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Root morphology, growth dynamics, and turf quality of perennial ryegrass grown in soil with water-retaining amendments and exogenous organic matter

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ABSTRACT

The establishment of high-quality turf on soils with limited water-retention capacity requires amendments that improve both nutrient availability and root-zone conditions. This study evaluated the effects of exogenous organic matter and water-retaining soil amendments on the growth dynamics, root morphology, physiological condition, and visual quality of perennial ryegrass (*Lolium perenne* L.). A three-year field experiment was conducted in eastern Poland from 2018 to 2020 using a split-plot design. The first experimental factor included sewage sludge-derived compost, sewage sludge granules, and an untreated control, while the second comprised coconut fiber, hydrogel, their combination, and a control without water-retaining amendments. Seedling emergence, shoot number, growth intensity, root length and dry mass, leaf chlorophyll index (SPAD), and turf visual quality were assessed. Compost increased seedling emergence and shoot number by 19.6% and 27.7%, respectively, compared with the control. The combined application of coconut fiber and hydrogel increased these parameters by 35.4% and 42.1%, respectively. Both forms of exogenous organic matter significantly enhanced root development. Mean root length increased from 13.5 cm in the control to 18.0 cm with compost and 19.2 cm with granules, while root dry mass increased from 4.1 to 5.5 and 5.1 g, respectively. Water-retaining amendments also improved root morphology, with the combined coconut fiber and hydrogel treatment producing the longest roots and the greatest root dry mass. The amendments increased SPAD values and improved turf visual quality, particularly when sewage sludge granules were combined with coconut fiber and hydrogel. The results demonstrate that integrating exogenous organic matter with water-retaining amendments can improve perennial ryegrass establishment, root development, physiological condition, and turf quality under variable hydrothermal conditions.

Keywords: compost, sewage, coconut fiber, granulate, hydrogel.

INTRODUCTION

The establishment of green areas on urban, recreational, and degraded land requires appropriate soil preparation to ensure favorable conditions for seed germination, root development, and sustainable turf growth. Soil quality is one of the key factors determining successful lawn establishment because it affects water retention, nutrient availability, aeration, and soil microbial activity. Urban soils often have low organic matter content, high compaction, and limited water capacity, which can considerably restrict grass growth (Loschinkohl and Boehm 2001, Larney and Angers 2012).

In recent years, increasing attention has been paid to exogenous organic matter (EOM) as a means of improving soil physical, chemical, and biological properties. Such materials include composts, sewage sludge, biosolids, digestate, and other processed organic waste products. Their use is consistent with circular economy principles by reducing waste disposal and enabling the recycling of organic matter and nutrients into soils (Barthod et al. 2018, Myszura-Dymek 2024, Paganini et al. 2024). EOM can improve soil structure by reducing bulk density, increasing porosity, and enhancing infiltration and water retention, which is particularly

important during lawn establishment when grass seedlings are sensitive to water shortages and unfavorable air-water conditions. Organic matter also supplies macro- and micronutrients, reduces wilting, improves turf color, and promotes aboveground and belowground biomass development (Liu and Guo 2019, Loschinkohl and Boehm 2001). Sewage sludge and its processed products, including composts and organic granules, are particularly valuable because of their high organic matter and nutrient content, especially nitrogen and phosphorus. Properly processed biosolids can support grass growth and improve substrate properties; however, their chemical composition must be controlled, particularly with regard to heavy metals and salinity (Liu and Guo 2019, Myszura-Dymek 2024, Paganini et al. 2024).

In addition to nutrient availability, the ability of the substrate to retain water and air in the root zone strongly affects plant establishment. Water deficiency during germination and root development can substantially delay turf formation, especially on sandy or anthropogenically transformed soils with low water-holding capacity. One approach to improving water availability is the use of polymer superabsorbents, commonly referred to as hydrogels. These materials absorb and store water and gradually release it into the root zone as substrate moisture decreases. Hydrogels can increase soil water-holding capacity, reduce losses through evaporation and percolation, and improve plant water-use efficiency (Akhter et al. 2004, Saha et al. 2020). Their benefits may be particularly important under water stress and in substrates with poor water retention. Coconut fiber represents an alternative amendment for improving substrate physical properties. As a natural by-product of coconut processing, it is widely used in horticultural substrates because of its high porosity, favorable air-to-water ratio, and ability to retain moisture. Coconut fiber can improve substrate structure, increase water availability, reduce compaction, improve aeration, and support root system development (Xiong et al. 2017, Londra et al. 2018). Unlike hydrogels, which mainly act as water absorbents, coconut fiber modifies both moisture conditions and substrate structure, thereby influencing the root environment over a longer period.

Despite numerous studies on exogenous organic matter and water-retaining amendments, relatively little is known about their combined effects on grass development during turf establishment, particularly on root system morphology. EOM primarily improves nutrient availability and the biological and structural properties of soil, whereas hydrogels and coconut fiber mainly modify substrate physical properties and water availability. Because these amendments influence the root environment through different mechanisms, their comparison may provide valuable information for selecting effective strategies for lawn establishment on poor-quality substrates and under limited water availability. Therefore, the aim of the experiment was to assess the effects of selected forms of exogenous organic matter and water-absorbing materials on perennial ryegrass root morphology, growth dynamics, and turf quality during lawn establishment in the first years of use.

MATERIALS AND METHODS

Experimental conditions

The lawn experiment was established in the experimental field of the University of Siedlce, eastern Poland (52°10'11.63" N; 22°17'14.99" E), in the autumn of 2017. The research was conducted on 4 m² plots with a split-plot design throughout the 2018–2020 growing periods. The climate in eastern Poland is temperate, with favorable conditions to conducting research on grass growth and development. The plant used in the experiment was perennial ryegrass (*Lolium perenne* L.) of the Boxer variety, sown in accordance with the seeding standard of 3 kg per 100 m². Boxer is an early, diploid lawn variety, with high durability, dense habit, and resistance to leaf and shoot diseases.

The experiment was conducted on light clay sand soil classified according to the FAO taxonomy (2005) as a technosol. The soil was of a neutral reaction (pH 6.92), with favorable conditions for the growth of most grass species. Total nitrogen content was 0.259 $g \cdot kg^{-1}$ of soil DM, while organic matter content was 5.64 $g \cdot kg^{-1}$DM. The level of soil organic carbon reached 3.27 $g \cdot kg^{-1}$DM, the content of absorbable phosphorus was high (106 mg P_2O_5 per 100 g of soil), with moderate amounts of potassium (15.5 mg K_2O per 100 g of soil) and magnesium (8.7 mg per 100 g of soil). Such properties indicate that the soil was of relatively good chemical parameters.

Experimental factors

The first experimental factor was exogenous organic matter applied in the following forms and doses: control (four plots without the addition of organic matter, but with different water-retaining amendments); sewage sludge compost applied at a dose of 100 kg per 100 m²; sewage sludge granules at a dose of 50 kg per 100 m². The above doses were established based on the content of organic matter in the soil. The materials were analyzed for their basic chemical properties and then introduced into the soil to a depth of about 5 cm. Compost was of a slightly alkaline reaction (pH 7.4), with organic matter content of 16.73%. The amounts of its available micronutrients were as follows: manganese 156.0 mg·kg^{-1}, copper 18.3 mg·kg^{-1}, zinc 125.0 mg·kg^{-1}, and iron 1325.0 mg·kg^{-1}. The following amounts of macronutrients were determined: phosphorus (P_2O_5) 396.0 mg·100 g^{-1}, potassium (K_2O) 73.2 mg·100 g^{-1}, and magnesium 216.0 mg·100 g^{-1}. The content of heavy metals was 43.4 mg·kg^{-1}DM of lead and 0.36 mg·kg^{-1}DM of cadmium. In granules the content of organic matter was high (69.01%), pH was close to neutral (6.8), and the content of available micronutrients was also high: manganese 563.0 mg·kg^{-1}, copper 125.0 mg·kg^{-1}, zinc 938.0 mg·kg^{-1}, and iron 15,000.0 mg·kg^{-1}. The determined macronutrients included phosphorus (P_2O_4) 1129.0 mg·100 g^{-1}, potassium (K_2O) 59.2 mg·100 g^{-1}, and magnesium 535.0 mg·100 g^{-1}. The concentration of heavy metals in granules was 19.1 mg·kg^{-1}DM of lead and 0.89 mg·kg^{-1}DM of cadmium. Both organic materials were added to substrate as a source of organic matter and nutrients. The doses of the applied materials were determined based on their organic matter and mineral nutrient contents, taking into account differences in their chemical composition. The granulated material contained higher amounts of organic matter and most of the analyzed micronutrients than the compost; therefore, it was applied at half the dose used for the compost.

The second experimental factor was the use of materials increasing soil water storage. Four variants were arranged: control (one plot, without amendments and without additional organic matter); coconut fiber at a rate of 200 dm³ per 100 m²; hydrogel with 5000 g per 100 m²; a combination of coconut fiber and hydrogel at doses of 100 dm³ per 100 m² and 2500 g per 100 m², respectively. Water-absorbing materials were placed in the soil at a depth of about 10 cm.

The experiment was established in a split-plot design, in which soil absorbents were applied as the main-plot factor, while exogenous organic matter (EOM) was applied as the subplot factor. Within each experimental block, the soil absorbent treatments were randomly assigned to the main plots. Soil absorbents were selected as the main factor for methodological and technical reasons, as their application required incorporation into a deeper soil layer than EOM. Subsequently, each main plot was divided into subplots, to which the individual EOM treatments were randomly assigned. The randomization of EOM treatments was carried out independently within each main plot.

Plants were not irrigated so as not to distort the findings. Additionally, all experimental plots were fertilized with doses of nitrogen (1.5 kg N per 100 m²) and potassium (0.8 kg K per 100 m²). In each growing period (2018–2020) 40% of the total dose of each fertilizer was applied in April after the first mowing, while the other two doses of 30% in May/June and August/September. Phosphorus fertilizers were not applied due to its high content in the soil.

Tested characteristics

Emerged plants were counted 30 days after grass seed installation**.** The unit of assessment was an area of 100 cm² (10 × 10 cm) determined with a randomly thrown quadrate. The measurement was conducted on each plot in three places. Three samples from each plot were collected for root morphometry once a year (i.e., in 2018, 2019, and 2020) in the second half of September. A root ball was removed from the ground using a 1500 cm³ cylindrical sampler. Each sample was rinsed and the number of shoots was counted, and then the aboveground part was cut off, leaving only the roots to measure their length and fresh matter weight. In the next stage, the roots were dried until the constant weight. Finally, they were weighted to determine their dry mass. Leaf chlorophyll content was measured with the SPAD-502 Chlorophyll Meter (Konica Minolta), which allowed for a fast, non-destructive measurement of leaf greenness, correlated with chlorophyll content. Measurements were taken on fully developed 10 leaves from each plot, and the results were expressed in SPAD units. Grass visual quality was assessed using a 1-9 scale, according to the National Grass Evaluation Program – NTEP

in the United States (Beard, 1973, Depth et al. 2020, Kazemi et al. 2020). Turf very unfavorable appearance and grass light green color meant the lowest assessment (1), while the highest rating (9) was assigned to leaves with excellent visual quality and dark green color. The assessment was done three times in each growing period (in 2018, 2019, and 2020). The growth intensity of plants was assessed measuring their height on all plots and comparing it with control, for the latter a value of 5 on a 9-point scale was assumed. Plants shorter than control ones were rated above 5, while grass growing faster received values below 5. Using this scale, the assessment was done at regular intervals during the growing period.

Hydrothermal conditions

The growing periods differed in terms of soil moisture and air temperature, both affecting plant growth and development. Periods of particularly unfavorable weather with limited rainfall and elevated temperatures resulted in drought stress (Figure 1). The highest monthly precipitation was recorded in June and July, with June 2020 being particularly wet with over 115 mm of rainfall, significantly above the multiannual mean. In 2019 the distribution of precipitation was more uneven, with periodic moisture shortages – a consequence of very low monthly rainfall in April, July, August, and October. Moderate precipitation was recorded in 2018, with an increased value in May and July. The highest temperatures were in 2019, especially in the summer when they exceeded the long-term average. Temperatures close to the multiannual average were recorded in 2018, while the growing period of 2020 was more favorable for plant growth than the others.

Statistical analysis

The results of the experiment were statistically processed using the Statistica 13.3 program (TIBCO Software Inc., Palo Alto, CA, USA). The data were analyzed at a significance level of $p \leq 0.05$. The significance of differences between means was assessed using analysis of variance (ANOVA). Tukey's test was applied to compare means. Means statistically significantly different from others were marked with different letters in charts below.

RESULTS

Plant growth dynamics and development

According to the charts below, the highest number of seedlings that emerged after 30 days was noted on the plots treated with compost, while the highest number of shoots in response to with granules (Figure 2a, b). In both cases, coconut fiber and hydrogel applied together increased plant emergence and the shoot number. The intensity of growth did not statistically significantly vary among plots with different experimental factors, but some trends were observed (Figure 2c). The highest values were usually recorded on the control plots, especially on the one not treated with water retention amendments, while exogenous organic matter and coconut fiber, hydrogel, and their combination decreased this parameter.

Presented as a bar chart, plant emergence was significantly varied in response to exogenous organic matter and amendments improving substrate water retention (Figure 3a). The highest three-year average value, 19.6% higher than for control, was recorded on the plots with compost.

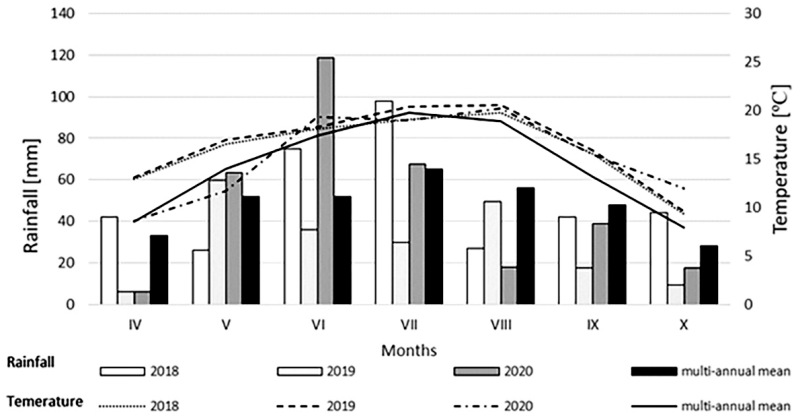

Figure 1. Average monthly air temperature (°C) and monthly precipitation (mm)

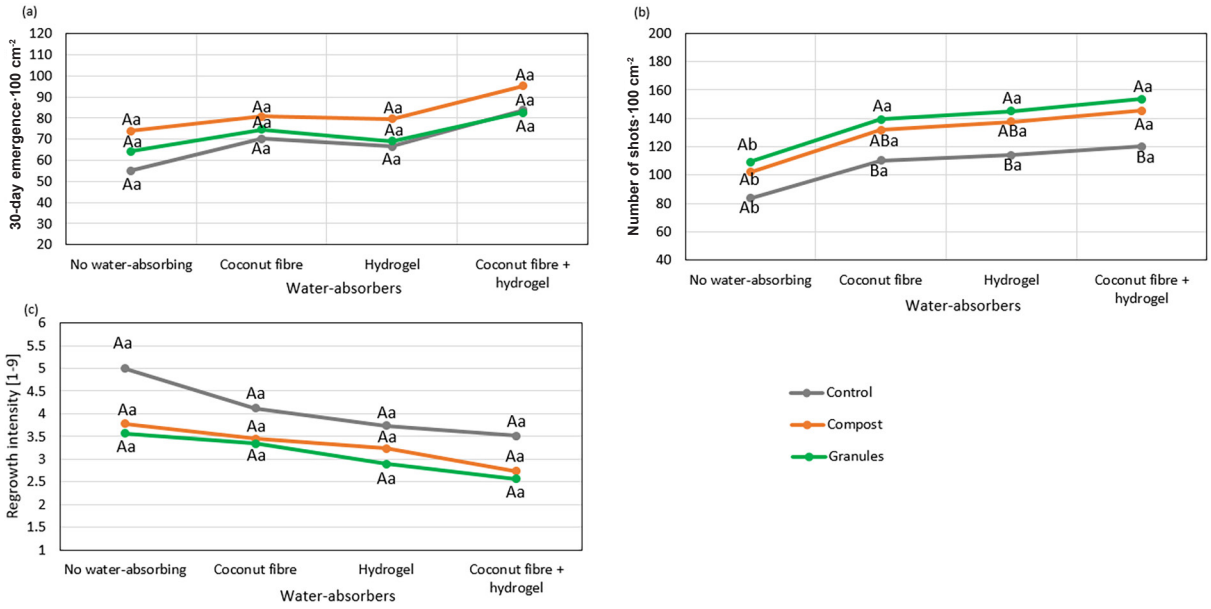

Figure 2. The effect of interaction between soil absorbents and exogenous organic matter on a) seedling emergence after 30 days from seed installation; b) number of shoots; c) the intensity of growth Horizontal values marked with different lowercase letters are significantly different ($p < 0.05$). Vertical values marked with different uppercase letters are significantly different ($p < 0.05$)

Across the effects of water-absorbing additives, the highest emergence was noted in the variant with a combination of coconut fiber and hydrogel, with an increase relative to control of 35.4%.

The number of shoots was significantly dependent on the types of exogenous organic matter and of additives improving substrate water properties (Figure 3b). Compost significantly increased the value, by 27.7% compared to control, while the lowest was on the control plots, without organic matter added. A similar relationship was observed with regard to amendments. The mixture of coconut fiber and hydrogel led to a significant increase in the number of shoots, by 42.1% relative to control. Different hydrothermal conditions across growing periods did not affect the number of shoots significantly. However, some changes across years were noted, with the highest value in 2018, and the lowest in 2019. The first year of the experiment was much wetter with good conditions for plant growth, and 2019 was with rainfall shortages reducing the number of shoots.

The intensity of growth did not vary significantly across the growing periods, but it was significantly dependent on the type of organic matter and of water retention additives (Figure 3c). Granule application resulted in the most intensive, unwanted plant growth, which lowered the turf rating by 32.4%. Similarly, in the case of additives improving water retention, the highest growth intensity was in response to coconut fiber and hydrogel applied together, lowering the grass rating by 32.8%.

Experimental factors significantly affected both root dry mass and length (Figure 4). Root dry mass was significantly dependent on the type of exogenous organic matter and of soil amendments (Figure 4a). Across the control plots, each without additional organic matter, the lowest value was recorded on the one without amendments (3.4 g), while the highest in the variant with coconut fiber (5.0 g). For the plots with compost, dry root mass, ranging from 4.0 to 5.9 g, was higher than for control units, the latter with the lowest value, while the highest was noted in the variant with hydrogel and compost. Across the granule-added plots, the dry mass of roots did not vary much and ranged from 5.0 to 5.9 g, with the highest value in response to hydrogel.

A similar tendency was noted for root length, ranging from 10.0 to 18.0 cm across control variants, with the shortest ones on the plot without soil amendments and the longest in response to the combined use of coconut fiber and hydrogel (Figure 4b). Root length was higher on the plots with compost, with the highest values when applied with coconut fiber and hydrogel (over 20.0 cm), and the lowest in the variant without amendments (over 15.0 cm). On the granulate-added plots, root length ranged from 13.0 to 19.0 cm, with the

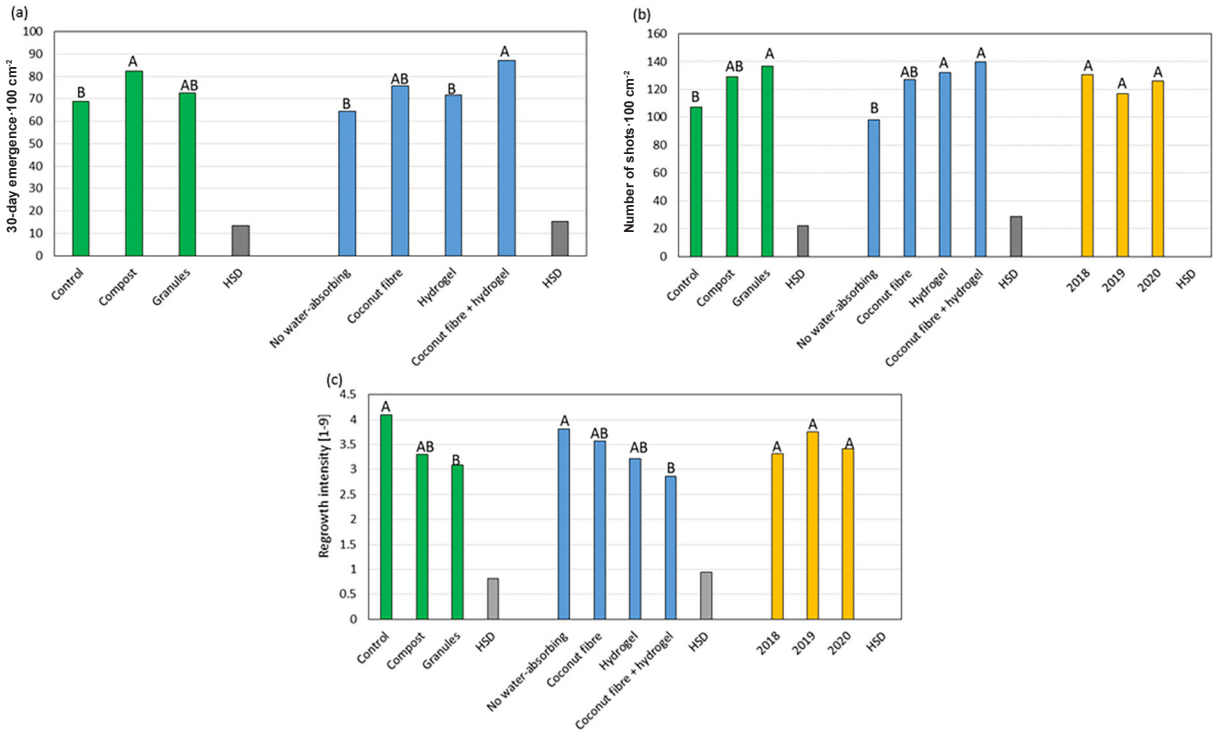

Figure 3. The effect of interaction between soil absorbents, exogenous organic matter, and growing periods on a) seedling emergence after 30 days; b) number of shoots; c) growth intensity
Values marked with different uppercase letters are statistically significantly different ($p < 0.05$)

longest ones recorded on the plot with coconut fiber. Dry root mass and length significantly varied across years and types of exogenous organic matter and soil amendments (Figure 5). The dry mass of roots was the lowest on the control plots (4.1 g), without additional organic matter, significantly lower than in substrate with compost (5.5 g) or with granules (5.1 g). No significant differences were noted between the effects of the latter two (Figure 5a). The lowest root dry mass was in the variant without amendments (4.2 g), with significantly higher values in response to coconut fiber (5.3 g), hydrogel (4.8 g), and their combination (5.4 g). The highest dry mass of roots was produced by plants on the plot with the combined use of coconut fiber and hydrogel, although it did not differ significantly from the effect of coconut fiber. The value increased with years – from 3.4 g in 2018, 5.4 g in 2019, to 6.0 g in 2020, with all differences being statistically significant.

Similar relationships were observed for root length (Figure 5b), with the average of 13.5 cm on the control plots (without exogenous organic matter), significantly lower than after the application of compost (18.0 cm) or granules (19.2 cm). Those two values did not differ significantly. Roots were shortest in the non-amendment variant (13.0 cm), while the use of coconut fiber (18.5 cm), hydrogel (17.0 cm), and a combination of coconut fiber with hydrogel (19.3 cm) significantly increased their length. The longest roots were recorded in response to the combined application of coconut fiber and hydrogel, whose effect did not differ significantly from that of coconut fiber on its own. Roots were shortest in 2018 (13.0 cm), significantly longer in 2019 (18.0 cm), and the longest in 2020 (19.3 cm), with no statistically significant differences between 2019 and 2020.

Physiological state and visual quality of plants

Turf visual quality significantly varied depending on the experimental factors. The lowest value of 4.50 was recorded on the control plot, the one without water retention additives, especially in 2019. The use of exogenous organic matter improved turf appearance, with granules being more effective than compost. Additives improving water retention also had a positive effect on turf quality, with the highest values for the variant with the combined use of coconut fiber and hydrogel. Across years the highest score (8.83) was noted

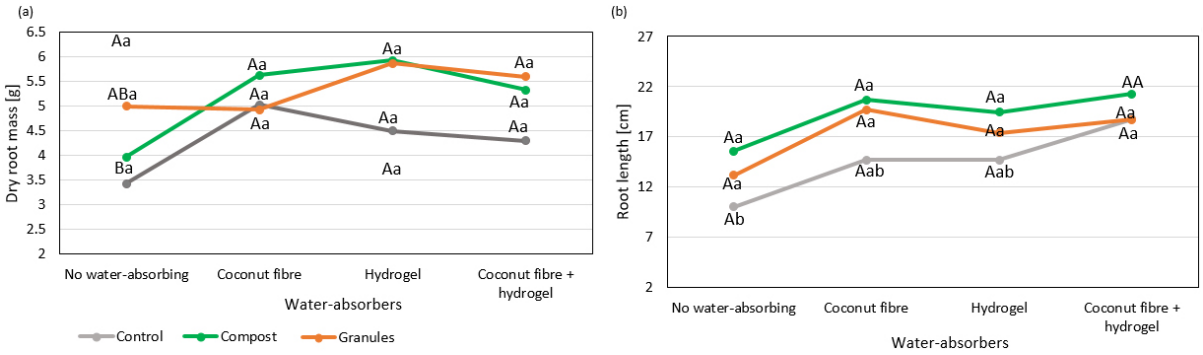

Figure 4. The effect of interaction between soil absorbent and exogenous organic matter on a) dry mass of roots; b) length of roots
Horizontal values marked with different lowercase letters are significantly different ($p < 0.05$).
Vertical values marked with different uppercase letters differ are significantly different ($p < 0.05$).

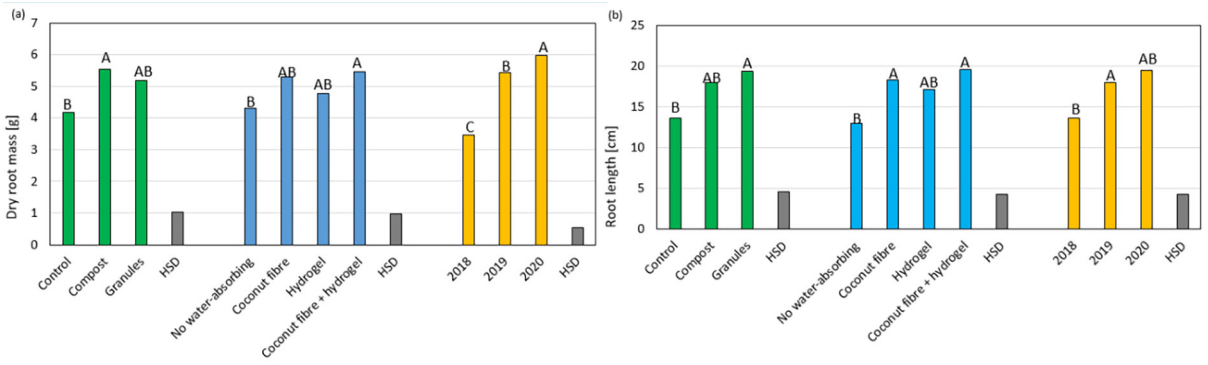

Figure 5. The effect of interaction between soil absorbents, exogenous organic matter, and years of research on a) dry mass of roots; b) root length. Values marked with different letters are significantly different ($p < 0.05$)

in 2018 in response to granules applied together with the mixture of coconut fiber and hydrogel.

According to the charts below, SPAD index values indicated a clear effect of exogenous organic matter and amendments improving substrate water retention on the physiological condition of plants (Figure 6a). The lowest values ranging from about 27 to 35 were recorded across the control plots, without additional organic matter. Compost increased this parameter, but higher values were noted in response to granules. The latter increased chlorophyll content gradually, with the plant weakest response to coconut fiber, stronger to hydrogel, and the strongest to the combination of coconut fiber and hydrogel (about 45). A similar trend was observed for compost, with an increase to about 43 when applied with the mixture of coconut fiber and hydrogel.

Similar responses to experimental factors were observed for turf visual aspect (Figure 6b): the lowest value of 5.5 points was noted on the control plot without water retention additives. The use of coconut fiber, hydrogel, and of their combination improved turf visual aspect. Higher ratings were assigned to plots fertilized with compost, but when it was applied with hydrogel, a noticeable decrease was observed compared to the effect of coconut fiber. The highest values were noted on the plots treated with granules, especially on the one with the combined dose of coconut fiber and hydrogel, with the rating exceeding 8.5 points.

According to the bar chart below, exogenous organic matter and soil amendments significantly affected the SPAD index (Figure 7a). Of both organic matter forms, a higher SPAD increase was noted in response to granules (about 39), although the differences between the effects of compost and granules were not statistically significant. The use of coconut fiber and hydrogel resulted in an increase in the SPAD index, while the lowest (about 30) was noted on the plot without water absorbents. The index was highest (about 41) in response to the combined application of coconut fiber and hydrogel, indicating their beneficial effect on water availability and on chlorophyll content in leaves. Of all experimental years the

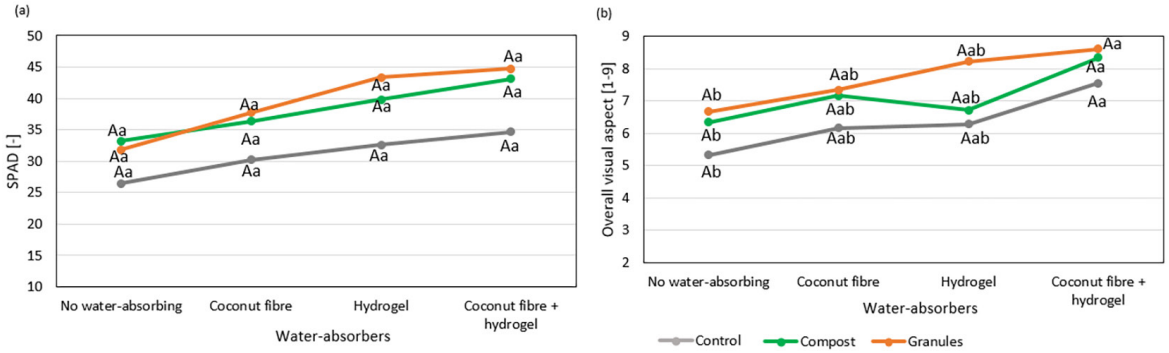

Figure 6. The effect of interaction between soil absorbents and exogenous organic matter on a) the grass SPAD index; b) visual aspect. Horizontal values marked with different lowercase letters are significantly different ($p < 0.05$)
Vertical values marked with different uppercase letters are significantly different ($p < 0.05$)

highest SPAD values were in 2018, and the lowest in 2019, which might have resulted from less favorable hydrothermal conditions that year.

The ratings of turf visual quality significantly varied in response to experimental factors (Figure 7b). The lowest one was assigned to control plots, with the average value of 6.3 points. The use of compost improved the rating to about 7.1 points, while the highest was assigned to the effect of granules (about 7.7 points). A similar trend was observed for amendments, with the lowest rating for the plot without their addition (about 6.0), while the mixture of coconut fiber and hydrogel improved the visual quality to over 8.0 points, which indicated the synergistic effect of these materials. Across years the highest rating of visual quality was noted in 2018, while in 2019 it was the lowest. In 2020, there was an improvement compared to the previous year, but the value was still lower than in the first year of the experiment.

DISCUSSION

Growth dynamics and plant development

The greatest seedling emergence was recorded on plots with compost, applied to the top layer of the soil, and in response to the mixture of hydrogel and coconut fiber, added to the deeper layer. According to the literature, exogenous organic matter in various forms is beneficial for the emergence of perennial ryegrass. Uzun and Bilgili (2011) observed that the addition of dried sewage sludge contributed to an increase, relative to control, in plant emergence and turf density and appearance. Similarly, Grabowski et al. (2008) confirmed that sewage sludge fostered the emergence and tillering of lawn grass. In the present experiment, hydrogel applied together with coconut fiber created a kind of synergy that provided stable conditions for germination. Hydrogel reduced the rapid drying of coconut fiber, and the latter limited excessive moisture caused by hydrogel. However, the use of hydrogel on its own did not significantly increase the emergence of plants. According to Jankowski et al. (2010), the application of hydrogel in the cultivation of perennial ryegrass lawn mixtures decreased emergence even below the values recorded on the control plot. The authors assumed that hydrogel bound water in the 10-cm layer of soil and restricted germination.

The largest number of shoots was recorded on the plot with granules applied together with a combination of hydrogel and coconut fiber, but compost also positively affected it. According to the classification proposed by Da Silva et al. (2015), the shoot number of 100–200 · 100 cm^{-2} noted in the present experiment is typical, while values below 100 · 100 cm^{-2}, recorded mainly on control plots, including the one without amendments, are not satisfactory. The literature lacks information on the number of shoots in response to exogenous organic matter or soil amendments. Many authors use a less precise term of 'turf density', whose meaning is anyway related to 'the number of shoots' (Laidlaw 2005).

Uzun and Bilgili (2011) confirmed that the use of sewage sludge in the cultivation of perennial ryegrass increased turf density. In turn, Garling and Boehm (2001) reported that the addition of compost resulted in a similar effect. According to Gislum and Griffith (2007), an increase

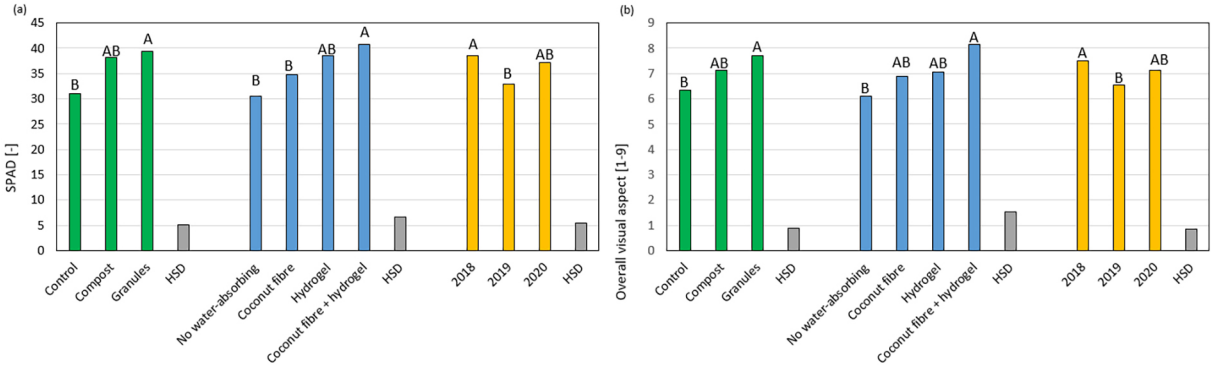

Figure 7. The effect of interaction between soil absorbents, exogenous organic matter, and growing seasons on a) the grass SPAD index; b) visual aspect
Values marked with different letters are significantly different ($p < 0.05$)

in nitrogen availability resulted in an increase in the number of vegetative and generative shoots, while lower nitrogen absorption decreased perennial ryegrass shoots. This mechanism explains why plants grown on substrate with the addition of organic matter, which is a source of nitrogen, produced more shoots. The literature does not provide information on the effect of coconut fiber added to substrate on the number of lawn grass shoots. However, according to Xiong et al. (2017), an addition of coconut fiber can stimulate plant growth by improving substrate properties, i.e., porosity, aeration, and water retention. In the case of hydrogel, the results of the present research confirmed the previous findings of Jankowski et al. (2013), who reported that improved water retention in the root zone significantly increased the number of shoots of lawn grasses.

The results of the present research indicated that sewage sludge granules statistically significantly affected perennial ryegrass growth. The doses of soil amendments also increased growth intensity. In the literature, reports on the impact of EOM on perennial ryegrass growth vary. According to Taşkın and Bilgili (2023), exogenous organic matter in the form of sewage sludge did not significantly affect the growth intensity of perennial ryegrass. Contrary to that, Antille et al. (2014) and Bai et al. (2014) reported that fertilizers containing sewage sludge intensified the growth and increased the biomass of perennial ryegrass. According to Shen et al. (2024), EOM increased soil moisture and availability of plant nutrients. EOM nutrients promote more intensive plant growth, but in the case of lawns this is a disadvantage because it increases the number of mowings. In addition, as the present results indicate, the addition of soil amendments in the form of hydrogel combined with coconut fiber also contributed to the more intensive grass growth. According to Jankowski et al. (2013), hydrogel reduces water stress, which translates into faster grass growth. In addition, coconut fiber stabilizes soil water retention, improves aeration, and increases porosity, which also means faster growth of the aerial part (Xiong et al. 2017).

Root morphometry

The most developed root systems in terms of weight and length were on the plots with granules or compost both applied together with soil absorbents. On the other hand, compost applied together with the combined dose of coconut fiber and hydrogel resulted in the greatest grass dry mass. In turn, in the case of root length, coconut fiber combined with hydrogel and granules was the most effective. Uzun and Bilgili (2011) noted an increase in perennial ryegrass root biomass in response to moderate doses of organic material. At the same time, they emphasized that excessive amounts might limit grass growth due to growing salinity or heavy metal content. Geisel et al. (2001) demonstrated that adding compost to substrate improved rooting, with better root penetration and higher root mass relative to control. EOM affects physical, chemical, and biological processes in the root zone and, in effect, the size of the grass root ball. It improves substrate physical structure by reducing its compaction and mechanical resistance, which in turn promotes more intensive development of the grass root system (Gregory 2006, Witzgall et al. 2024). Another mechanism of EOM is its ability to retain water.

The addition of organic matter to soil improves its moisture, reducing plant stress and promoting root elongation (Watt et al. 2006, Witzgall et al. 2024). Additionally, while decomposing, EOM releases many macro- and micronutrients into the soil. Phosphorus and nitrogen are particularly important because the first supports the development of young roots and the other positively affects biomass production (FAO 2005, Shah et al. 2018, Gerke 2024, Yuan et al. 2022).

The use of hydrogels in the cultivation of lawn grass usually leads to an increase in root dry mass. In lawn mixtures, this increase can range from about 4 to 8% (Hadam et al. 2011, Jankowski et al. 2014), while, according to Agaba et al. (2011), the root biomass of *Agrostis stolonifera* in a variant with hydrogel was up to four times higher than in the control. The mechanism of hydrogel action is mainly based on its ability to increase water retention in the root zone, which promotes root elongation, increases branching, and reduces dieback during periodic water shortage (Zhang et al. 2019). Contrary to hydrogel, few studies have directly analyzed the effect of coconut fiber on root length and dry matter content. However, the literature indicates that the addition of coconut fiber improves substrate physical properties, this way fostering the development of the root system. Mogale and Maluleke (2025) found that substrates containing coconut fiber were of very high air porosity (28–95%) and high-water capacity, creating favorable conditions for root growth.

Across the growing periods the most favorable hydrothermal conditions were in 2020. Despite slightly lower temperatures in some months, a more even distribution of precipitation during that year provided steady water supply for plants. In such conditions, the greatest values of root dry mass and length were obtained. This proves the synergistic effect of hydrothermal conditions and treatment with EDM and amendments on soil physical and water properties.

Physiological condition and visual quality of plants (SPAD and overall aspect)

The results indicated that by increasing soil water retention both exogenous organic matter and amendments positively affected turf physiological condition and visual quality, with the most beneficial effects achieved with the use of granules applied together with a combination of coconut fiber and hydrogel. According to Gáborčík (2003), the SPAD value is positively correlated with the content of nitrogen and total chlorophyll in plants. The use of exogenous organic matter usually increases SPAD values in lawn grasses, which means increased nitrogen availability and more intensive chlorophyll synthesis. That has been confirmed by some authors (Montemurro et al. 2004, Wang et al. 2014) in their experiments with perennial ryegrass (*Lolium perenne),* reed fescue (*Festuca arundinacea*), and meadow ryegrass (*Poa pratensis*). In addition, as reported in the literature (Hric et al. 2018, Taher et al. 2023), exogenous organic matter improves magnesium and iron availability in the soil. Those chemical elements are necessary for the synthesis of chlorophyll, which can increase the SPAD value. The use of hydrogel and coconut fiber can lead to an increase in the SPAD value in lawn grass by improving soil moisture in the root zone and reducing water stress (Holman et al. 2005, Hadam et al. 2011). However, the literature lacks a direct presentation of the effect of hydrogel and coconut fiber applied to grass on SPAD value.

The use of exogenous organic matter usually improves the visual quality of turf, increasing its density and improving its coloration. This has been demonstrated by many authors for both perennial ryegrass (*Lolium perenne*) and other grass species (Garling and Boehm 2001, Geisel et al. 2001, Loschinkohl and Boehm 2001). According to Schwarz et al. (2007) and Evanylo et al. (2016), introduced into the soil, organic matter improves its physical properties and increases availability of nutrients. Hydrogel increases water retention in the root zone, which promotes more intense leaf coloration and density of turf and its visual value (Hadam et al. 2011). According to Jankowski et al. (2012), when grown on substrate with hydrogel, grass received higher color ratings than control, with the effect being particularly visible in mixtures with a high proportion of perennial ryegrass (*Lolium perenne*). Currently, there are no publications dealing with visual quality ratings (e.g., scale 1–9) of *Lolium perenne* in response to coconut fiber. Its positive effect on lawn visual value is due to the mechanism of its action. According to Abad et al. (2002), a beneficial effect of coconut fiber on turf visual value originates from its ability to improve soil water-air properties. Increased water retention and better conditions for root growth are conducive to even grass coverage and better density and to more intense leaf coloration, which all result in a higher aesthetic rating of the turf.

CONCLUSIONS

Exogenous organic matter and soil amendments both significantly improved perennial ryegrass growth and development during turf formation, but their effects differed in their impact on particular characteristics. The most beneficial, compared to control, was the effect of compost on the *Lolium perenne* number of shoots, root length, dry mass, and seedling emergence. In turn, granules strongly stimulated plant development, increasing the number of shoots and chlorophyll content in leaves (SPAD) and improving turf overall visual quality. The use of hydrogel and coconut fiber positively affected root system development, increasing the length and dry mass of roots and improving plant density and physiological condition. The best results were noted after the combined use of coconut fiber and hydrogel, which ensured the highest plant emergence, the highest number of shoots, the highest values of the SPAD index, and the highest assessment of visual quality. The combination of sewage sludge granules with the mixture of coconut fiber and hydrogel proved to be the most effective technology for establishing turf, ensuring high quality of grass, intensive development of the root system and, in effect, ensuring better condition of plants during limited water availability.

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