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Unlocking the promising potential: *Trichoderma* TrB (CNCM strain I-5327) in Golf course management

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A R T I C L E I N F O

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Turfgrass management
Natural solution
Soil health
Fungicide
Microbial activity

A B S T R A C T

In the pursuit of sustainable turfgrass management for golf courses, a series of experiments was conducted to assess the potential of *Trichoderma* TrB (CNCM strain I-5327) as a natural solution. The research encompassed greenhouse and field trials across two golf courses. The comprehensive pot experiment investigated *Trichoderma* effectiveness, including native (TrB) and commercial strains, with and without organic amino acids, for turfgrass and soil health. The study followed a two-stage process, stimulating beneficial microorganisms with TrB and introducing *Fusarium* for biocontrol. Preliminary field trial on one golf course utilized a randomized block design to examine the effects of TrB and Trianum with amino acids, and fungicide on soil microbial community. A second field trial analyzed soil metabolic profiles after applying TrB, Trianum, and fungicide on another golf course. The greenhouse experiments demonstrated promising outcomes from the application of TrB, especially when combined with organic amino acids. This combination not only promoted plant growth and improved soil health but also effectively prevented the activation of *Fusarium*. In both field trials, it was observed that the introduction of TrB into the soil led to an increase in the population of soil fungi and bacteria and stimulated their activity. Our field data revealed that enriching the soil with TrB had a positive effect on soil microbial communities, while the application of fungicide resulted in a decrease in microbial activities. In summary, our research underscores *Trichoderma*'s potential (TrB) in sustainable golf course management. These findings highlight TrB as a promising natural solution for improving turfgrass health and soil quality in sustainable management of golf course.

1. Introduction

In the domain of turfgrass management, chemical treatments and fungicides have traditionally played a crucial role in maintaining turfgrass quality. These chemical interventions are essential in controlling a variety of turfgrass diseases and pests, ensuring that golf courses, sports fields, and lawns remain healthy and visually appealing. For decades, the use of synthetic fungicides has been a common practice to combat fungal pathogens that can cause significant damage to turfgrass (Johnson, 2013). For instance, *Fusarium*, a prevalent plant pathogen, poses a significant threat to turfgrass health and has become a notable challenge in golf course management. This pathogen is responsible for *Fusarium* patch, a disease that can cause severe damage to turfgrass, leading to poor turf quality and unsightly patches on the greens. To combat this issue, many fungicides have been employed to control *Fusarium* outbreaks and prevent the spread of the disease. These chemical treatments are applied regularly to ensure the health of the turf, which are critical for the performance of golf courses (Stackhouse et al., 2020). However, increasing environmental concerns and potential health implications associated with these chemical practices have prompted the exploration of alternative environmentally friendly strategies (Pathak et al., 2022).

The promising potential of beneficial soil microorganisms offers a greener and more ecologically friendly approach against pathogens to maintaining the health and vitality of turfgrass ecosystems. Among these microorganisms, the genus *Trichoderma* stands out as a promising candidate due to its multifaceted potential in fostering turfgrass growth

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and enhancing soil microbial populations(Hermosa et al., 2012; Vinale et al., 2008). However, despite significant advancements in comprehending *Trichoderma*'s function within agronomic systems (Harman et al., 2004; Shoresh et al., 2010), its precise influence on turfgrass growth and its capacity to modulate soil microbial populations within turfgrass ecosystems remain insufficiently investigated. Previous studies have demonstrated the potential of *Trichoderma* spp. in various aspects of plant and soil health. For instance, research by Moussa et al. (2023) showed that *Trichoderma* species can significantly stimulate soil microbial activities, which are crucial for nutrient cycling and soil fertility. These microorganisms enhance the decomposition of organic matter, leading to increased availability of essential nutrients for plant uptake. Additionally, Shoresh et al. (2010) found that *Trichoderma* could promote plant growth through improved inorganic nitrogen acquisition. This process involves the conversion of nitrogen into forms that are more readily absorbed by plants, resulting in enhanced growth and development. Furthermore, Wu et al. (2022) demonstrated the broader ecological benefits of *Trichoderma* by studying its impact on soil microbial populations and nutrient cycling in cucumber plants. Their findings indicated that *Trichoderma* not only supported plant health directly but also fostered a more balanced and active microbial community in the soil, which was vital for sustainable agriculture. Moreover, Bononi et al. (2020) identified *Trichoderma* strains from the Amazon rainforest with remarkable abilities to solubilize phosphate, thereby making this critical nutrient more accessible to plants. Their research showed that these strains could significantly promote soybean growth, highlighting the potential of *Trichoderma* to enhance agricultural productivity under diverse environmental conditions.

Additionally, previous studies have shown that adding various types of fertilizers containing amino acids to soil can enhance the effectiveness of the soil microbial community (Li et al., 2022). These amino acids can serve as a nutrient source, facilitating the growth and activity of *Trichoderma* and other beneficial soil microbes. They may also help improve plant resilience and nutrient uptake, further promoting plant health and vigor (Li et al., 2022). Understanding the effects of organic amino acid application is crucial for developing a comprehensive, nature-based approach to turfgrass management that minimizes reliance on chemical fungicides.

To address this knowledge gap, we conducted experiments using specific *Trichoderma* strain, CNCM (Pasteur Institute, France) strain I-5327 (TrB) (for more information: https://patents.google.com/patent/CA3106569A1/en), to enhance turfgrass growth and positively influence soil microbial populations, thus fostering a more resilient golf course environment. To comprehensively explore this concept, we conducted experiments in both controlled greenhouse conditions and actual golf course fields. This multifaceted approach enabled us to gain intricate insights into the complex interactions between turfgrass, soil microorganisms, and organic amino acid fertilizer. By conducting experiments in both controlled greenhouse settings and actual golf course fields, we were able to observe the effects of *Trichoderma* under varying conditions and management practices. Importantly, our study also investigated the efficacy of *Trichoderma* in mitigating *Fusarium*, a prevalent plant pathogen that posing a significant threat to turfgrass health. By addressing the following two questions, we aimed to provide a comprehensive understanding that had the potential to significantly influence the future of golf course management:

1. Could the introduction of *Trichoderma*, specifically our TrB strain, effectively control *Fusarium* patch disease, while concurrently promoting the health and vitality of turfgrass?
2. How did this introduction impact the composition and functionality of soil microbial community in golf course ecosystems?

2. Material and methods

2.1. Greenhouse experiment

The greenhouse experiment was conducted at IDEEV Greenhouse platform, Paris-Saclay University, France. Throughout the greenhouse experiment, environmental conditions were tightly regulated to ensure optimal growth conditions for turfgrass. The greenhouse maintained a controlled temperature range, with the minimum and maximum average temperatures set at 15 °C and 25 °C, respectively. The humidity level was maintained within a range of 35–45 %, ensuring optimal growing conditions for turfgrass. Additionally, the photoperiod was set to 12 hours, simulating natural day-length conditions conducive to plant growth. Illuminance levels in the greenhouse typically ranged from 5000 to 20000 lux during daylight hours, providing adequate light for photosynthesis and plant development. Along the experiment period, a daily sprinkler irrigation system was implemented as the watering strategy. This consistent watering regime ensured uniform moisture distribution and met the hydration needs of the turfgrass seedlings.

A randomized complete block design with five replications was implemented in the greenhouse. In each block, we used large aluminum molds (37×22×7 cm, rectangular aluminum tray drip trays for cooking) as pots. Each block consisted of multiple pots, each representing a different treatment or control group, randomly assigned to eliminate bias and ensured that the results were due to the treatments rather than environmental factors. Turfgrass species (*Agrostis stenifolia*) were selected for their relevance to turfgrass management in golf courses and other high-maintenance landscapes. These were cultivated in the aluminum molds (1.8 g per pot) filled with a substrate composed of 70 % sand and 30 % peat. The fungal inoculant, *T. afroharzianum* strain (TrB), was sourced from Biophytech company, France, while commercial strains of Trianum were obtained through purchase. Employing the sprinkling method, turfgrass was inoculated at the time of seed sowing, ensuring uniform distribution. Each planting pot received a precise application of 150 mL of the *Trichoderma* (10^9 spores per m^2) and Trianum (5×10^8 spores per m^2) spore suspension. Over a 2-month stimulation stage, our goal was to enhance turfgrass growth and soil respiration. To achieve this, TrB and Trianum were applied to the soil, with and without organic amino acids (50 µL per pot). A comprehensive assessment was conducted by comparing these treatments with a control group (without any agents) and examining the impact of organic amino acids alone. The turfgrass plants were harvested using fine-bladed scissors, ensuring accurate measurement of their above-ground biomass, a key indicator of plant production. After this stage, we sprayed *Fusarium graminearum* suspension (2.10×10^{4} spores mL^{-1}) to initiate the biocontrol phase, assessing the efficacy of TrB in suppressing the soil-borne plant pathogen during the next one month. Subsequently, we evaluated various parameters including soil respiration by means of a closed dynamic system, composed of a portable infrared gas analyzer (EGM4, PPsystems, Hitchin, UK), connected to a soil respiration chamber (SRC1, PPsystems, Hitchin, UK), visualization of fungi and bacterial populations by PDA Plate Culture method, nitrogen balance and chlorophyl indices by Multiplex 330 (by using fluorescence-based sensors), soil metabolic profile using the Microresp™ technique and then total turfgrass biomass. Three soil samples (0–7 cm) were randomly taken from each pot using a small cylindrical sampler to ensure a representative analysis of soil properties.

2.2. Field experiments

Two distinct field trials were conducted on the putting greens of two golf courses, Golf Bluegreen Saint-Aubin (FR 91) and UGOLF Buc Toussus (FR 78), located in the southern region of Paris. These trials followed a randomized complete block design on the putting green space, with each treatment replicated three times. In each putting green area, a 5×4-meter section was selected, and then we established our block design, consisting of three rectangular areas, each with dimensions of 50×100 cm, assigned for each treatment. Based on the favorable results observed in the greenhouse trial, treatments demonstrating promise (TrB and Trianum enriched with organic amino acids) were further evaluated in subsequent field trials. In the Golf Bluegreen Saint-Aubin trial, deliberate inoculation of *Fusarium* was conducted, whereas in the UGOLF Buc Toussus trial, no pathogens were intentionally introduced. This allowed us to evaluate treatment efficacy under both controlled pathogen-infested conditions and natural conditions. In our investigation, we also compared these treatments with a routine fungicide treatment used on golf courses (Detailed records of the exact concentration was not provided). This allowed us to highlight the effectiveness of the biological agents in contrast to chemical approaches for managing diseases. The Golf Bluegreen Saint-Aubin field trial focused on evaluating the impact of various treatments on the abundance of fungal and bacterial populations. This investigation was carried out utilizing the qPCR technique to provide quantitative insights into the microbial dynamics after different land management (Zarafshar et al., 2024). Five soil samples (0–7 cm) were randomly taken from each rectangular area using a small cylindrical sampler to ensure a representative analysis of soil properties. Microbial DNA was extracted, purified and quantified from the topsoil samples using a commercial kit. The abundance of fungi and bacteria was assessed by real time, or quantitative, PCR (qPCR). We amplify the 16 S (bacteria) and 18 S (fungi) small ribosomal subunit genes. These genes were amplified from global population of sample DNA in a thermocycler, and the increasing absorbance of DNA is measured with spectrophotometry throughout the amplification. The final absorbance is then converted to initial number of gene copies by comparison with a standards curve, made by measuring absorbance of amplified DNA samples at known initial concentrations.

The UGOLF Buc Toussus field trial was centered around assessing changes in soil metabolic profiles by MicroResp™ technique following the application of different treatments. The resultant dataset not only encompasses genuine field conditions but also facilitates a scientifically robust comparison with data derived from controlled greenhouse experiments. Soil samples were randomly collected from each rectangular area using a small cylindrical sampler to ensure a representative analysis of soil properties. Using MicroResp™ (Campbell et al., 2003), the study analyzed soil metabolic profiles by monitoring carbon dioxide (CO_2) release from topsoil treated with diverse carbon substrates. After a two-week incubation at 25°C to stabilize microbial communities, substrate concentration reached 30 mg C mL^{-1}, adjusting water content to 60 %. Sealed conditions at 25°C with a detection gel enabled continuous CO_2 measurement over six hours. Calibrated absorbance readings unveiled respiration rates and complex metabolic profiles, shedding light on fundamental soil processes.

2.3. Statistical analysis

All statistical analyses were conducted using the R software package. To evaluate the statistical significance of treatment differences, we employed one-way analysis of variance (ANOVA). Subsequently, Tukey's Honestly Significant Difference (HSD) test was utilized for pairwise comparisons, enabling the identification of specific treatments with significant differences.

3. Result

3.1. Greenhouse experiment

3.1.1. Soil respiration

During the stimulation stage, soil respiration was monitored over time to assess the impact of various treatments (Fig. 1). Analysis through repeated measures ANOVA revealed significant variations ($P < 0.05$) among the treatments, indicating that the different treatments had distinct effects on soil respiration rates. Throughout the experimental period, soil inoculated with TrB enriched with amino acids consistently demonstrated higher respiration rates compared to other treatments. Interestingly, no significant differences in soil respiration were observed among the other treatments. This indicated that while the addition of TrB with amino acids had a marked effect, the other treatments, including TrB alone or other control treatments, did not significantly alter soil respiration rates. Meanwhile, soil respiration data demonstrated a general increase in respiration rates across all treatments as the plants grew, reflecting the natural progression of microbial activity associated with root development. However, the rate of increase in soil respiration was notably higher for the treatments inoculated with TrB +

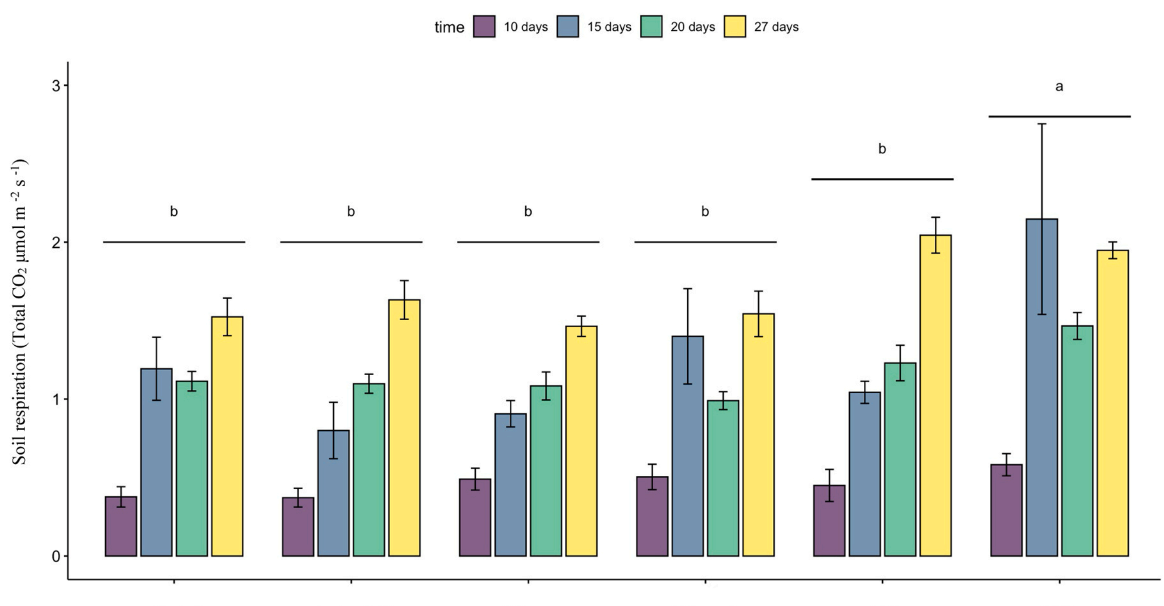

Fig. 1. Temporal changes in soil respiration were monitored throughout the stimulation stage. Repeated measures ANOVA analysis revealed significant variations ($P < 0.05$). Different lower-case letters indicate significant differences across treatments. TrB refers to the *Trichoderma* strain, and aa stands for the amino acids added to that treatment.

amino acids.

3.1.2. Plant function

During the stimulation stage, no statistically significant effects were observed for the nitrogen balance index (NBI), although a minor effect was noted for Chlorophyll levels (Fig. 2, A and C). Particularly, the treatment involving TrB combined with organic amino acids exhibited higher values during this stage. However, during the biocontrol stage, the impact of TrB became evident, displaying a positive effect on both NBI and Chlorophyll content (Fig. 2, B and D). Specifically, statistical analysis revealed significant differences in chlorophyll content between the treatments. Plants inoculated with TrB showed significantly higher chlorophyll content compared to the control ($P < 0.001$). In contrast, the other treatments did not show significant differences in chlorophyll content compared to the control pots. Furthermore, when comparing TrB to Trianum, TrB alone resulted in higher chlorophyll content ($P < 0.001$), underscoring its superior performance in promoting turfgrass vitality. In line with the chlorophyll data, the highest NBI values were observed in the TrB treatment. While TrB alone resulted in higher chlorophyll content, the other treatments did not show significant differences from the control.

3.1.3. Total plant biomass

The statistical analysis did not reveal significant differences between the various treatments in terms of above-ground biomass during the stimulation stage (Fig. 3, A). However, the highest values were observed in the TrB combined with organic amino acids (TrB+aa) treatment, suggesting a potential trend toward improved biomass accumulation with this combination (Fig. 3, A). On the other hand, significant differences appeared at the end of the biocontrol stage when we measured the whole dry biomass (Fig. 3, B). Our data clearly exhibited that turfgrass inoculated with TrB, both with and without amino acids, had greater plant dry biomass, while the rest of the treatments were comparable to control plants (Fig. 3, B).

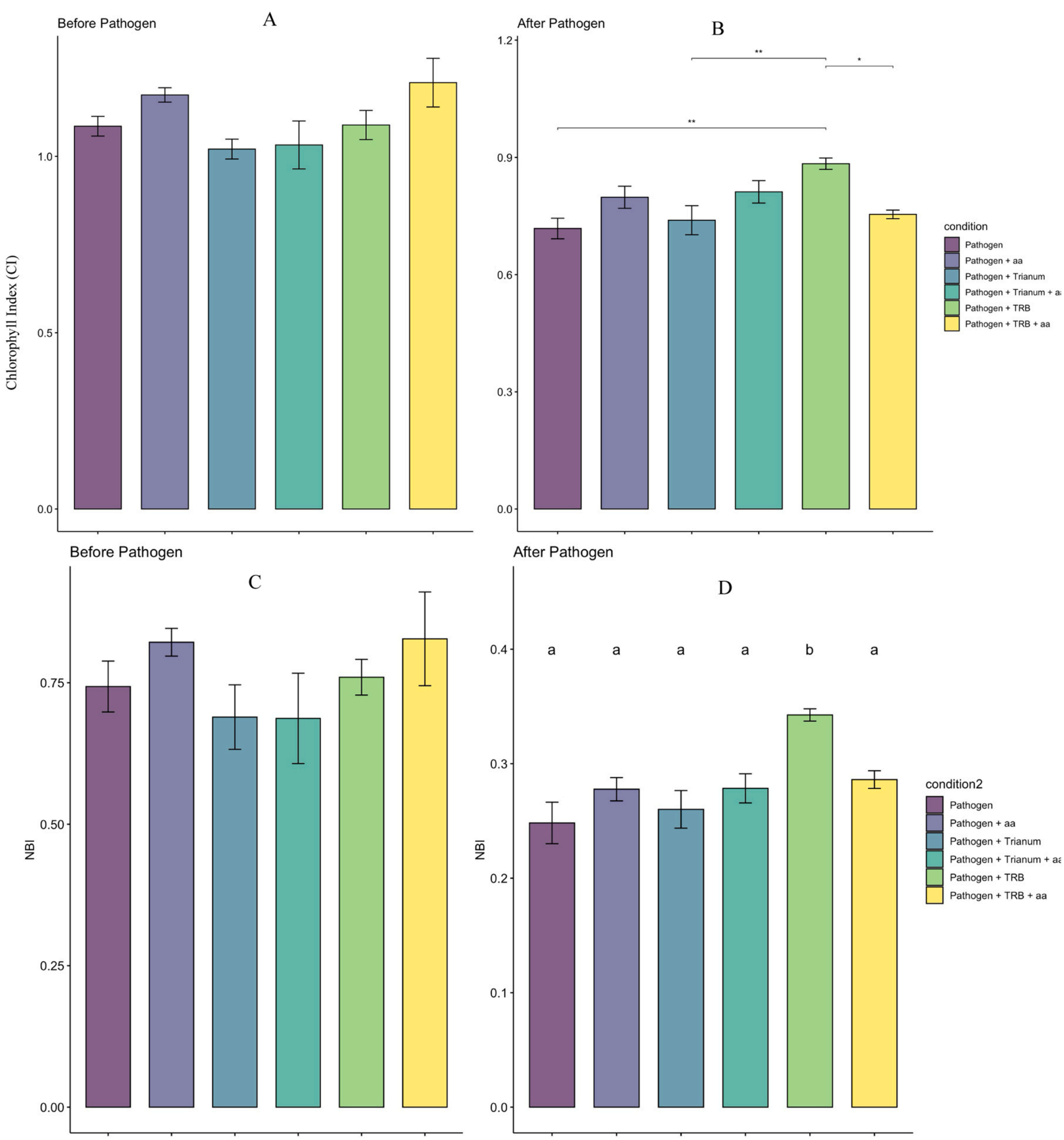

Fig. 2. Chlorophyll index (CI) and Nitrogen Balance Index (NBI) trends during the stimulation and biocontrol stages. Different lower-case letters indicate significant differences across treatments. TrB refers to the *Trichoderma* strain, and aa stands for the amino acids added to that treatment.

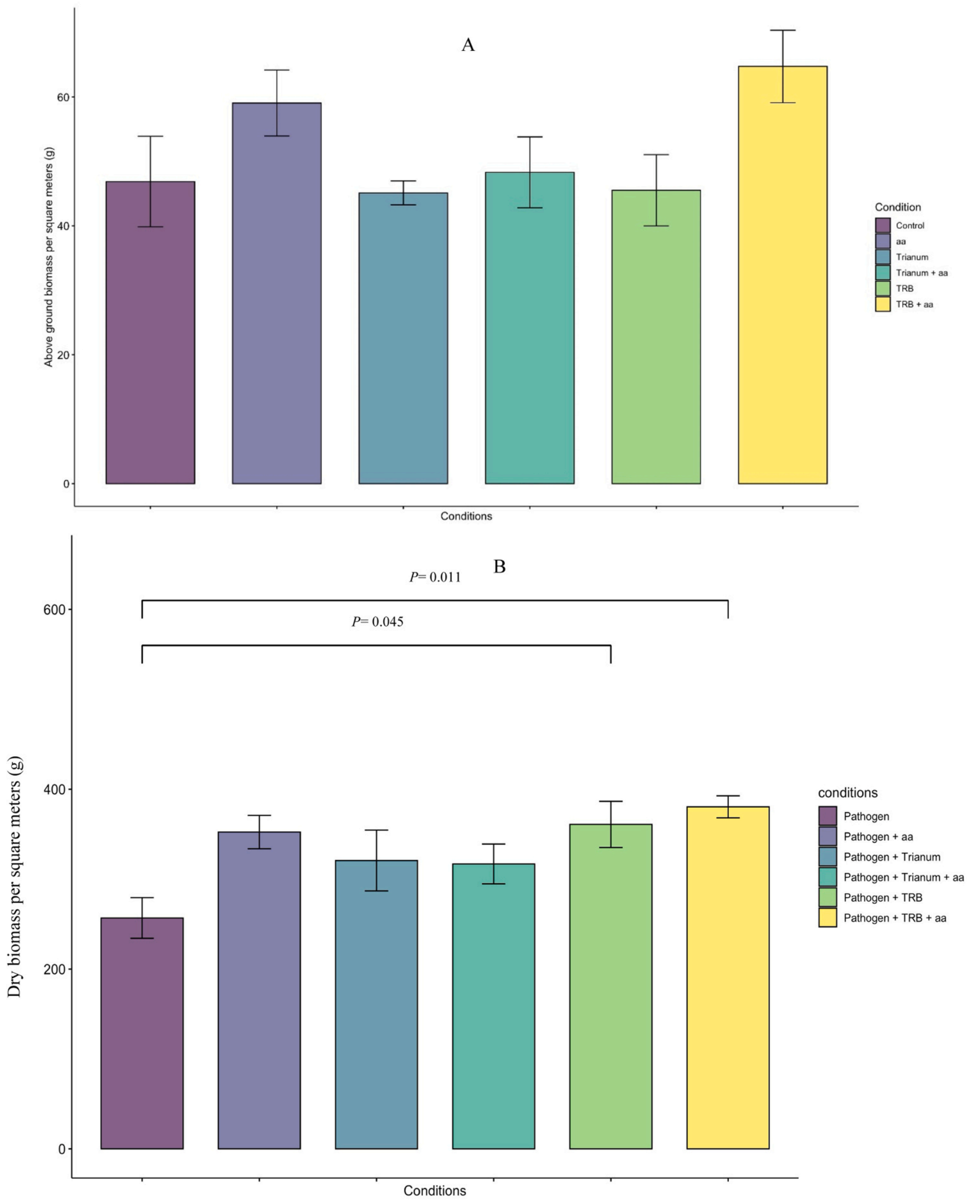

Fig. 3. Turfgrass above-ground production during biostimulation and total dry biomass at biocontrol completion. TrB refers to the *Trichoderma* strain, and aa stands for the amino acids added to that treatment.

3.1.4. Antagonistic impact of Trichoderma

Fig. 4 displays our PDA culture plates (Fig. 4). TrB effectively inhibited *Fusarium* growth, while control plates showed *Fusarium* growth. Trianum exhibited a weaker inhibitory effect compared to TrB. In total, our PDA cultures confirmed the higher antagonistic ability of TrB compared to Trianum. The experiment clearly indicated that the growth of the TrB strain was significantly stimulated by the addition of organic amino acids. In contrast, adding the fertilizer to Trianum had no considerable effect on the growth of Trianum.

3.1.5. Soil metabolic profile

Our heat map analysis revealed a significant difference in carbon source utilization between soil samples with and without *Fusarium* (pathogen), as well as with and without *Trichoderma* suppression (Fig. 5). In the absence of *Trichoderma*, *Fusarium* displayed extensive carbon source utilization, increased soil respiration, and released more CO_2. However, the presence of TrB exhibited a suppressive effect on *Fusarium* activity, evident from the distinct pattern of carbon source consumption. Trianum also exerted efforts to suppress *Fusarium* activity; however, its efficacy was comparatively lower than that of TrB.

3.2. Field experiments

3.2.1. Soil metabolic profile

MicroResp™ data obtained from UGOLF Buc Toussus revealed that the application of fungicide suppressed the metabolic activity of the microbial community. Conversely, the application of TrB resulted in a significant enhancement of their activity. While Trianum also demonstrated a positive impact, its effect was less pronounced compared to TrB (Fig. 6).

3.2.2. Soil molecular assay

Our qPCR assay at Golf Bluegreen Saint-Aubin revealed a pronounced impact of TrB inoculation on both fungal and bacterial abundances (Fig. 7). Notably, the introduction of TrB resulted in a significant increase in the population of both fungi and bacteria within the soil, even in the presence of plant pathogens. Regarding fungal abundance, there was no significant difference observed between soil affected by the

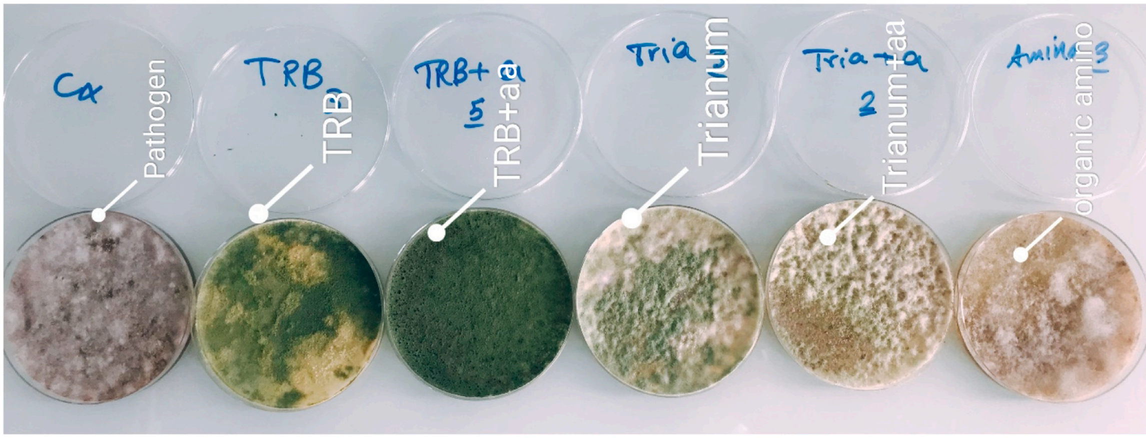

Fig. 4. PDA assay revealed robust TrB growth and its impressive *Fusarium* suppression capacity. From left to right, the treatments are as follows: water extraction from soil affected by *Fusarium* without TrB, soil inoculated with TrB, TrB enriched by organic amino acids, Trianum, Trianum enriched by amino acids, and then soil fertilized by amino acids. The TrB strain grew significantly and profoundly inhibited the growth of any pathogens. TrB refers to the *Trichoderma* strain, and aa stands for the amino acids added to that treatment.

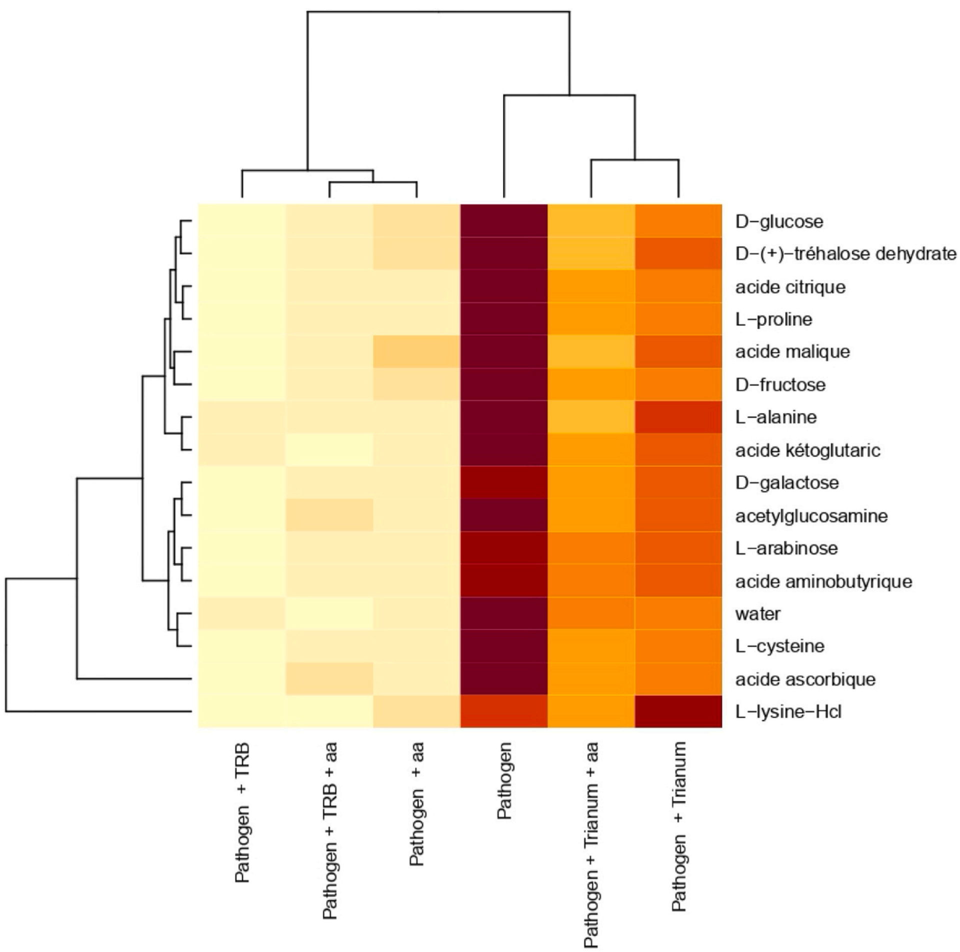

Fig. 5. Soil metabolic profile heat map from MicroResp™ assay in the biocontrol stage of the greenhouse trial, displaying color intensity variations indicative of higher metabolic activity. TrB refers to the *Trichoderma* strain, and aa stands for the amino acids added to that treatment.

pathogen, even when fungicide was applied. In contrast, soil bacterial abundance was slightly higher in the soil where fungicide was applied.

4. Discussion

In the context of the ongoing transition towards sustainable golf course management practices, our study explored the potential advantages of substituting chemical fertilizers with biological agents, with a

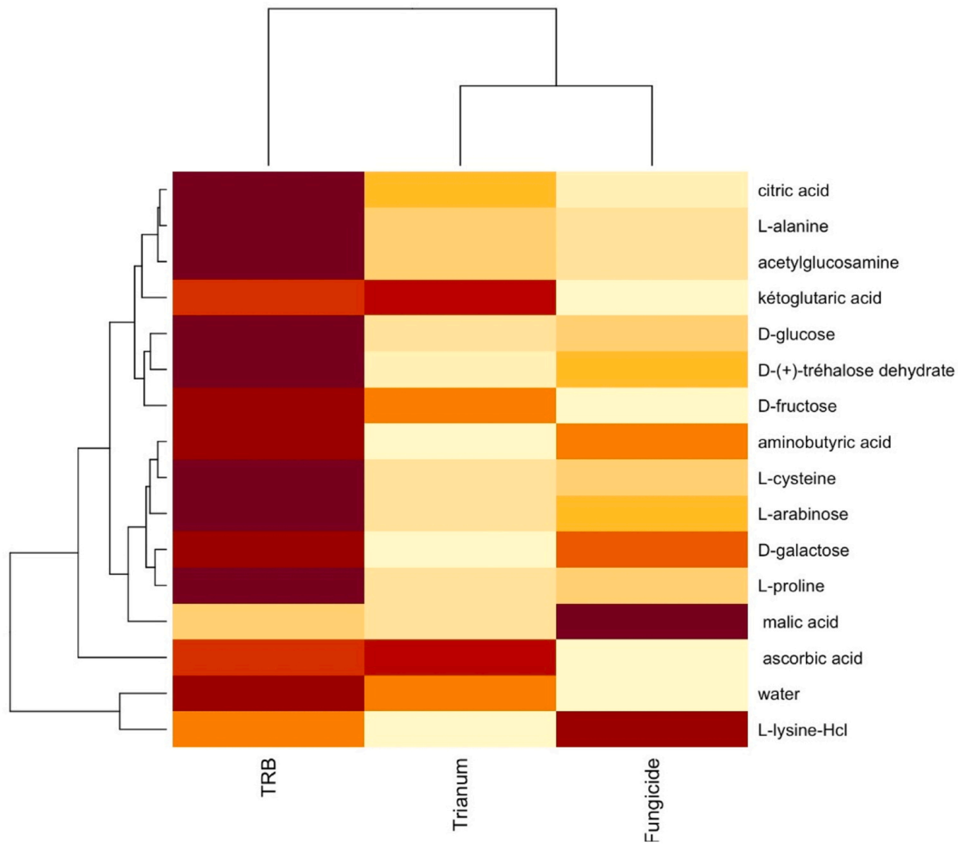

Fig. 6. Soil metabolic profile heat map obtained from the MicroResp™ assay during the UGOLF Buc Toussus field trial, illustrating color intensity variations that reflect differences in metabolic activity within the soil ecosystem. TrB refers to the *Trichoderma* strain, and aa stands for the amino acids added to that treatment.

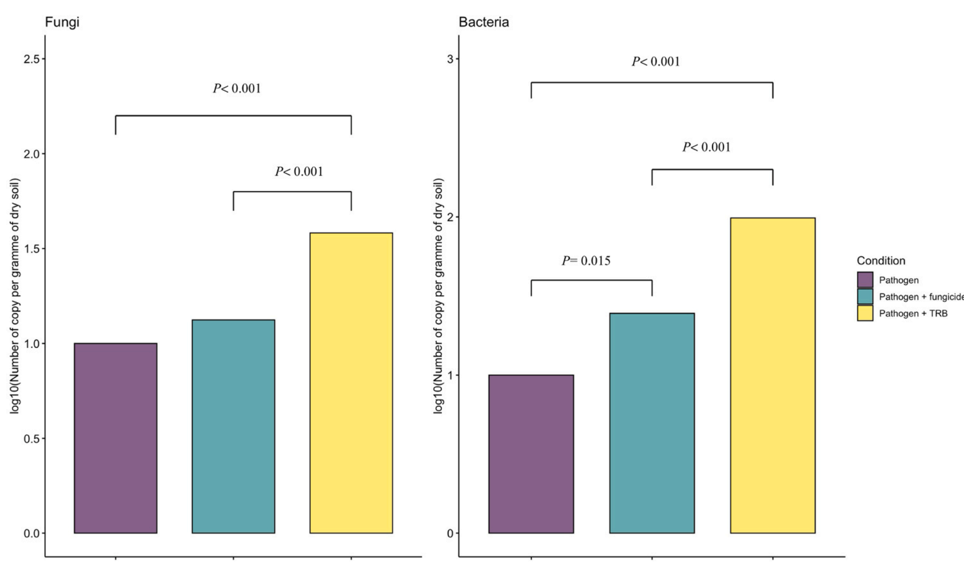

Fig. 7. Variation in microbial abundances within the treatment groups across different stages of the study, highlighting responses of fungi and bacteria to TrB inoculation during the UGOLF Saint-Aubin field trial. TrB refers to the *Trichoderma* strain, and aa stands for the amino acids added to that treatment.

specific focus on *Trichoderma*. Our results highlighted the significantly positive impacts of *Trichoderma* on both turfgrass health and the dynamics of soil microbial communities. The significant temporal variations in soil respiration, supported by repeated measures ANOVA results ($P < 0.05$), underscoring the dynamic interplay between soil microbial and root activity across diverse treatments. Particularly, the TrB and organic amino acid combination consistently yielded heightened soil respiration levels throughout the observation period. This outcome is attributed to the synergistic influence of TrB and organic amino acids, enhancing both microbial and root vitality. Root exudates are well-established as a source of organic compounds that fuel microbial growth (Badri and Vivanco, 2009; Pacaldo and Aydin, 2023), suggesting that the synergistic effect of TrB and organic amino acids may stimulate microbial and root activity concurrently. This alignment with previous research findings (Asghar and Kataoka, 2021) underscores the positive impact of *Trichoderma* and organic amendments on soil microbial activity.

The stimulation stage of the study revealed that the application of TrB, alone or in combination with organic amino acids, did not significantly affect the NBI or chlorophyll index. However, the TrB combined with organic amino acids treatment consistently exhibited higher values, suggesting a potential positive impact on turfgrass health. During the biocontrol stage, TrB showed a significant effect on both the NBI and Chlorophyll index. TrB increased NBI by approximately 37.1 %, highlighting its ability to enhance nutrient utilization in turfgrass systems, particularly under stress from pathogens. Additionally, TrB treatment, especially when combined with organic amino acids, led to a notable increase in chlorophyll index (approximately 23.8 %), indicating improved plant photosynthetic capacity. These findings underscore TrB's potential to optimize nutrient availability and physiological performance in plants, particularly under stressful conditions. This aligns with the findings of Andrzejak and Janowska (2022), who emphasized that the intricate interplay between microbial activity and nutrient availability, facilitated by *Trichoderma*, can positively influence plant physiological processes. Although the mechanism behind this enhancement requires further exploration, the role of *Trichoderma* in promoting nutrient availability through improved mineralization and solubilization processes has been highlighted in studies by Shoresh et al. (2010) and Yedidia et al. (1999).

The application of TrB combined with organic amino acids resulted in a 38.15 % increase in above-ground biomass compared to the control, though this difference did not reach statistical significance. Nevertheless, this finding suggests the potential of TrB and organic amino acids to positively influence above-ground biomass accumulation, highlighting the complex factors affecting turfgrass growth. These trends underscore the necessity for further investigation into the long-term effects of TrB on turfgrass growth. This consistent elevation in above-ground biomass aligns with the findings of Natsiopoulos et al. (2022) which demonstrated *Trichoderma*'s growth-promoting effects in tomato plants. Total plant biomass measured at the end of the biocontrol stage provided valuable insights, with plants infected with *Fusarium* but lacking *Trichoderma* treatment exhibiting the lowest biomass values, while those inoculated with *Trichoderma* (TrB and Trianum) displayed higher biomass values, indicating its positive impacts on plant growth and health. This finding is consistent with previous research showing *Trichoderma*'s ability to suppress pathogen's detrimental effects, enhancing plant vigor and resilience (Harman., 1998; Shoresh et al., 2005). The substantial increase in total biomass for TrB -treated plants, representing approximately a 48.44 % increase compared to the control, underscores *Trichoderma*'s significance in mitigating soil-borne pathogen adversities.

The biocontrol stage was pivotal, assessing TrB, Trianum, and *Fusarium* interactions in the soil ecosystem through water extraction followed by growth observation on PDA plates for direct visualization. TrB markedly inhibited *Fusarium* growth, showing stronger inhibition compared to Trianum, and aligning with prior research on *Trichoderma*'s multifaceted biocontrol potential, involving mechanisms like nutrient competition and antifungal compound secretion (Shoresh et al., 2010; Vinale et al., 2008). These findings underscore TrB's efficacy against soil-borne pathogens like *Fusarium*, crucial for golf course management. Our MicroResp™ data from greenhouse underscore the importance of TrB's role in shaping soil microbial dynamics, particularly in the context of *Fusarium* suppression. In the absence of TrB, *Fusarium* displayed extensive carbon source consumption, indicative of its robust metabolic activity, consistent with previous findings on *Fusarium*'s saprophytic nature (Alabouvette et al., 2006). However, upon TrB introduction, a significant shift occurred, as illustrated by the heat map, which clearly depicted TrB's suppressive effect on *Fusarium*'s metabolic activity, altering carbon source consumption patterns. These finding echoes research highlighting Trichoderma's ability to disrupt fungal metabolism (Chaverri et al., 2015). Trianum also demonstrated some inhibitory effect on *Fusarium* activity, although less pronounced than TrB, consistent with studies indicating variable antagonistic activity among *Trichoderma* strains (Hermosa et al., 2012).

Linking our greenhouse findings to real-world golf course conditions, MicroResp™ data obtained from UGOLF Buc Toussus yielded insights into the effects of fungicide and *Trichoderma* on soil microbial activity. Interestingly, fungicide application correlated with reduced microbial activity, consistent with studies indicating the adverse impact of chemical interventions on soil microbial dynamics (Han et al., 2021). In contrast, TrB introduction led to a significant enhancement in microbial community activity, aligning with *Trichoderma*'s recognized biostimulant properties, as highlighted by Zhang et al. (2023), emphasizing its positive influence on nutrient cycling and organic matter decomposition.

In our investigation, our objective was to discern the impacts of *Trichoderma* (TrB) and fungicides on the microbial communities within golf course ecosystems, as these minute organisms exert considerable influence on soil vitality and plant development (Berg et al., 2014). Upon introducing TrB into the soil at Golf Bluegreen Saint-Aubin, we observed a notable response, with both fungal (approximately 1.5-fold) and bacterial (approximately 2-fold) populations experiencing significant increases, indicating *Trichoderma*'s capacity to promote a more conducive environment for these beneficial soil microorganisms (Mendes et al., 2013). This rise in microbial abundance is of considerable importance, highlighting TrB's role in fostering a robust soil microbial community. Importantly, our findings show that TrB had a stronger impact on soil microbes compared to the fungicide, as it not only helped control harmful elements but also boosted the growth of fungi and bacteria (Harman et al., 2004). This difference highlights TrB's potential to bring about a more beneficial change in the soil ecosystem.

5. Conclusions

In summary, our study unveils promising pathways for eco-friendly golf course management. We found that *Trichoderma*, particularly the native strain TrB, combined with organic amino acids, positively impacted soil respiration, potentially enhanced nutrient cycling and turfgrass health. TrB also exhibited greater efficiency in suppressing *Fusarium* compared to Trianum (commercial agent), suggesting its potential as an effective biocontrol agent. Our data indicate TrB's influence on soil microbial dynamics, crucial for soil health and nutrient cycling. These findings offer practical implications for golf course management, highlighting the potential benefits of investing in promising *Trichoderma* strains like TrB for sustainable improvements in turfgrass and soil conditions. Considering native strains like TrB presents a greener and more resilient approach to golf course maintenance, addressing both environmental concerns and practical considerations.

CRediT authorship contribution statement

Mehrdad Zarafshar: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis. **Auriane Thomas:** Investigation, Data curation. **Olivier Besnard:** Resources, Project administration, Methodology. **Stéphane Bazot:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Gaëlle Vincent:** Validation, Resources, Investigation. **Bastien Perrot:** Visualization, Software, Investigation, Formal analysis.

Declaration of Competing Interest

The authors declare no conflicts of interest.

Data availability

Data will be made available on request.

Acknowledgment

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