; SOAP: Premier Peat; SOAG: G1-Soil; SOAS: Supersoil; SOAE: Eco-Peat.
‡Turf performance: + = low, ++ = low to medium, +++ = medium, ++++ = medium to high, +++++ = high.

Therefore, it was considered that the optimum mixing rate would be variable with SOAs as well as turfgrass growth parameters. Also, even for the same soil organic materials, its effects might be variable with turfgrass species and its shoot-growth type. As for SOAB, the lowest rate of 10% (v/v) in rootzone mixtures demonstrated consistent turf performance, producing fast establishment in both CB and Kentucky bluegrass and also the highest density in CB [21, 22]. In a rhizomatous-type Kentucky bluegrass turf treated with SOAP [21], the fast establishment was associated with the lowest mixing rate of 10% (v/v), but a medium mixing rate of 30% (v/v) in this study with a stoloniferous-type CB. In the case of SOAE treatments, SOAE 20 showed fast establishment vigor in CB turf, while both SOAE 10 and SOAE 20 produced fast establishment in Kentucky bluegrass turf [21]. However, the other growth parameter of turfgrass density in the CB study [22] was highly associated with a rate over 40 to 50% (v/v) in mixtures with SOAE and SOAP. Regarding shoot growth, the highest rate of 50% rootzone mixtures (v/v) with SOAS demonstrated the highest value of plant height in this CB study, but a medium mixing rate of 30% (v/v) produced the highest height in the Kentucky bluegrass study [21]. This means that there would be feasibility to different requirements to soil organic amendments on sand-based soccer fields and golf course putting greens.

These species-specific responses to SOAs have been inconsistent and the impact of soil organic materials as part of repeated soil incorporation to rootzone remains unclear. In other words, further field study to assess turfgrass species-to-soil amendment variation be required in future. Also, it is necessary to test soil organic materials by other species before on-site planting.]

IV. CONCLUSION

Considering total responses to this study's early-stage growth characteristics,domestic SOAEand imported SOAB amendments are rated as the most useful amendments for the high-maintenanceCB of the sand-based rootzone. Further, domestic amendment SOAG is also a good organic source for rootzone mixture. However, the amendmentSOASwould be considered for the low-maintenance turfs like rough and utility areas because of its vertically greater shoot growth.However, repeated studies and field performance experiments are necessary to decide reasonable SOA and ratio for domestic sports turf application as a high-priced, importing peat substitute. This preliminary data would be valuable for rootzone treatment mixtures for further field study.

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