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Second Cycle Degree M.Sc in Sustainable Agriculture

Comparison of Biostimuant and fertilization programs in relation to Bermudagrass performance during fall and spring Season

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1. Abstract

Bermudagrass is a perennial, warm-season grass species that is commonly used for turfgrass and is well adapted to climates with low precipitation. The aim of this study was to evaluate the effect of fertilization and biostimulants on three different cultivars of bermudagrass over a period of 2 years. The study was conducted at the experimental agricultural farm of the University of Padua located at Legnaro. Surveys were carried out every 1 weeks starting from October 2022 and included: overall aesthetic appearance (rated on a visual scale from 1 to 9), density, uniformity, texture, color, percentage of green coverage, NDVI. This thesis aimed to compare the effects of biostimulant and fertilization programs on the performance of bermudagrass during the fall and spring seasons. Three varieties of bermudagrass, namely Sultan, MBG002, and Arden, were subjected to different treatments, and their color, quality, Normalized Difference Vegetation Index (NDVI), green-up, dormancy, and carbohydrate levels were evaluated. The results revealed that the treatment effect had a significant impact on all three bermudagrass varieties, as determined by statistical analysis using ANOVA test. In terms of color, no significant differences were observed among the three cultivars. However, Sultan and MBG002 exhibited better color performance compared to Arden. Regarding turfgrass quality, the P2 treatment demonstrated higher quality compared to the P1 and P2 treatments, with a high level of significance ($p < 0.001$). These findings support existing research that highlights the influence of both cultivar selection and treatment application on turfgrass quality. The analysis of NDVI indicated that both cultivar and treatment significantly affected bermudagrass performance. The interaction between cultivar and treatment showed a higher level of significance ($p < 0.01$), emphasizing the importance of considering both factors for achieving desired vegetation density and health. While cultivar selection had a significant effect on green-up ($p < 0.05$), treatment application did not exhibit a significant impact. Hence, this study revealed the importance of cultivar selection and treatment application in optimizing bermudagrass performance. While color and quality were influenced by treatment programs, cultivar selection played a crucial role in green-up. These findings contribute to our understanding of how to tailor biostimulant and fertilization programs to specific bermudagrass varieties, thereby enhancing their overall performance during the fall and spring seasons.

Key words: Turfgrass, Sustainability, Warm season species, Plant Bio stimulants, Fertilization

2. Introduction

2.1 Climate change and its impacts

The detrimental impacts of climate change are clearly visible in every sector, including agriculture sector. Even if the average temperature rise is only 1.20 degrees Celsius, the world is already facing the threats caused due to changes in environmental conditions. Increased cyclone frequency and intensity, and variability in rainfall events resulting in floods and droughts, forest fires, heat waves, and other potential effects (IPCC, 2013). The last century has witnessed a warming of around 1°C in Europe, which is faster than the global average. While climate change impacts can be observed across various climatic variables, recent specialized studies have primarily focused on changes in precipitation, temperature, and climatic variability. Anthropogenic activities have caused an increase in greenhouse gases in the atmosphere, leading to a temperature rise of approximately 1°C since the last century in Italy. This increase in temperature has resulted in heat waves and droughts. Italy's vulnerability to climate change is influenced by its geographic location and climate heterogeneity, resulting in higher temperatures and changes in rainfall distribution (figure 1 and figure 2). Additionally, the scientific reports predict a 20% reduction in total annual rainfall in most of the Mediterranean region from 2071 to 2100 compared to 1961-1990 (Philandras et al., 2011). The agricultural sector will be most affected by changes in temperature, rainfall distribution, and intensity, due to an increase in extreme weather events. Agriculture is the most vulnerable sector to these impacts, as weather conditions heavily influence crop productivity, yield variability, lack of water availability, and the reduction of cultivable areas. Farmers around the world face significant challenges related to climate change, it includes identifying suitable adaptation and mitigation efforts. Climate change poses a significant challenge for European agriculture, exposing it to relevant risks due to new local meteorological conditions (FAO, 2013). In many countries, the past decade has seen an increase in extreme temperatures, economic losses from extreme weather events, and a decrease in water availability. Northern Europe has seen an increase in the intensity of rainfall and snowfall, resulting in more frequent floods, while southern regions have experienced significant decreases in rainfall, leading to more frequent drought periods than in the past.

The adverse effects of climate change are critical to future crop productivity and have been shown to threaten various agricultural systems. It has already been noted that the changes in temperature-moisture conditions observed in Italy during the summer pose a significant risk to agricultural production (Orlandi et al., 2020). However, as temperatures and precipitation become more extreme, the risk to crop production will increase significantly (Li Y et al., 2019). It has already been observed that various parts of the world may experience lower crop productivity in the near future under the changing climate (Benke et al., 2017). Italy is one of the world's leading producers of wine, olive oil, and other agricultural products. However, the effects of climate change significantly threaten the country's agricultural sector, which is already facing challenges such as a declining rural population and an aging workforce. In addition, higher temperatures and changing rainfall patterns are leading to more frequent and severe droughts and heat waves, which can cause significant damage to crops and reduce yields (IPCC, 2021). For example, the olive oil industry, an important contributor to the Italian economy, has been hit hard by droughts and higher temperatures, resulting in lower yields and higher production costs (Pellegrino et al., 2021). In addition, changing rainfall patterns also affect crop growth and soil health. In some areas, increased rainfall leads to soil erosion, while in others, prolonged droughts cause the soil to become more compact and less fertile (Mastrorilli et al., 2020). There is also the spread of pests and diseases that can damage crops and reduce yields (Sicard et al., 2019). To address these challenges, farmers in Italy are using a variety of strategies to adapt to the effects of climate change. For example, some farmers are switching to crops that are better adapted to the changing climate, such as drought-resistant varieties like grapes and olives (Pellegrino et al., 2021). Others are implementing irrigation systems and soil conservation measures to improve soil health and reduce erosion (Mastrorilli et al., 2020). In addition, the Italian government is implementing measures to help farmers adapt to the impacts of climate change. For example, the government provides financial support for the installation of renewable energy systems and for the adoption of sustainable agricultural practices (Mastrorilli et al., 2020). The government also invests in research to develop new crop varieties and technologies that can help farmers adapt to climate change (Pellegrino et al., 2021). In summary, the effects of climate change pose a threat to agricultural production in Italy, which is an important contributor to the country's economy. However, farmers and the government are taking measures to adapt to the effects of climate change and mitigate its impact on agricultural production. The implementation of these strategies will be crucial to ensure the sustainability and resilience of the Italian agricultural sector in this changing climate scenario. The Organization for Economic Co-operation and Development (OECD) defines adaptation as the process of adjusting environmental, social, and economic systems to minimize negative impacts of climate change while capitalizing on new opportunities

(Schipper, 2007). Assessing the cost-effectiveness of climate adaptation measures for farmers is crucial to mitigate the environmental and economic risks of changing climate conditions. However, quantifying the costs and benefits of adaptation can be challenging due to uncertainties associated with climate change. Thus, it is essential to consider each adaptation measure's unique characteristics and weigh its potential costs and benefits to determine its overall cost-effectiveness (Mechler, 2016). As such, it is crucial to consider the unique characteristics of each adaptation measure and carefully weigh its potential costs and benefits to determine its overall cost-effectiveness. Additionally, continued monitoring and evaluation of the effectiveness of implemented measures can help guide future adaptation efforts and improve decision-making in the face of ongoing climate change. Effective climate change adaptation strategies must prioritize risk management at the local and farm levels. This can be achieved through different types of actions, including structural improvements to infrastructure, better management practices, and the use of economic tools such as insurance and investment funds (Sachs et al., 2019). Adapting risk management tools to be effective for climate change adaptation requires a review of the entire process, including identifying and assessing risks based on changing scenarios, adjusting strategies and objectives for maximum effectiveness. Successful climate change adaptation requires a comprehensive and flexible approach to risk management.

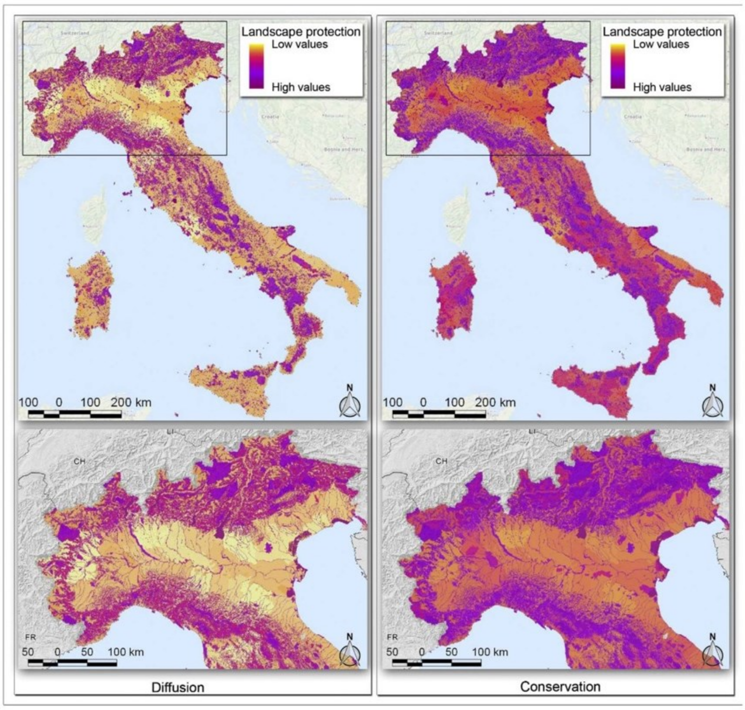

Fig 1. SLEUTH's exclusion layers representing the resistance to land transformation in the Diffusion (left) and Conservation (right) scenarios. Bottom: zoom-in on Northern Italy where the differences are more evident (Martellozzo et al., 2018).

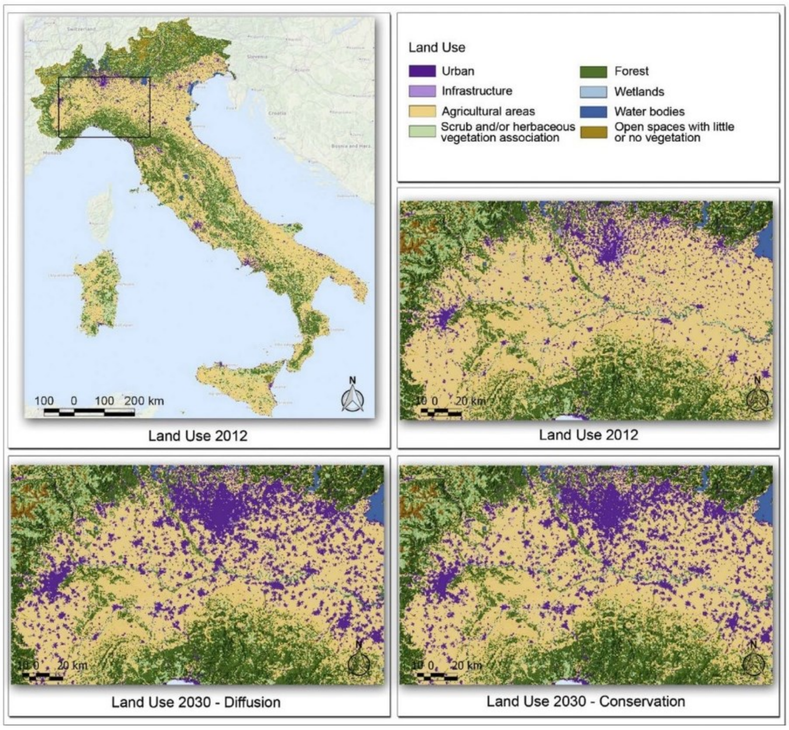

Fig. 2. Difference in land consumption between 2012 and the forecasts from the Conservative and Diffusion scenarios up to 2030 for northern Italy (Martellozzo et al., 2018).

Reference: Martellozzo et al., 2018

2.2 General view about turf management

Turf management involves different processes including maintaining and improving the health and appearance of turfgrass areas such as golf courses, parks, sports fields, and residential lawns. Turf management involves a wide range of practices, including soil preparation, fertilization, watering, mowing, pest and weed control, and disease management (McCarty, 2018). Turfgrasses are an important component of many landscapes, increasing the aesthetic value of the area, reducing erosion, filtering pollutants, and providing habitat for living organisms (Beard and Green, 1994). However, turfgrasses also require a significant amount of maintenance to ensure they remain healthy and attractive. Proper turf management can enhance the quality of life and the environment, while improper management can result in reduced aesthetic quality, increased water usage, and the release of pollutants into the environment (Farid et al., 2016). In recent years, there has been increasing interest in sustainable turf management practices that are both effective and environmentally friendly. This has led to the development of new techniques, such as integrated pest management, which focuses on reducing the use of chemical pesticides and fertilizers through the use of natural pest predators and other non-toxic methods.

Turf management is a comprehensive field that encompasses commercial, residential, and recreational settings. It involves the science and business of turfgrass management. Turf management also refers to best practices for taking care of your yard, not just limited to sports fields. This means that turf management involves maintaining grass in tip-top shape, resulting in green and lush grass. It also addresses the challenges presented by different types of sporting pitches, making sure they are safe and ready for the athletes to play. Turf management is often associated with sports fields and golf courses, but it can also be practiced in your own backyard (McCarty, 2014). Furthermore, it involves taking the best possible care of your yard, as well as environmental reasons for practicing high-quality lawn care. Turf management is a potential career field, and one can become a groundsman in professional sports turfs, or greenkeeper in golf courses, or work in lawn care companies managing amateur sports venues and outdoor recreational areas. The responsibilities of a turf manager include repairing damage, regulating pest control, creating a safe space for athletes to play, creating a schedule for field use, and overseeing a maintenance crew, mowing, aerating, top dressing, irrigating, and fertilizing the turf (Held and Potter, 2012).

Water management is also an important aspect of turf management. Water is essential for the survival and growth of turf species, but improper watering can result in waste and contribute to environmental problems such as water scarcity and contamination (Lazarova and

Bahri, 2004). Efficient irrigation systems, drought-resistant grass varieties, and regular soil analysis to monitor moisture levels are all important components of a sustainable water management plan. Further, mowing is another critical component of turf management. Proper mowing can enhance the appearance and health of turfgrass, while improper mowing can cause damage and lead to disease (Trenholm et al., 2000). Mowing height, frequency, and the type of mower used can all impact the health and appearance of vegetation. In addition to these core practices, turf management also involves fertilization, monitoring and managing pests, weeds, and diseases that can impact the health and appearance of turfgrass. This includes the use of chemical and non-chemical control methods, as well as the use of cultural practices such as proper fertilization, soil preparation, and irrigation (Bahadur et al., 2015). The impacts of climate change are clearly visible on turfgrass production, and the cool-season species might be replaced by warm-season species. Maintaining soil water content in non-irrigated areas will be a challenge, but genotypic variation in water use and root exploration could help sustain turfgrass. Quantifying abiotic stresses and genotypic differences in response to these stresses will be crucial for turfgrass management under climate change. This understanding can improve our ability to sustain crop production and other ecosystem services, making it relevant to all biological systems. Sustainable turf management is essential for maintaining and improving the health and appearance of turfgrass. This requires a comprehensive and integrated approach that balances the needs of the turfgrass with the needs of the environment and the surrounding community. Ongoing research and development in the field of turf management will continue to play a critical role in advancing our understanding of the best practices for sustainable turf management.

2.3 Turfgrass Sustainability

Sustainability has become an increasingly important issue in turf management due to the numerous environmental challenges that we are facing, such as climate change, water scarcity, and biodiversity loss. The maintenance of high-quality turf is crucial for environmental, social, and economic benefits, but it heavily relies on synthetic agrochemicals which have negative impacts on the environment. To address this issue, innovative technologies involving natural substances, such as plant biostimulants, are being developed to support plant growth and development (Nephali et al., 2020). Turfgrass possesses the ability for carbon sequestration, and it will ultimately produce more environmental benefits (Selhorst, 2013). However, greenhouse gases emissions can be significant for different turfgrass management practices (VanDelden et al., 2016).

The maintenance of turfgrass is an intensive process that requires significant resources, including water, fertilizers, pesticides, and fuel, among others. As such, the sustainability of turf management practices is critical in minimizing the negative impacts of turf maintenance on the environment. One of the main reasons why sustainability is important in turf management is that it helps to minimize the environmental impact of turfgrass maintenance practices. For instance, the use of chemical fertilizers and pesticides can have negative effects on soil health, water quality, and wildlife, among other environmental factors. By adopting sustainable practices such as integrated pest management, organic fertilization, and water conservation, turf managers can reduce the amount of chemicals applied to the turf, which in turn helps to preserve the natural environment. Another reason why sustainability is essential in turf management is that it helps to conserve natural resources such as water and energy. Turfgrass maintenance requires a lot of water, especially in areas with hot and dry climates. However, water is becoming an increasingly scarce resource in many regions, and the demand for water is expected to increase due to population growth and climate change. By adopting sustainable practices such as reducing water consumption, collecting, and storing rainwater, and using drought-tolerant turf varieties, turf managers can help to conserve water resources, which is critical in ensuring long-term sustainability. Energy conservation is also an important consideration in sustainable turf management. Mowing, fertilization, and irrigation are energy-intensive processes that require fuel or electricity. By adopting sustainable practices such as using electric mowers, reducing the frequency of mowing, and optimizing irrigation systems, turf managers can reduce their energy consumption and carbon footprint, which is essential in mitigating the impacts of climate change.

Biodiversity conservation is another key aspect of sustainable turf management. Turfgrass monocultures can have negative impacts on local wildlife, as they provide limited habitat and food resources. By adopting sustainable practices such as planting wildflowers, shrubs, and trees, and using integrated pest management practices, turf managers can enhance the biodiversity, which in turn benefits local ecosystems. In addition to the environmental benefits, sustainable turf management can also have economic and social benefits. For instance, by reducing the use of chemical fertilizers and pesticides, turf managers can reduce their operating costs, which can improve the economic sustainability of their operations. Sustainable practices can also enhance the aesthetic value of turfgrass areas, which can benefit the local community by providing recreational spaces and improving the quality of life.

In summary, sustainability is a critical consideration in turf management, as it helps to minimize the negative environmental impacts of turf maintenance practices, conserve natural resources such as water and energy, enhance biodiversity, and provide economic and social benefits. By adopting sustainable practices such as reducing chemical use, conserving water and energy, enhancing biodiversity, and improving soil health, turf managers can ensure the long-term sustainability of their operations, while also contributing to the broader sustainability of the environment.

Hence, it is very important to adopt suitable management strategies that could cause minimum negative environmental impacts and ensure sustainability in turfgrass industry. Further, the management strategies could focus mainly on minimum soil disturbances which could ultimately result in reducing loss of soil organic carbon and eradicating the carbon emissions associated with mowing, irrigation, fertilization, and pest management (McCarty, 2002). Achieving sustainability in turfgrass management requires a comprehensive approach that considers all management practices and their impact on the surrounding environment, global environment, and social implications. To achieve sustainability, it is essential to understand ecological relationships in turf communities, soil-microbe communities, and the impact and interactions with the urban environment (Nugent and Allison, 2022). Furthermore, it is important to have proper guidance for turf users and make them aware about the importance to achieve sustainability goals.

Fig 3. Importance of sustainability in turf management.

2.4 Species selection

A key aspect of turf management is the selection of the appropriate type of grass for the environment and the intended use of the turf. Two main categories of grasses are used in turf management: warm-season and cool-season grasses.

Warm-season grasses are types of grasses that sustain in warm climatic conditions and are found mainly in tropical regions around the world. These grasses include bermudagrass, Zoysia grass, and St. Augustine grass (Hanna, 2013). They are known for their ability to tolerate high temperatures, drought, and heavy foot traffic. Warm-season grasses are best suited for areas with hot summers and mild winters, as they can become dormant and turn brown in the winter (Baxter et al., 2022). Cool-season grasses, on the other hand, are those that grow best in cooler climates, such as those found in temperate regions and adapted to the winter climates. These grasses include Kentucky bluegrass, perennial ryegrass, and tall fescue. Cool-season grasses are known for their ability to tolerate cold temperatures and can remain green throughout the year in regions with mild winters (Casler and Kallenbach, 2020).

Selection of turf speciesis an important criterion for sustainable turf management, it mainly depends on the type of turf and the climatic and soil conditions that prevailed in the area. If the turf is intended for soccer fields or high-traffic surfaces, a warm-season grass may be a better choice, as it could manage heavy traffic and be able to recover easily from the damage caused by players (Christians, 2020). Conversely, if the turf is intended for a residential lawn or an area with light foot traffic, a cool-season grass may be more appropriate, as it is more tolerant of shade and less likely to require frequent mowing (Christians and Patton, 2016). Moreover, it is important to consider the maintenance requirement of turfgrass which involves a lot of financial requirements, and selecting a suitable grass could help to implement the management practices in a cost-effective manner. According to different research studies, it is already identified that warm-season grasses require less water and fertilizer compared to cool-season grasses and can be mowed to a shorter height (Schleicher, 2005). In contrast, cool-season grasses require more water and fertilizer and should be mowed to a higher height to promote healthy growth (Goss, 2017). Moreover, turfgrass management has a multi-faceted approach that requires attention to several factors, including climate, soil, irrigation, fertilization, and pest management. Warm-season and cool-season grasses have different characteristics that make them better suited for specific conditions and uses.

2.4.1 Warm-season grasses:

Warm-season grasses are adapted to warm, humid, and arid climates and can tolerate high temperatures, drought, and traffic. The most common warm-season grasses used for turf management include bermudagrass, Zoysia grass, Centipede grass, and St. Augustine grass. These grasses are very popular in Italy and well known for their characteristics and adaptability to specific environmental conditions.

Bermuda grass (*Cynodon spp.*) is a warm-season grass that is commonly used for sports fields, golf courses, and lawns in the southern United States. It is known for its excellent wear tolerance, recovery ability, and heat and drought tolerance. However, bermudagrass requires high maintenance and can become invasive in some areas (Baxter et al., 2022).

Zoysia grass (*Zoysia spp.*) is a warm season grass well known for its characteristics like tolerance to temperature and drought, fine texture, and density. It is commonly used for golf courses, lawns, and parks in the southern United States and Asia. Zoysia grass has a low maintenance requirement and can thrive with less water and fertilizer compared to bermudagrass. On the other hand, it grows slowly and often takes a long time to establish (Patton and Schwartz, 2017).

Centipede grass [*Eremochloa ophiuroides* (Munro) Hack**]** is a type of warm-season grass that is native to China and Southeast Asia. It is often used for lawns and parks in the southeastern region of the United States due to its low-maintenance requirements. This grass can withstand drought conditions and does not need much fertilizer. However, it is vulnerable to damage during the winter season and has a slow recovery rate (Islam, 2005).

St. Augustine grass [*Stenotaphrum secundatum* (Walt.) Kuntze**]** is a warm-season grass that is widely used for lawns, parks, and golf courses in the southern United States. It has a medium texture, good shade tolerance, and a rapid growth rate. However, St. Augustine grass is prone to insect and disease problems and requires frequent watering and fertilization (Busey and Casler, 2003).

2.4.2 Cool-season Grasses:

Cool-season grasses are adapted to cool, temperate climates and can tolerate cold temperatures and shade. The most common cool-season grasses used for turf management in temperate climates include Kentucky bluegrass, perennial ryegrass, tall fescue, and fine fescue.

Kentucky bluegrass (*Poa pratensis* L.**)** is a cool-season grass that is widely used for lawns, golf courses, and parks in the northern United States and Europe. It has a medium to fine texture, good color, and excellent recuperative ability. However, Kentucky bluegrass is prone to disease and requires frequent watering and fertilization (DeKeyser et al., 2015).

Perennial ryegrass (*Lolium perenne* L.**)** is a cool-season grass that is commonly used for sports fields, golf courses, and lawns in all temperate regions. It has a fine texture, good color, and fast germination. Some perennial ryegrass cultivars are also drought-tolerant and resistant to disease. However, it has a shallow root system and requires frequent watering (Cool and Hannaway, 2004).

Tall fescue (*Festuca arundinacea* Schreber=*Schedonorus arundinaceus* (Schreb.) Dumort.) is a cool-season grass that is widely used for lawns, parks, and sports fields in the northern United States and Europe. It has a coarse texture, good shade tolerance, and good drought tolerance. Tall fescue is also resistant to disease and pests. However, it may require more frequent mowing than other cool season grasses due to the high growth rate (Christians and Engelke, 2020).

Fine fescue (*Festuca spp.*) is a cool-season grass that is commonly used for lawns, parks, and golf courses in the northern United States and north Europe. It has a fine texture, good shade tolerance, and excellent drought tolerance. Fine fescue is also resistant to disease and requires less fertilizer than other cool-season grasses. However, it may not be as traffic tolerant as other grasses (Demiroglu et al., 2010).

2.5 Selection Criteria:

The selection of warm-season or cool-season grasses for turf management depends on several factors, including climate, soil type, intended use, maintenance requirements, and personal preferences. For example, warm-season grasses are better suited for hot, dry climates, while cool-season grasses are better suited for cooler, wetter climates. The following table summarizes the characteristics and uses of common warm-season and cool-season grasses.

Table 1. Indicates the different turf species and its major characteristics.

Grass	Climate	Texture	Shade Tolerance	Traffic Tolerance	Drought Tolerance	Maintenance
Bermuda grass	Warm, humid	Coarse	Low	High	High	High
Zoysia grass	Warm, arid	Fine	Low	Medium	High	Low
Centipede grass	Warm, humid	Medium	Medium	Low	High	Low
St. Augustine	Warm, humid	Medium	High	Low	High	High
Kentucky blue	Cool, temperate	Fine	Low	Low	Medium	High
Perennial rye	Cool, temperate	Fine	Medium	Medium	High	Medium
Tall fescue	Cool, temperate	Coarse	High	High	High	Medium
Fine fescue	Cool, temperate	Fine	High	Low	High	Low

(Reference: Emmons and Rossi, 2015)

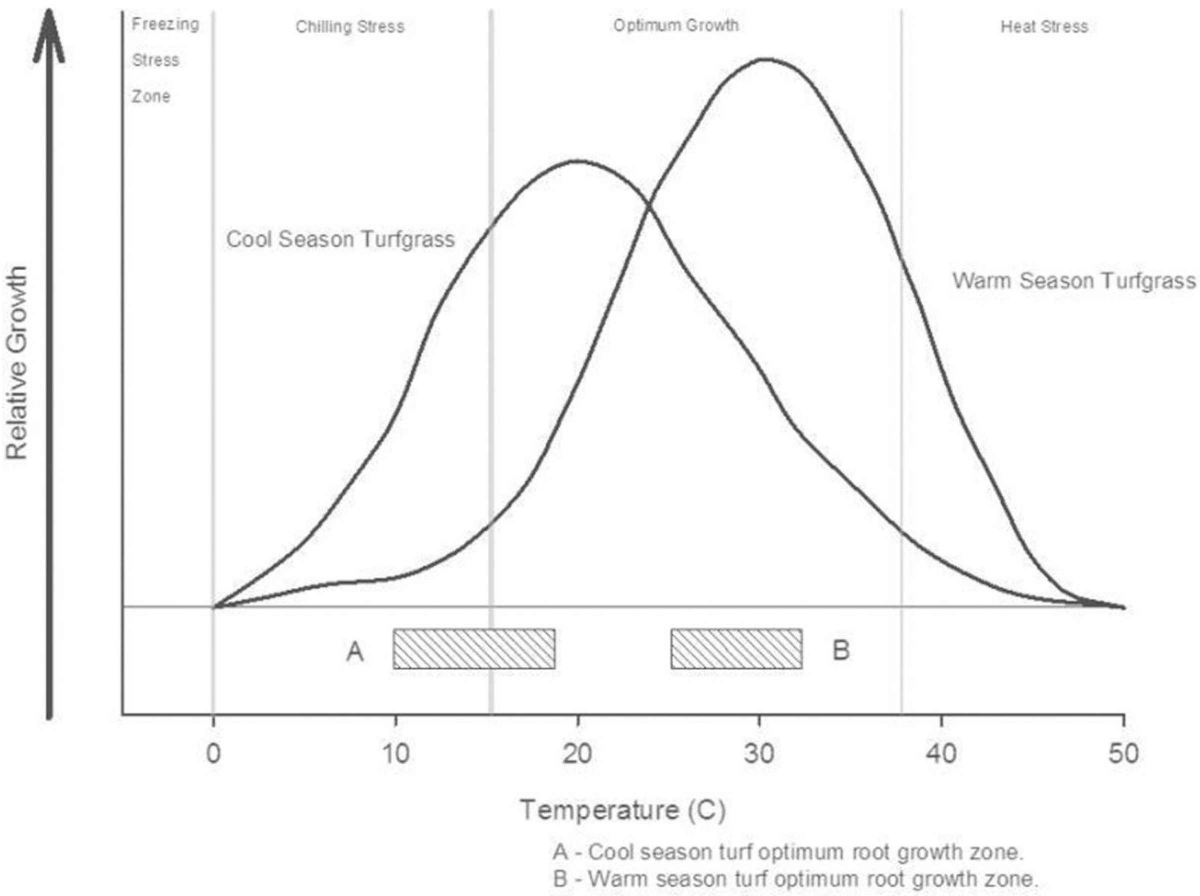

Fig. 4. Temperature responses of cool-season and warm-season turfgrass. Adapted from DiPaola and Beard (1992).

2.6 Characteristics of Bermudagrass

Bermuda grass (*Cynodon spp.)* is a warm-season perennial grass that is native to Africa, and it is now widely distributed throughout the world. It is a highly valued turfgrass species for sports fields, golf courses, and lawns due to its drought tolerance, wear resistance, and rapid regrowth ability (Huang et al., 2019). The grass has a prostrate growth habit and can form a dense, matted turf. The leaf blades are fine-textured and range from 1-4 mm in width. The leaf sheath is hairy, and the ligule is membranous with a fringe of hairs. The grass can produce both stolons and rhizomes, which enables it to quickly spread and establish new growth. bermudagrass is a warm-season grass, meaning it thrives in temperatures between 23.8°C and 32.22°Cand will go dormant during cooler temperatures (Christians et al., 2016). It can tolerate a wide range of soil types but prefers well-drained soils. Bermudagrass is also known for its ability to withstand heavy foot traffic and is often used in high-traffic areas such as athletic fields and golf courses. Overall, bermudagrass is a versatile and highly adaptable turfgrass species that is well-suited for use in warm climates (Guerrero, 2016). The species has a fine texture and a low, dense growth habit, making it an ideal choice for areas that require high traffic tolerance. Bermudagrass grows best in full sunlight and requires a minimum of 6 hours of direct sunlight per day for optimal growth. It is also tolerant to salt and can grow in a wide range of soil types, including clay, sand, and loam. Managing bermudagrass in the transition zone requires careful attention to its unique characteristics and the challenging environmental conditions. To successfully maintain a healthy and attractive turf, it is important to select bermudagrass varieties specifically bred for the transition zone. Proper establishment, including good soil preparation, is crucial. Overseeding with cool-season grasses can help maintain green color during cooler months. Implementing a tailored fertilization program, providing efficient irrigation practices, and adjusting schedules based on weather conditions are also essential. By considering these factors, turf managers can effectively manage bermudagrass in the transition zone and promote its health and vigor (Rimi et al., 2011).

Bermuda grass is known for its excellent drought tolerance, and its deep roots allow it to withstand long periods of water deprivation. In addition, this species is also resistant to many common turfgrass diseases and pests, including dollar spot, brown patch, and chinch bugs. To maintain the health and vitality of bermudagrass, proper cultural practices such as regular mowing, fertilization, and irrigation are recommended. Mowing should be done frequently during the growing season, with the recommended height of cut ranging from 0.5 to 2 inches depending on the intended use of the turf. Fertilization should be done according to soil test recommendations and timing, and irrigation should be applied deeply and infrequently to promote deep root growth and drought tolerance (Zhang et al., 2017). Despite its many benefits, bermudagrass can also pose challenges in turfgrass management. One of the main issues is that it can become invasive and take over other areas, especially in regions with mild winters. It can also be difficult to control weeds in bermudagrass turf, as the grass itself can be sensitive to herbicides. To overcome these challenges, research has focused on developing new management practices that can help to maintain healthy bermudagrass turf without causing harm to the environment. One approach is to use integrated pest management (IPM) strategies that combine cultural, biological, and chemical methods to control pests and weeds (Branham et al., 2015). This can include practices such as regular mowing, irrigation, fertilization, and soil testing, as well as the use of natural enemies and selective herbicides. Another strategy is to incorporate biostimulants into bermudagrass management programs. Biostimulants are natural compounds that can enhance plant growth and stress tolerance by stimulating beneficial microorganisms in the soil and improving nutrient uptake (Crouch et al., 2004). Research has shown that biostimulants can improve the growth and quality of bermudagrass turf, as well as increase its resistance to stress factors such as drought, heat, and cold. In conclusion, bermudagrass is a highly adaptable and versatile turfgrass species that has many benefits for use in sports fields, golf courses, and other applications (Soldat et al., 2019). While it can pose challenges in turfgrass management, advances in research have led to new management strategies that can help to maintain healthy turf without harming the environment. Further research is needed to continue improving our understanding of the biology and management of this important grass species.

2.7 Use of Biostimuant in the Turfgrass Industry

Biostimulants are defined as EU fertilizing products that stimulate plant nutrition processes to improve certain characteristics of plants or their rhizosphere. Studies have shown that combinations of non-microbial or microbial biostimulants with humic acids, plant extracts, or protein hydrolysates provide more consistent benefits to plant growth (Rouphael et al., 2020). Biostimulants have been tested on various crops, including horticultural crops like turfgrass, but incorporating them into turfgrass management programs can be challenging due to the lack of organic matter and microbial life in rootzones. To address this, increased degradation of organic matter and improved humification would be necessary.

Biostimulants are a relatively new and rapidly growing category of products in the turf management industry. Biostimulants are defined as substances and microorganisms that, when applied to plants or the rhizosphere, stimulate natural processes to enhance or benefit growth, health, and stress tolerance (Barritt et al., 2018). The use of biostimulants in turf management has become increasingly popular due to their potential to improve the overall quality of turfgrass and reduce the need for traditional chemical inputs. One of the key benefits of biostimulants in turf management is their ability to improve soil health and nutrient uptake. Biostimulants can help to increase the availability of nutrients in the soil, leading to improved plant growth and development (Gross et al., 2019). Additionally, biostimulants have been shown to enhance the rhizosphere microbiome, which can lead to improved soil structure and water-holding capacity (Fernández-Pérez et al., 2019). Another benefit of biostimulants in turf management is their ability to enhance plant stress tolerance. Turfgrass is often subjected to a variety of environmental stressors, such as drought, high temperatures, and disease pressure. Biostimulants have been shown to help plants better withstand these stressors by improving root development, increasing photosynthetic efficiency, and reducing oxidative stress (Gross et al., 2019).

In addition to the benefits outlined above, biostimulants have also been shown to reduce the need for traditional chemical inputs, such as fertilizers and pesticides. This reduction in chemical inputs can result in a more sustainable and environmentally friendly turf management approach (Gross et al., 2019). Despite the many benefits of biostimulants in turf management, there are still many questions and challenges that need to be addressed. For example, there is a lack of standardization and regulation in the biostimulant industry, which can make it difficult for turf managers to determine the quality and efficacy of different biostimulant products (Barritt et al., 2018). Additionally, there is a need for more research to better understand the mechanisms by which biostimulants enhance plant growth and stress tolerance, as well as the long-term effects of biostimulant use on soil health and the environment (Fernández-Pérez et al., 2019).

Biostimulants are natural or synthetic substances that improve plant growth and development by enhancing nutrient uptake, stress tolerance, and overall plant health. The use of biostimulants in turfgrass management has gained increasing attention in recent years to enhance turf quality and performance while reducing the reliance on traditional fertilizers and pesticides. Several studies have investigated the effect of biostimulants on bermudagrass, and the results have been promising. Biostimulants have been shown to improve root system development, increase turf density, enhance stress tolerance, and improve the overall quality and appearance of bermudagrass.

There has been increasing focus on controlling thatch in turfgrass in recent years, particularly in creeping bentgrass, which is commonly used on golf greens. Thatch is made up of living and dead plant tissue that accumulates on the soil surface due to excess organic matter buildup and slow decomposition rates and can lead to decreased plant rooting, water filtration, and cold tolerance, as well as increased dry zones and disease-related problems. This requires frequent maintenance activities, which can be costly and have negative environmental impacts. Biostimulants are seen as a potentially important tool for thatch degradation and improving soil health, but there is a lack of reliable scientific knowledge on their effects on grasses. Aesthetic standards also present challenges for turf management. For instance, a study conducted by Xu et al. (2020) investigated the effect of a commercial biostimulant containing humic acids and seaweed extracts on the growth and quality of bermudagrass under drought stress conditions. The results showed that the biostimulant significantly increased root length, shoot dry weight, and chlorophyll content compared to untreated control plants. The biostimulant also reduced lipid peroxidation and electrolyte leakage, indicating improved membrane stability and stress tolerance. Similarly, a study conducted by Teixeira et al. (2018) evaluated the effect of a biostimulant containing amino acids and plant extracts on the growth and quality of bermudagrass under low nitrogen conditions. The biostimulant was shown to increase turf density, shoot growth, and chlorophyll content compared to untreated control plants. The biostimulant also enhanced the activity of antioxidant enzymes and reduced the accumulation of reactive oxygen species, indicating improved stress tolerance and overall plant health.

In conclusion, the use of bio stimulants in turf management has the potential to improve soil health, enhance plant stress tolerance, and reduce the need for traditional chemical inputs. However, further research and standardization are needed to fully understand and realize the benefits of biostimulants in this industry. Bermudagrass is a popular warm season turfgrass that is widely used in residential and commercial lawns, sports fields, and golf courses. It is known for its drought tolerance, disease resistance, and ability to withstand heavy traffic. However, maintaining healthy and lush bermudagrass can be challenging, especially in harsh environmental conditions. Hence, the use of biostimulants in bermudagrass management can be an effective and sustainable way to enhance turf quality and performance. There has been a growing interest in the use of biostimulants for plant growth, including turfgrass management. This is partly driven by the need to reduce the use of pesticides and fertilizers, as well as by the effects of climate change on plant growth. The use of biostimulants has been shown to increase the visual parameters and plant development of turfgrass while reducing microbial infestations. Effective microorganisms (EMs) and humic acid-based biostimulants have also been found to be effective in promoting root growth and improving soil ecology, leading to healthier plants. As a result, the use of biostimulants is expected to continue to increase in the coming years. However, more research is needed to fully understand the optimal application rate, timing, and frequency of biostimulant use, as well as the potential long-term effects on soil and plant health.

2.8 Effect of fertilization on turfgrass quality and growth

The term "turfgrass quality" refers to various characteristics such as greenness, density, leaf discoloration, disease damage, and growth rate. Typically, it is measured on a visual scale of 1 to 9, where 1 is yellow or brown, and 9 is dark green (Morris and Shearman, 1998). Different forms of fertilizers have been used in turfgrass research, particularly for nitrogen (N), including soluble fertilizers like ammonium nitrate, urea, ammonium sulfate, and potassium nitrate, as well as controlled-release fertilizers (CRFs) like isobutylidine diurea (IBDU), urea-formaldehyde, sulfur-coated urea (SCU), and polymer-coated urea. These CRFs are designed to slowly degrade and release nutrients, thus reducing nutrient losses to the environment. Several studies have evaluated the effects of CRFs on turfgrass growth and quality. Obreza and Sartain (2010) have reviewed the various sources of fertilizers used to enhance nitrogen (N) use efficiency in horticultural crops, including turfgrass. When essential nutrients are lacking in soil, it can impair normal plant growth and reproduction. Nitrogen is the most commonly applied fertilizer as it is the most yield-limiting nutrient for grass plants, followed by phosphorus. While both agricultural and urban areas use fertilizers, studies on nutrient losses from urban landscapes are relatively scarce compared to those on agricultural soils. Turfgrass growth, quality, and nutrient exports are influenced by cultural management practices, such as recycling grass clippings, which can improve nutrient sequestration in the landscape. Grass clippings typically represent the largest N sink in established turfgrass, storing 25% to 60% of applied N. Returning clippings without adjusting fertilization rates can increase dry matter yields for turfgrass, and reducing N fertilization rates by 50% to 75% may not have a negative impact on turfgrass quality. Various studies have been conducted on this topic, including those by Beard and Green (1994), Bell and Moss (2008), Linde et al. (1995), Hull and Liu (2005), Qian et al. (2003), Starr and DeRoo (1981), Petrovic and Easton (2005), Heckman et al. (2000), and Kopp and Guillard (2002). Managing clippings in turfgrass systems can affect the dynamics of N, but it has no significant impact on phosphorus transport from the landscape. The potential for runoff and sediment movement is influenced by various factors, including slope and precipitation rate, as well as fertilizer sources and application rates. Studies conducted in the US have examined the effects of fertilizer sources and rates on turfgrass growth, and while the terminology is generally consistent among scientists, certain terms are specifically defined for use in this article. According to a report by Bell and Xiong (2008), optical sensing, particularly spectral reflectance, has been a popular research topic for a long time, with studies involving both mobile devices and remote sensing by satellites. The normalized difference vegetation index (NDVI) is commonly used to measure crop performance or stress, with a strong correlation to turf quality, influenced by various factors such as environmental stresses, pest infestations, and fertilizer treatments. Spectral reflectance can help quantify crop response to stress, fertilizer applications, or disease pressure, but a controlled study or field observation is necessary to determine the actual cause. However, the lack of systematic measurements of key soil properties linked to spectral data on plant performance remains an issue (Carrow et al., 2010). As a result, our aim is to go beyond optical sensing of plant information and develop approaches that combine direct soil and plant information, which necessitates the creation of appropriate mobile sensing platforms for key soil and plant properties.

The objective of this study is to compare the performance of different biostimulants and fertilization programs on three cultivars of bermudagrass, namely Sultan, MBG002, and Arden, during the fall and spring seasons in a transition zone environment. Several factors will be analyzed to assess the turf's overall condition, including turf color, turf quality, normalized difference vegetation index (NDVI), green up, dormancy, carbohydrate levels, and total carbohydrate levels. The study aims to investigate the potential interactions between the treatment methods (biostimulants and fertilization programs) and the specific cultivars of bermudagrass, as well as how these interactions vary across different dates within the fall and spring seasons. By examining these factors, the study aims to provide valuable insights into the most effective biostimulants and fertilization programs for optimizing bermudagrass performance and maintaining its overall health and appearance throughout the seasons.

3. Materials and Methods

The study was conducted at the agricultural experimental farm of the University of Padua, located in Legnaro (45°20' N, 11°57' E; altitude 8 m above sea level). The area is characterized by a humid subtropical climate (Köppen-Geiger climate classification system) with annual precipitation of 820 mm, mostly occurring from April to November, and an average annual temperature of 12.3°C over a forty-year period. The soil was a silty loam composed of 14% clay, 64.9% silt, and 17.9% sand, with a pH of 8.1.

3.1 Design and Sowing:

The experiment was conducted over a period of 2 years, involving three cultivars of bermudagrass (*Cynodon* spp.): MBG002, Arden 15, and Sultan. The experimental design was a strip-plot with three replicates. The elemental plot size was 2 x 2 m. The sowing was carried out on June 9, 2022.

3.2 Fertilization and biostimulants application:

A pre-sowing fertilization was applied using a combination of 50 kg/ha of nitrogen (N), 150 kg/ha of phosphorus pentoxide (P_2O_5), and 150 kg/ha of potassium oxide (K_2O). During the growing season, three different fertilizer application programs were implemented, as outlined in the following tables (Table 2.). Fertilization programs consisted of N application through urea and the biostimulant Hicure (Syngenta Italia SpA, Milan, Italy) a foliar biostimulant of natural origin based on aminoacids and peptides. Hicure was applied using a hand pressure knapsack sprayer.

3.3 Mowing:

Throughout the experiment, a rotary mower was used to maintain a mowing height of 3 cm. Mowing frequency varied depending on the season. A weekly mowing was conducted for most of the growing season, while in June, July, and August, mowing was performed twice a week. In autumn, the mowing frequency returned to once a week. Additionally, vertical mowing or aeration was considered during the second summer, following appropriate methods and timing.

3.4 Irrigation:

Irrigation was carried out based on specific stages of the experiment. Before seedling emergence, irrigation was applied at a rate of 5-7 mm/day to ensure optimal moisture for germination. After seedling emergence, weekly irrigation was performed, targeting 80% of the evapotranspiration (ET) rate. The evapotranspiration was estimated using an evapotranspiration (ET) gauge meter (Spectrum Technology, Inc., Plainfield, IL, USA). data.

3.5 Weed Control:

Weed control were carried out to manage both grassy and broadleaf weeds. Grassy weeds were controlled manually by hand, where they were identified and removed from the plots. For broadleaf weeds, a post-emergence herbicide treatment (Dicamba + Mecoprop) was conducted once, 40 days after sowing. After achieving full establishment, broadleaf weeds were manually removed by hand. The specific herbicide and application method should be chosen based on herbicide efficacy and safety guidelines.

Table 2. Fertilizer application´s programs during the growing season

Sowing Year	Programe 1	Programe 2	Programe 3
May	Pre-sowing fertilization (50 kg/ha N + 150 kg/ha P_2O_5 + 150 kg/ha K_2O)		
June			
15-July	25 kg/ha N (urea)	25 kg/ha N (urea)	25 kg/ha N (urea)
10-August	25 kg/ha N (urea)	25 kg/ha N (urea)	25 kg/ha N (urea)
5-September	25 kg/ha N (urea)	12,5 kg/ha N (HICURE) = 90 L/ha Hicure	6,25 kg/ha N (HICURE) = 45 L/ha Hicure
1-October 15-October	- -	12,5 kg/ha N (HICURE) = 90 L/ha Hicure -	6,25 kg/ha N (HICURE) = 45 L/ha Hicure 6,25 kg/ha N (HICURE) = 45 L/ha Hicure
1-November	-	-	6,25 kg/ha N (HICURE) = 45 L/ha Hicure
December	-	-	-
TOTAL nitrogen	125 kg/ha	125 kg/ha	125 kg/ha

Second Year	Programe 1	Programe 2	Programe 3
January	-	-	-
February	-	-	-
At 20-30% green-up	25 kg/ha N (urea)	25 kg/ha N (urea)	25 kg/ha N (urea)
1-May 15-May	- 25 kg/ha N (urea)	25 kg/ha N (HICURE) = 180 L/ha Hicure -	12,5 kg/ha N (HICURE) = 90 L/ha Hicure 12,5 kg/ha N (HICURE) = 90 L/ha Hicure
1-June 15-June	- 25 kg/ha N (urea)	25 kg/ha N (HICURE) = 180 L/ha Hicure -	12,5 kg/ha N (HICURE) = 90 L/ha Hicure 12,5 kg/ha N (HICURE) = 90 L/ha Hicure
1-July 15-July	- 25 kg/ha N (urea)	25 kg/ha N (HICURE) = 180 L/ha Hicure -	12,5 kg/ha N (HICURE) = 90 L/ha Hicure 12,5 kg/ha N (HICURE) = 90 L/ha Hicure
1-August 15-August	- 25 kg/ha N (urea)	25 kg/ha N (HICURE) = 180 L/ha Hicure -	12,5 kg/ha N (HICURE) = 90 L/ha Hicure 12,5 kg/ha N (HICURE) = 90 L/ha Hicure
5-September	25 kg/ha N (urea)	12,5 kg/ha N (HICURE) = 90 L/ha Hicure	12,5 kg/ha N (HICURE) = 90 L/ha Hicure
1-October 15-October	- -	12,5 kg/ha N (HICURE) = 90 L/ha Hicure -	12,5 kg/ha N (HICURE) = 90 L/ha Hicure
1- November	-	12,5 kg/ha N (HICURE) = 90 L/ha Hicure	
December	-	-	-
Total Nitrogen	150 kg/ha	150 kg/ha	150 kg/ha
Third Year	Programe 1	Programe 2	Programe 3
January	-	-	-
February	-	-	-
At 20-30% green-up	25 kg/ha N (urea)	25 kg/ha N (urea)	25 kg/ha N (urea)
1-May 15-May	- 25 kg/ha N (urea)	- 25 kg/ha N (HICURE) = 180 L/ha Hicure	12,5 kg/ha N (HICURE) = 90 L/ha Hicure 12,5 kg/ha N (HICURE) = 90 L/ha Hicure
Total Nitrogen	50 kg/ha	50 kg/ha	50 kg/ha

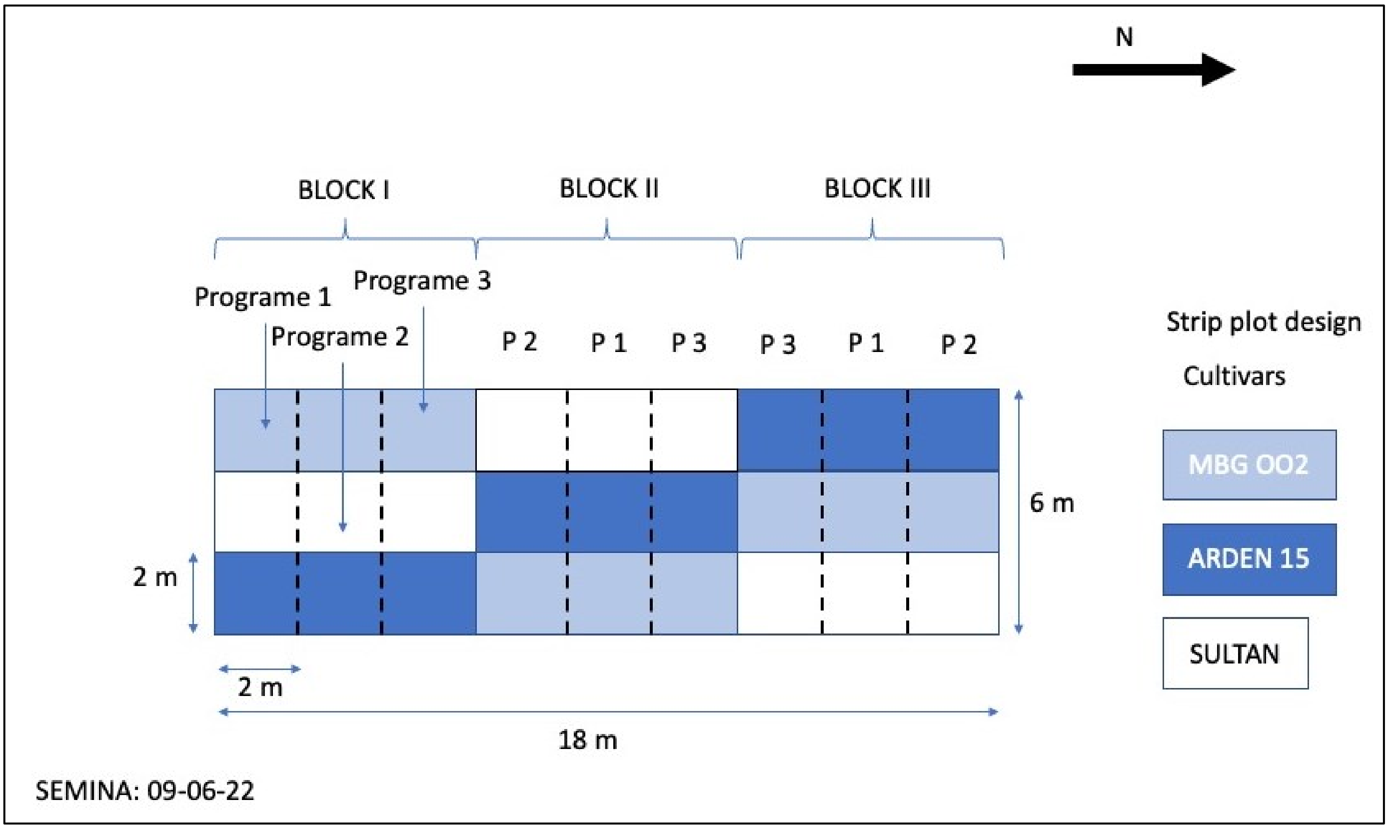

Figure 5. Experimental design.

3.6 Climatic Characterization

The year 2022, and 2023 were particularly significant in terms of climate, both at the national level and specifically for the study area. The total rainfall in Legnaro until September 2022 was 369.6 mm. The months of August and September 2022 were the only months with precipitation values similar to or higher than the long-term average, but in August, there were few rainy days with high-intensity events. In April and May, on the other hand, there were many rainy days, but the precipitation amounts were low.

Furthermore, the number of rainy days in the year 2022 (48 rainy days) is lower compared to the average number of rainy days during the period 1994-2020 (80 rainy days). The year 2021 also experienced a reduced number of rainy days compared to the 1994-2020 period, with 67 rainy days occurring instead of the reference period's 80 days. The total rainfall in millimeters was also largely reduced, with 660.4 mm of rainfall in 2021 compared to 836 mm in the 1994-2020 period. This reduced rainfall is evident in Figure 9, where the months of February, March, June, September, and October were particularly dry compared to the average of the reference period. Specifically, in 2021, rainfall was primarily concentrated in the periods of January, April, May, and July.

3.7 Data Collection

3.7.1 Weather Data Collection

Weather Data Collection at LegniaroWeather Station for the Years 2022 and 2023. The Legniaro Weather Station is located in 45°20' N, 11°57' E; altitude 10 m above sea level. The station serves as a vital data collection point for weather observations in the region. It is equipped with various instruments and equipment, including thermometers, barometers, anemometers, and rain gauges. The station infrastructure is regularly maintained and calibrated to ensure accurate and reliable data collection.

Every two weeks throughout the duration of the experiment in both years, the following measurements were recorded:

3.7.2 Turf green coverage

The turf green coverage was measured using digital image analysis (Richardson et al., 2001; Karcher and Richardson 2013). Photos of each plot were taken with a manually set CANON PowerShot G5X Mark II digital camera. The camera settings were ISO 200, exposure +2, aperture f/3.5, and shutter speed 1/30. The photos were taken with the help of a fully enclosed steel box (light box) equipped with four lamps to ensure standardized photos for all plots and dates. One photo per plot was taken every two weeks. Subsequently, the photos were subjected to digital analysis using Sigmascan Pro v. 5.0 software (SPSS Inc., Chicago, IL).

3.7.3 NDVI (Normalized Difference Vegetation Index)

The NDVI index was used to evaluate the physiological status of the turf. The RapidSCAN CS-45 Handheld Crop Sensor was employed to perform one measurement per plot. This instrument provides a more reliable and objective assessment, complementing visual evaluations that may be subject to high levels of subjectivity. The sensor evaluates the light reflected by the leaves based on a known light beam. If the plant is healthy, it reflects in the near-infrared range, while if it is stressed, it reflects in the near-infrared range, leading to a decrease in the NDVI value. One measurement per plot was taken every two weeks, resulting in a total of 27 measurements per week. The sensor is not affected by ambient lighting, allowing for accurate biomass measurements during the day or night due to its internal polychromatic light source. The sensor can gather data from vegetation at distances ranging from 0.3 meters to over 3 meters. The information produced by the sensor includes NDVI/NDRE (Normalized Difference Red Edge) vegetation indices, latitude/longitude and sample statistics, as well as basic reflection information. The RapidSCAN CS-45 sensor incorporates three optical measurement channels, simultaneously measuring crop/soil reflectance at 670 nm, 730 nm, and 780 nm. A unique feature of the RapidSCAN CS-45 sensor is its ability to perform height-independent spectral reflectance measurements. Holland Scientific refers to these reflectance measurements as pseudo solar reflectance (PSR) measurements. As such, the spectral reflectance bands are rescaled into percentages and do not vary with the sensor height above a target.

3.7.4 Aesthetic aspect evaluation (Color and Quality)

The aesthetic aspect evaluation involved visual assessments of texture, uniformity, density, color, and overall aesthetic appearance. Each plot was assigned a score ranging from

1 to 9, with 6 indicating sufficiency (Morris and Shearman, 1998). Texture refers to the width of the leaf blade and depends on the species and variety used. Uniformity assesses the degree of homogeneity of the turf. Density estimates the amount of tillering and is strongly influenced by the species, environmental conditions, and cultural practices employed. Color is evaluated, giving higher values to darker cultivars. The overall aesthetic appearance takes into account all the aforementioned characteristics.

3.7.5 Carbohydrates in stolons

The soluble carbohydrates (glucose and fructose) were extracted from freeze-dried and grounded stolon tissue in 50 ml of a 0.1N sulfuric acid solution and stirred for 60 minutes and then quantified by using the HPLC method (Jasco Corporation, Tokyo, Japan) (Kupiainen et al., 2010; Kim et al., 2001; Lopez-Hernandez et al., 1994). For starch analysis, stolon ground tissue was primarily used to determine total glucose by means of enzymatic hydrolysis with AGS and glucose residues. Starch content was determined as the difference between the sample subjected to enzymatic hydrolysis and the one which has not undergone this treatment and quantified by using the HPLC method using Jasco HPLC (Xiang et al., 2004; Simsek et al., 2012; AOAC Official Method 996.11).

3.7.8 Statistical Analysis

All the collected data were subsequently subjected to analysis of variance using R software (R Development Core Team, 2021). For parameters such as green turf cover, NDVI, overall aesthetic appearance, color, texture, uniformity, and density, the analysis of variance was performed using a mixed-effects linear model to test the effects of 'cultivar,' 'measurement date,' and their interaction. The models were executed for each measurement.

Figure 6. NDVI measurements during turfgrass green up.

Figure 7. Photos from experimental plots for turfgrass green cover determination through digital image analysis.

Figure 8. Collection of turfgrass samples for carbohydrate stolons analysis.

Figure 9. Laboratory analysis of carbohydrates content in bermudagrass stolons.

4. Results and Discussion

4.1 Weather Data

The weather data were analyzed by using Excel software. The fluctuation of temperature and precipitation at the experimental location was investigated from August 2022 to May 2023. The average temperature for August 2022 was recorded at 25^0C, indicating warm conditions at the beginning of the observation period. Subsequently, the temperature steadily declined, reaching a minimum of 5^0C in both December 2022 and January 2023, reflecting a significant drop in temperature during the winter months. From February 2023 onwards, there was a gradual increase in temperature, ultimately reaching a level of 10^0C in May 2023. This rise in temperature suggests a transition towards milder conditions as spring approached. Figure 10 illustrates the temporal pattern of temperature variations throughout the study period, depicting the observed fluctuations.

Regarding precipitation, the average value for August 2022 was 9mm, indicating a moderate level of rainfall during that month. Notably, the months of December, July, and April exhibited an average precipitation range between 6 and 10mm, suggesting consistent but relatively lower levels of rainfall during those periods. In contrast, the highest precipitation range was recorded in May 2023, with a value of 12mm. This indicates a notable increase in rainfall during that month, potentially influencing the local ecosystem and experimental conditions. The precipitation trends are visually represented in the form of a graph, providing a clear visualization of the observed patterns (figure 11.).

These findings regarding temperature and precipitation fluctuations are crucial in understanding the environmental conditions under which the experimental study was conducted. They provide valuable insights into the potential influence of climatic factors on the experimental outcomes and contribute to the comprehensive analysis presented in this thesis.

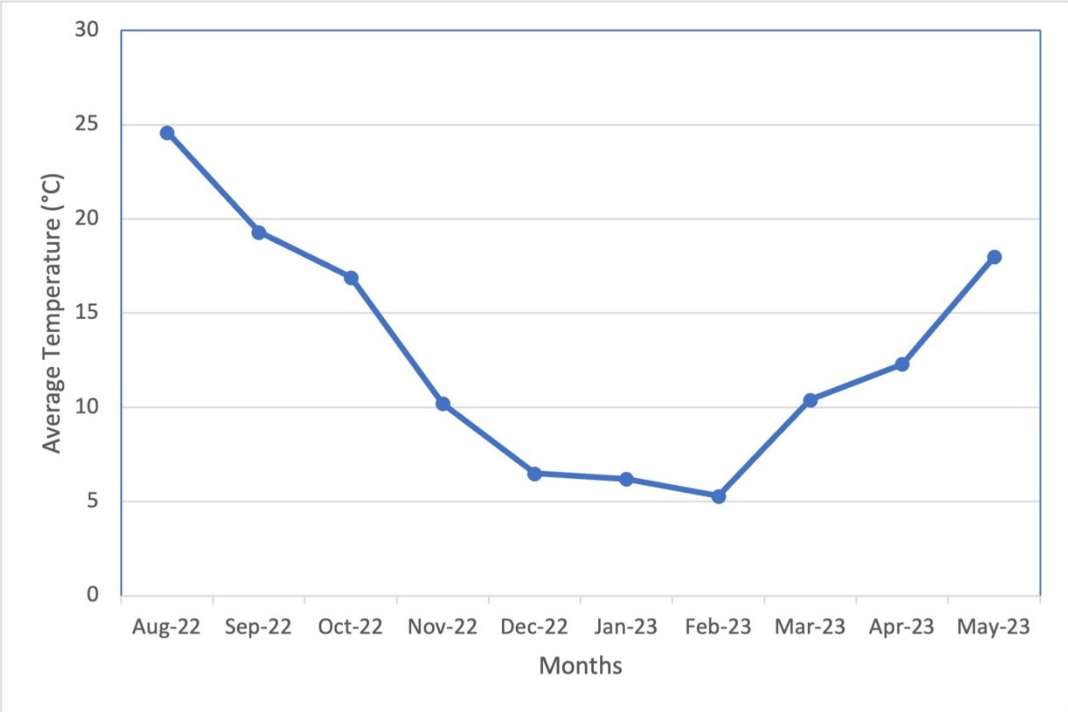

Figure 10 Average monthly mean temperatures in Legnaro during the experimental period.

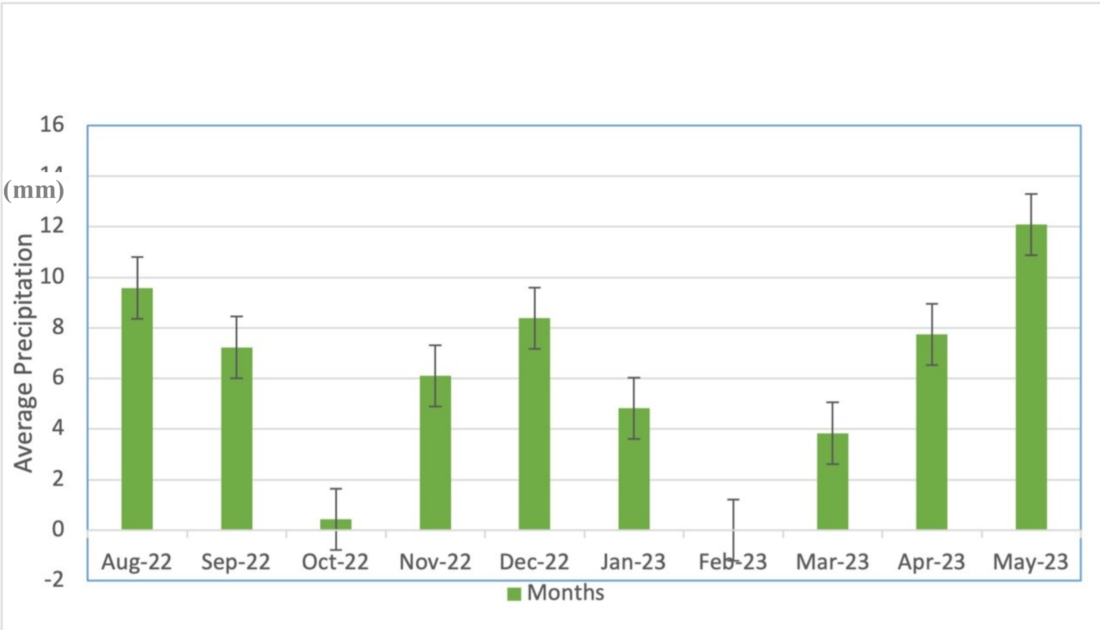

Figure 11. Total monthly precipitations in Legnaro during the experimental period. Vertical bars indicate standard error.

In table 3 and 4 are reported the results of analysis of variance (ANOVA) regarding the following parameters: turfgrass quality, color, NDVI and, carbohydrates (glucose, fructose, and starch) and the number of weeks to reach 80% green coverage (spring) and 80% yellow coverage (autumn) of three bermudagrass cultivars. From the table, we found significant effect on Turf quality and color for the factor's 'treatment', 'date', and interaction 'cultivar x date'. Similarly, for NDVI, it was found that the effects 'cultivar', 'date', interaction 'cultivar x date', 'treatment x date', and 'cultivar and date have significant effect.

Table 3. Results of ANOVA for the parameters Turfgrass quality, Color, and NDVI of three bermudagrass cultivars.

	Turf Quality	**Color**	**NDVI**
Cultivar	NS	NS	*
Treatment	***	***	NS
Date	***	***	***
Cultivar* Treatment	NS	NS	**
Treatment* Date	NS	NS	***
Cultivar* Date	***	***	***
Cultivar* Treatment* Date	NS	NS	NS

*Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$*

** Significant at the 0.01 probability level. *** Significant at the 0.001 probability level. [NS] Not significant at the 0.05 probability level.

Table 4. Results of ANOVA for the parameters soluble carbohydrates (Glucose and Fructose) and Starch content in stolons, and the number of weeks to reach 80% green coverage (spring) and 80% yellow coverage (autumn) of three bermudagrass cultivars.

	Sugar	**Starch**	**Total Carbohydrate**	**Greenup 80**	**Dormancy 80**
Cultivar	*	NS	*	*	NS
Treatment	NS	NS	NS	NS	*
Cultivar * Treatment	NS	NS	NS	NS	NS

*Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$*

** Significant at the 0.01 probability level. *** Significant at the 0.001 probability level. [NS] Not significant at the 0.05 probability level.

4.2 Turf Color

The results indicated that the treatment effect had a significant impact on all three varieties of bermudagrass, as evidenced by the statistical analysis showing a significance level of $p < 0.001$ (Table 3.).

Figure 1 indicates the effect of treatments on the color of three different bermudagrass verities such as Sultan, MBG002 and Arden. It is found that cultivars do not show any significance on the color of three different verities of bermudagrass (Table 3).

It explains the effect of treatments on color of all three bermudagrasses with respect to the cultivars (Figure 12.). It is well understood that P2 treatment showed higher quality compared to the treatment P1 and P2 (details of the treatment has mentioned in Chapter 2. Materials and Methods). Here, we can find a higher color value of 4.6 on treatment P2. This result suggests that P2 might be a more effective treatment for enhancing the color of bermudagrass in comparison to the other treatments tested. Hence, the higher level of significance strengthens the confidence in the results and suggests that the observed differences are indeed attributable to the treatments applied.

The statistical analysis revealed that the cultivar effect was highly significant ($p < 0.001$) (Table 3.), indicating that the choice of cultivar has a substantial impact on the color intensity of bermudagrass. The results of ANOVA also revealed the significant effect of dates on the color of the three different cultivars of bermudagrass (Table 3.). Interestingly, the above results demonstrate the seasonal variations in color for each cultivar. The results indicated that all three cultivars, Sultan, MBG002, and Arden, exhibited a consistent decrease in color during the winter season, spanning from October 20, 2022, to December 14, 2022. This decline in color is likely attributed to the climatic conditions prevalent in the region during that period (Figure 13.), as this species enter dormancy when soil temperatures are lower than 10 °C (Rimi et al., 2011). Similar observations have been reported in previous studies, where winter dormancy and reduced photosynthetic activity resulted in decreased color intensity in bermudagrass.

Furthermore, all three varieties of bermudagrass shown the lowest color intensity from December 29, 2022, to March 30, 2023. This prolonged period of reduced color can be attributed to the combination of low temperatures and limited sunlight exposure during the winter months, inhibiting the growth and pigment production in bermudagrass (Ihtisham et al., 2018). However, a noteworthy finding in this study is that the three varieties of bermudagrass started showing signs of regaining green color from April 6, 2023, onwards. This revival of color suggests a resumption of active growth and photosynthetic activity in response to improving weather conditions. Subsequently, a considerable increase in color intensity was observed, indicating the recovery of bermudagrass after the winter period. Further, it clearly indicates the ability of bermudagrass to adapt and recover from dormancy periods and resilience to adverse environmental conditions as a warm season turfgrass species.

It is understood that color variations among cultivars of bermudagrass has specific environmental conditions and geographical locations. Different regions may experience variations in temperature, sunlight exposure, and other climatic factors, which can influence the color and overall health of bermudagrass differently. These findings contribute to the understanding of cultivar selection and the management of bermudagrass for optimal color and performance in various environmental conditions.

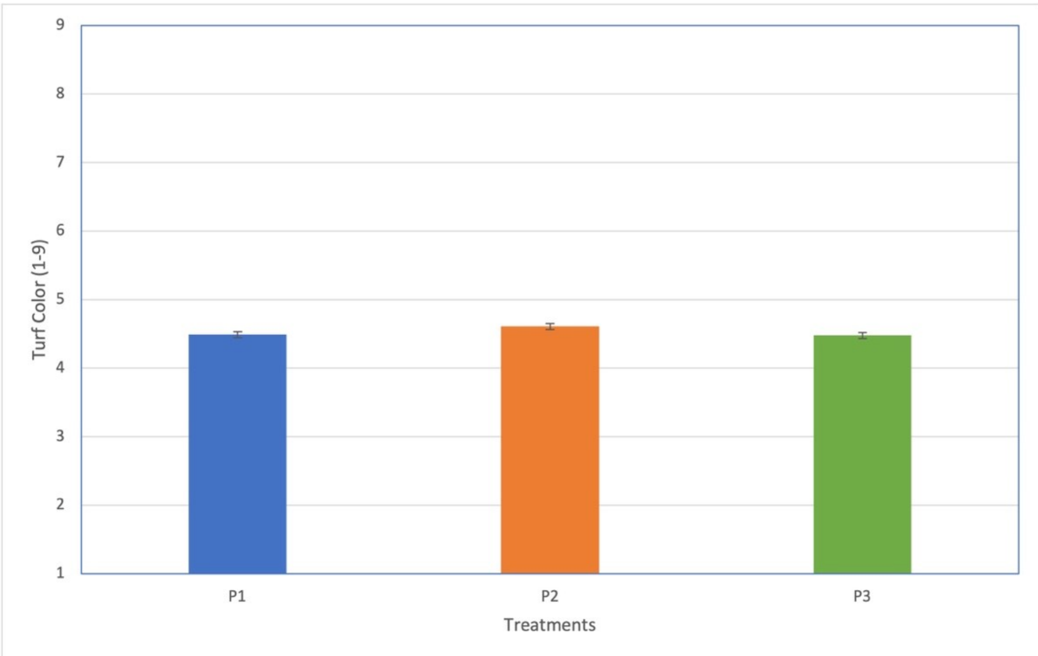

Figure 12. Treatment effect for the parameter turf color of three cultivars of bermudagrass. Vertical bars indicate standard error.

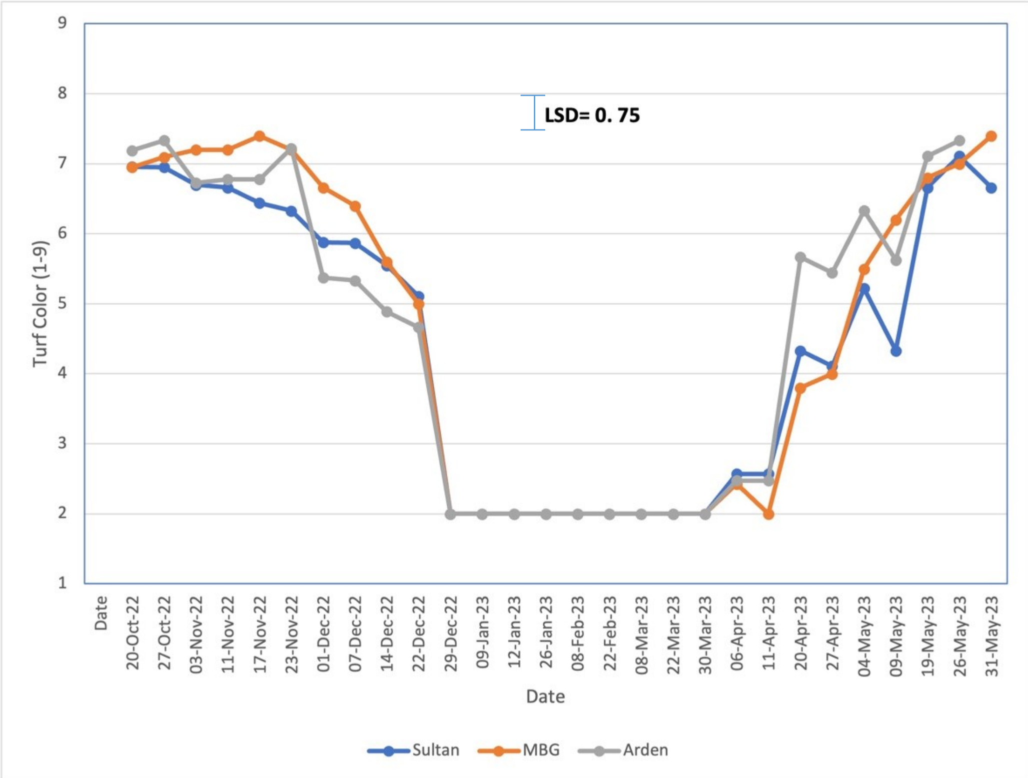

Figure 13. Interaction cultivar x date for the parameter turf color

4.3 Turf Quality

The below figure 14, represents the effects of cultivar on the quality of three varieties of bermudagrass, namely Sultan, MBG002, and Arden. The statistical analysis revealed that there was no significant difference observed among the cultivars individually. This could be due to the observed differences in quality may be attributed more to treatment effects rather than genetic variations among the varieties.

Figure 15 explains the effect of treatments on the turf quality of all three cultivars of bermudagrass. The statistical analysis revealed a highly significant level of $p < 0.001$ (Table 3.), indicating that the treatment effect has a substantial impact on the quality of bermudagrass. This finding is consistent with previous research highlighting the influence of both cultivar selection and treatment application on turfgrass quality. The results also indicated that treatment had a significant influence on the quality of all three varieties of bermudagrass. Treatment P2 consistently led to higher quality in all three varieties compared to other treatments. This finding suggests that P2 could be used as an effective treatment programme for improving the turfgrass quality. Similar findings have been reported in previous studies, where specific treatments or management practices were found to enhance turfgrass quality parameters, including color and overall appearance (Smith et al., 2020).

In addition, the figure 6 indicates the seasonal variations in quality for each cultivar. It was observed that all three varieties of bermudagrass exhibited a consistent decrease in quality during the winter season, spanning from November 23, 2022, to December 29, 2022. This decline in quality can be attributed to the unfavorable climatic conditions prevailing in the region during that period, such as lower temperatures and reduced sunlight. Furthermore, all three varieties displayed the lowest quality from December 29, 2022, to April 11, 2023. This extended period of reduced quality can be attributed to the cumulative effects of winter dormancy, limited sunlight, and potentially other stress factors, such as cold temperatures. However, all three varieties of bermudagrass started showing signs of regaining green color and quality from April 20, 2023, onwards. This recovery and subsequent increase in quality indicate the resumption of active growth and photosynthetic activity in response to improving weather conditions. The higher quality observed in the Arden variety compared to Sultan and MBG002 suggests that Arden may possess certain characteristics or genetic traits that contribute to its superior quality during the recovery phase. Hence, these findings suggest that while cultivar selection may have some influence on quality, treatment application plays a more significant role. Additionally, the seasonal variations in quality highlight the challenges of maintaining optimal turfgrass quality during winter dormancy periods.

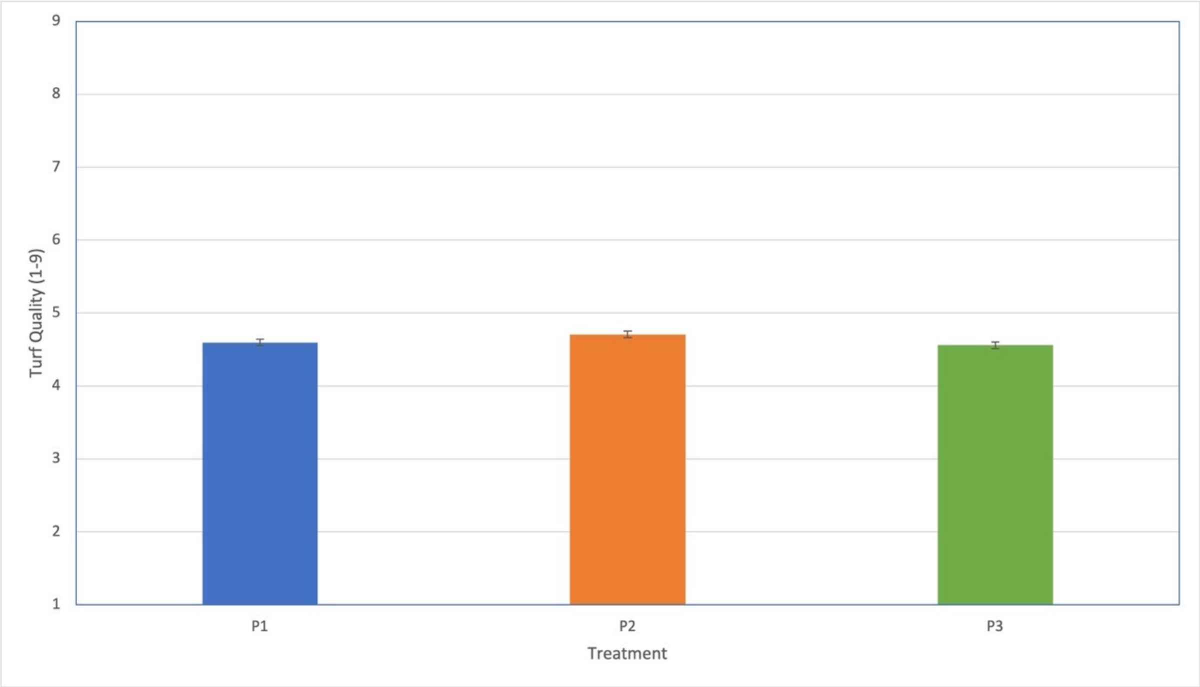

Figure 14. Treatment effect for the parameter turf quality of three cultivars of bermudagrass. Vertical bars indicate standard error.

Figure 15. Interaction cultivar x date for the parameter turfgrass quality

4.4 NDVI (Normalized Difference Vegetative Index)

The below figures (figures 16, figure 17 and, figure 18) represent the effect of cultivar and treatment on the Normalized Difference Vegetation Index (NDVI) of three varieties of bermudagrass. The statistical analysis revealed that cultivars had a significant effect on the NDVI at a significance level of $p < 0.05$ (Table 3.). Additionally, the interaction between cultivar and treatment showed a significant effect on the NDVI at a higher significance level of $p < 0.01$ (Table 3.).

The significant effect of cultivar on NDVI suggests that different varieties of bermudagrass exhibit variations in their vegetative growth and health. This finding aligns with previous research that has demonstrated the influence of cultivar selection on the performance and physiological characteristics of turfgrass species (Reinert et al., 2017; Johnson et al., 2021). The observed differences in NDVI among the cultivars may be attributed to genetic variations, which can affect factors such as chlorophyll content, leaf area, and photosynthetic efficiency. Moreover, the significant interaction between cultivar and treatment on NDVI indicates that the response of each cultivar to the applied treatments was not uniform.

This finding suggests that specific management practices or treatments may have differential effects on the NDVI of different bermudagrass varieties. The interaction between cultivar and treatment could be influenced by various factors, including the physiological characteristics of the cultivars, their response to specific inputs, and their overall adaptability to environmental conditions (Smith et al., 2020; Reinert et al., 2022). It is important to note that NDVI is a commonly used index to assess vegetation health and vigor, based on the measurement of near-infrared and red reflectance. It provides an indirect measure of plant biomass, leaf area, and chlorophyll content, which are essential indicators of plant growth and photosynthetic activity. Therefore, the significant effects of cultivar and the interaction with treatment on NDVI highlight the importance of cultivar selection and management practices in optimizing the health and vigor of bermudagrass. The results of this study highlight the significant effects of cultivar and the interaction between cultivar and treatment on the NDVI and seasonal changes on NDVI of three varieties of bermudagrass. The findings suggest that different cultivars can exhibit variations in their vegetative growth and response to specific treatments. These results contribute to our understanding of the importance of cultivar selection and tailored management practices in optimizing the health and vigor of bermudagrass.

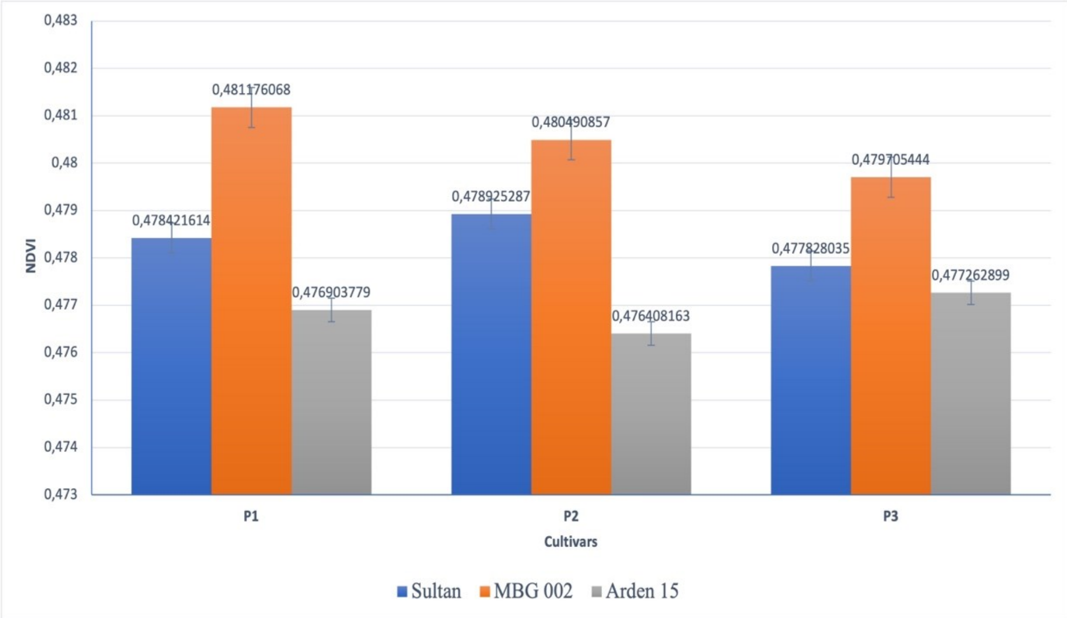

Figure 16. Cultivar effect for the parameter NDVI of three bermudagrass turfgrasses.

Figure 17. Interaction cultivar x date for the parameter NDVI.

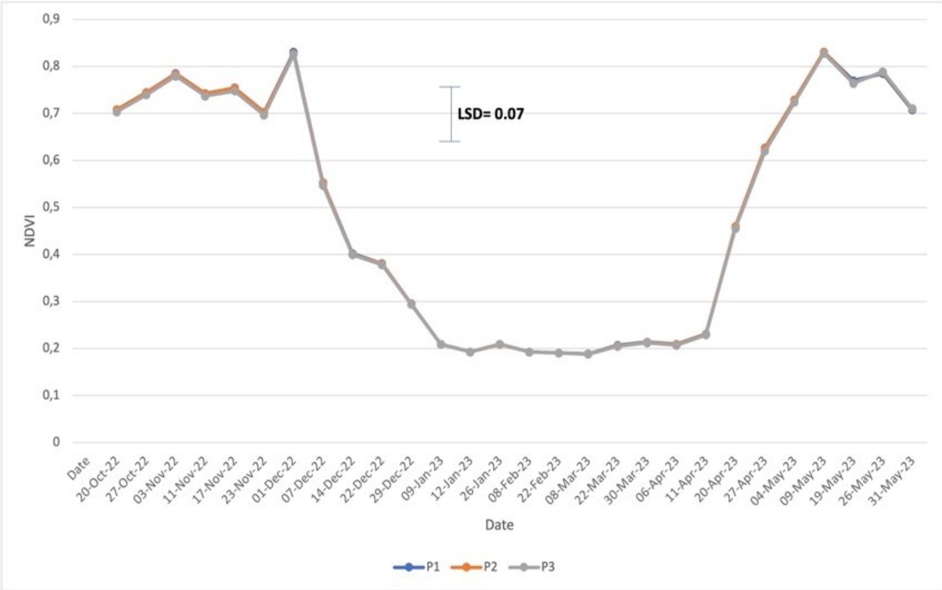

Figure 18. Interaction treatment x date for the parameter NDVI.

4.5 Green up

From below figures (figure 19, figure 20, figure 21 and 22), it shows the percentage green cover for spring green up of cultivars such as Sultan, MBG 002 and Arden of bermudagrass for three programs of fertilization (P1, P2, and P3). The statistical analysis revealed that cultivar had a significant effect on green-up at a significance level of $p < 0.05$ (Table 4.). However, no significant effect of treatment on green-up was observed. The significant effect of cultivar on green-up suggests that different varieties of bermudagrass exhibit variations in their ability to resume active growth and regain green color. This finding is consistent with previous research that has shown cultivar-specific differences in the timing and rate of green-up in turfgrass species (Raudenbush et al., 2014; Yu et al., 2019). The observed variation in green-up among the cultivars may be attributed to genetic differences, including variations in dormancy-breaking potential and early-season growth characteristics.

Specifically, in the present study, the cultivar Arden reached 80% green-up on April 27, 2023, whereas Sultan and MBG002 achieved the same level of green-up in the first week of May. This indicates that Arden exhibits a slightly delayed green-up compared to the other two cultivars. The variation in the timing of green-up among the cultivars may be influenced by factors such as genetic traits, temperature thresholds, and growth regulators.

The findings of this study have practical implications for turfgrass management. Understanding the cultivar-specific differences in green-up can help turfgrass professionals and landscapers in selecting the most suitable cultivars for specific applications and desired green-up timelines. For example, if an early green-up is desired, selecting cultivars such as Arden might be advantageous, as they reached the 80% green-up threshold in the last week of April. On the other hand, if a slightly delayed green-up is acceptable, Sultan and MBG002 may be a suitable choice.

It is worth noting that green-up is an important indicator of turfgrass health and aesthetics. Rapid and uniform green-up contributes to the overall visual appeal of turf areas and indicates the successful transition from winter dormancy to active growth. The findings of this study provide valuable insights into the cultivar-specific variations in green-up and contribute to the knowledge base of bermudagrass management. However, no significant effect of treatment on green-up was observed. These findings have practical implications for turfgrass professionals in cultivar selection and provide insights into the factors influencing green-up in bermudagrass.

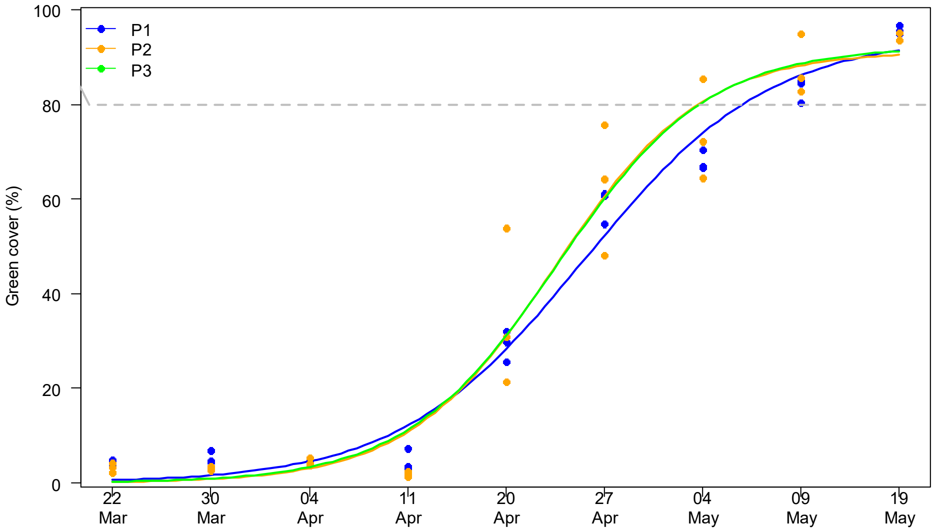

Figure 19. Percentage green cover for spring green up of cultivar Sultan of bermudagrass for three programs of fertilization (P1, P2, and P3).

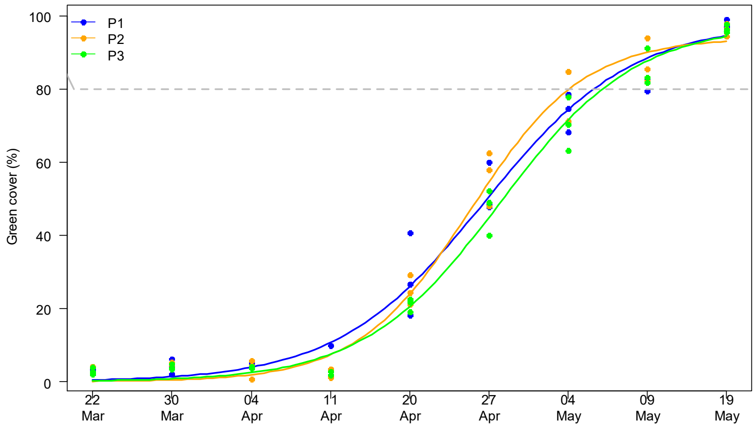

Figure 20. Percentage green cover for spring green up of cultivar MBG 002 of bermudagrass for three programs of fertilization (P1, P2, and P3).

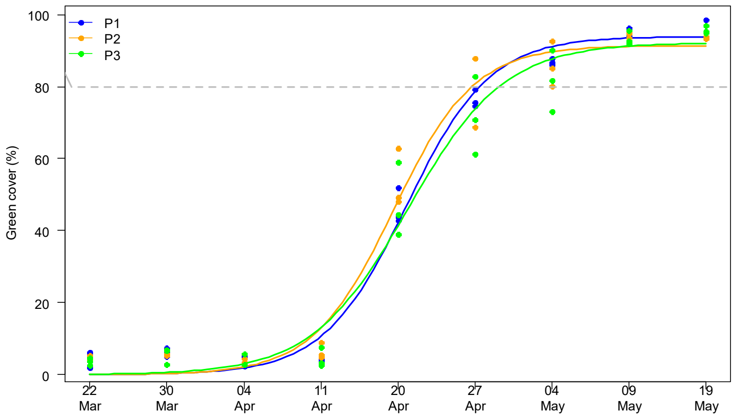

Figure 21. Percentage green cover for spring green up of cultivar Arden of bermudagrass for three programs of fertilization (P1, P2, and P3).

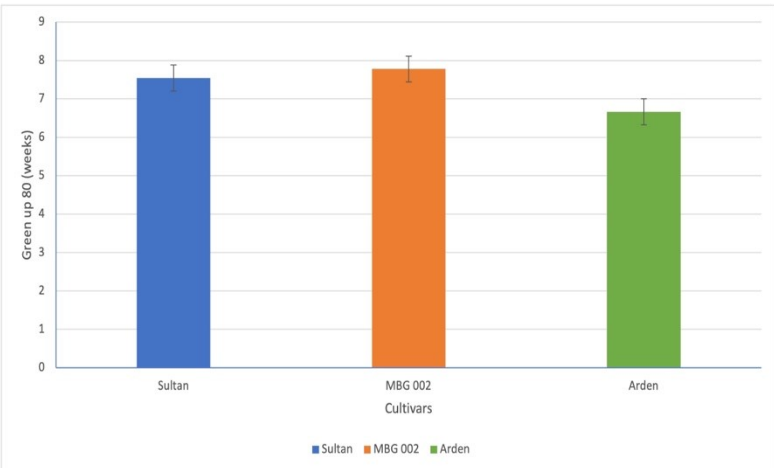

Figure 22. Cultivar effect for the green cover at a range of 80% during spring green up. Vertical bars indicate standard error.

4.6 Dormancy

The results from Table 2 indicate that the treatments had a significant effect on the dormancy of all three bermudagrass cultivars such as Sultan, MBG 002 and Arden. The graph illustrates the yellow cover during the spring green up period, providing visual representation of the changes in dormancy over time (figure 23, figure 24, figure 25, and figure 26).

The findings demonstrate distinctive patterns of dormancy and spring greenup among the Sultan, MBG002, and Arden cultivars of bermudagrass. From the results obtained from this study, the cultivars exhibited variations in the timing and rate of dormancy onset and recovery. Notably, Sultan reached 80% dormancy by December 7, 2022, while MBG002 achieved the same level of dormancy on December 14, 2022. Similarly, Arden reached 80% dormancy during the early part of the second week of December 2022. It is important to note that dormancy is influenced by various environmental factors, including temperature, photoperiod, and soil moisture.

The differences in spring greenup observed in the yellow cover graph indicate that the cultivars exhibit varying rates of recovery from dormancy. Sultan appears to have the fastest spring greenup, as evidenced by the earlier onset of green color compared to MBG002 and Arden. However, it is important to note that the specific factors influencing spring greenup, such as temperature and nutrient availability, should be considered in future studies to provide a comprehensive understanding of the dynamics.

The results of this study have practical implications for turfgrass management. By understanding the variations in dormancy and spring greenup patterns among bermudagrass cultivars, turfgrass managers could suggest cultivar-specific management strategies can be developed to optimize the performance and aesthetics of each bermudagrass variety.

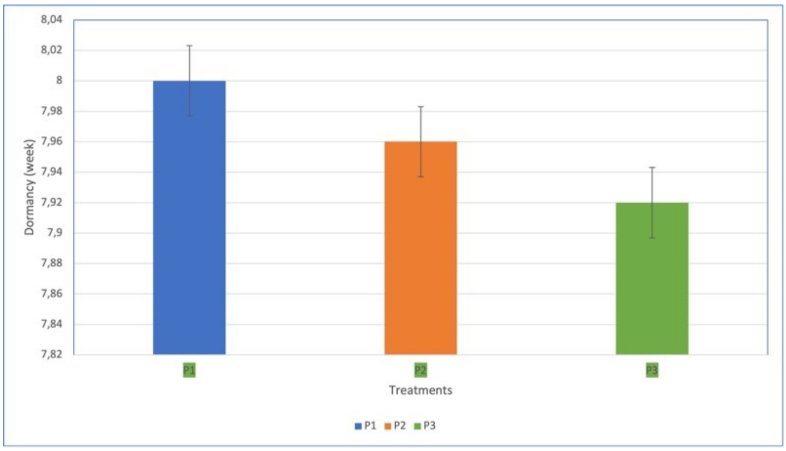

Figure 23. Cultivar effect for the yellow cover at a range of 80% during fall dormancy. Vertical bars indicate standard error.

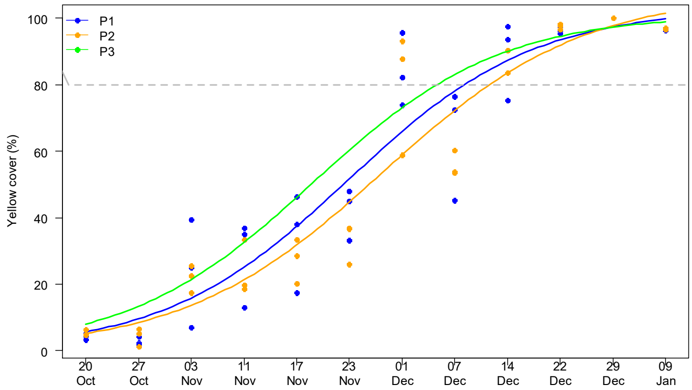

Figure 24. Percentage yellow cover during spring green up of cultivar Sultan of bermudagrass for three programs of fertilization (P1, P2, and P3).

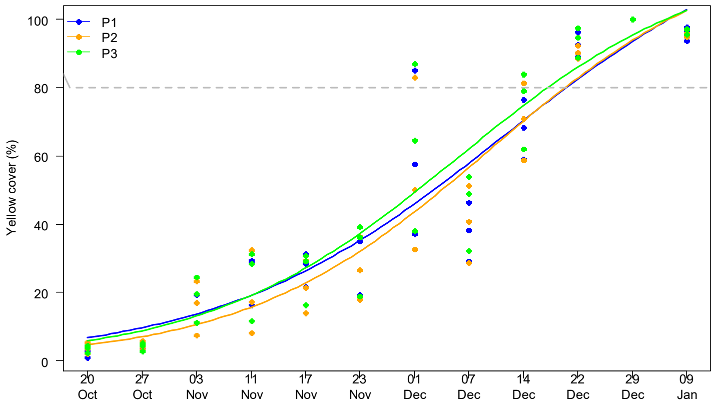

Figure 25. Percentage yellow cover during spring green up of cultivar MBG 002 of bermudagrass for three programs of fertilization (P1, P2, and P3).

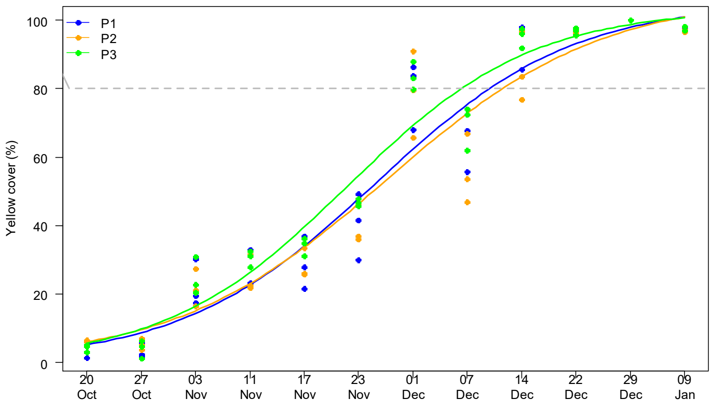

Figure 26. Percentage yellow cover during spring green up of cultivar Arden of bermudagrass for three programs of fertilization (P1, P2, and P3).

4.7 Carbohydrates reserves (glucose, fructose, starch, and total non-structural carbohydrates)

The ANOVA did not show differences in starch content for cultivars, treatments, and their interaction. From the results obtained from this study, cultivar had a significant effect on both carbohydrate content (glucose and fructose) and total non-structural carbohydrate levels at a significance level of $p < 0.05$ (Table 4.). Among the cultivars, Arden exhibited higher levels of water-soluble carbohydrates and total non-structural carbohydrates compared to Sultan and MBG002 (figure 27 and figure 28).

The significant impact of cultivar on carbohydrate levels suggests that different varieties of bermudagrass possess inherent differences in carbohydrate metabolism. Carbohydrates play a crucial role in plant growth, energy storage, and stress tolerance, and their levels can fluctuate in response to various environmental and physiological factors. The observed variations in carbohydrate content among the cultivars may be attributed to genetic characteristics, including variations in carbohydrate synthesis, allocation, and utilization pathways.

Arden cultivar of bermudagrass exhibited higher levels of water-soluble carbohydrates compared to Sultan and MBG002. Carbohydrates are readily available energy sources that plants can utilize during periods of stress or rapid growth (Pollock et al., 2003). The higher levels of water-soluble carbohydrates in Arden may indicate its greater capacity for carbohydrate accumulation or its ability to maintain higher energy reserves, potentially contributing to its superior growth and stress tolerance compared to the other cultivars.

Similarly, Arden also displayed higher levels of total non-structural carbohydrates compared to Sultan and MBG 002. Total non-structural carbohydrates include a wider range of carbohydrates, such as starch and other storage forms, which can be mobilized to support plant growth and development. The higher levels of total non-structural carbohydrates in Arden suggest its greater capacity for carbohydrate storage and utilization, which may confer advantages in terms of growth recovery and resilience under adverse environmental conditions. It is worth noting that MBG 002 exhibited the lowest levels of both water-soluble carbohydrates and total non-structural carbohydrates among the three cultivars. This may indicate its relatively lower capacity for carbohydrate synthesis or storage. Interestingly, the study found no significant impact of treatment or the interaction between cultivar and treatment on water-soluble carbohydrate and total non-structural carbohydrate levels. This implies that the applied treatments in this study did not influence the carbohydrate metabolism or accumulation in bermudagrass. The study did not observe significant effects of treatment or the interaction between cultivar and treatment on carbohydrate levels. These findings contribute to our understanding of the physiological variations among bermudagrass cultivars and highlight the importance of considering carbohydrate metabolism in cultivar selection and management practices.

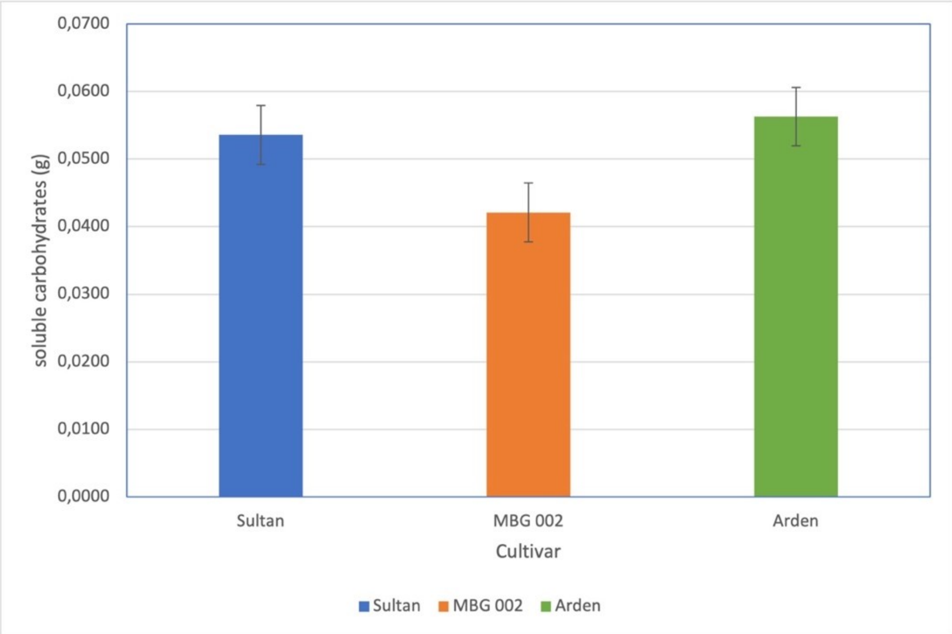

Figure 27. Soluble carbohydrates (glucose and fructose) content in three different cultivars of bermudagrass. Vertical bars indicate standard error.

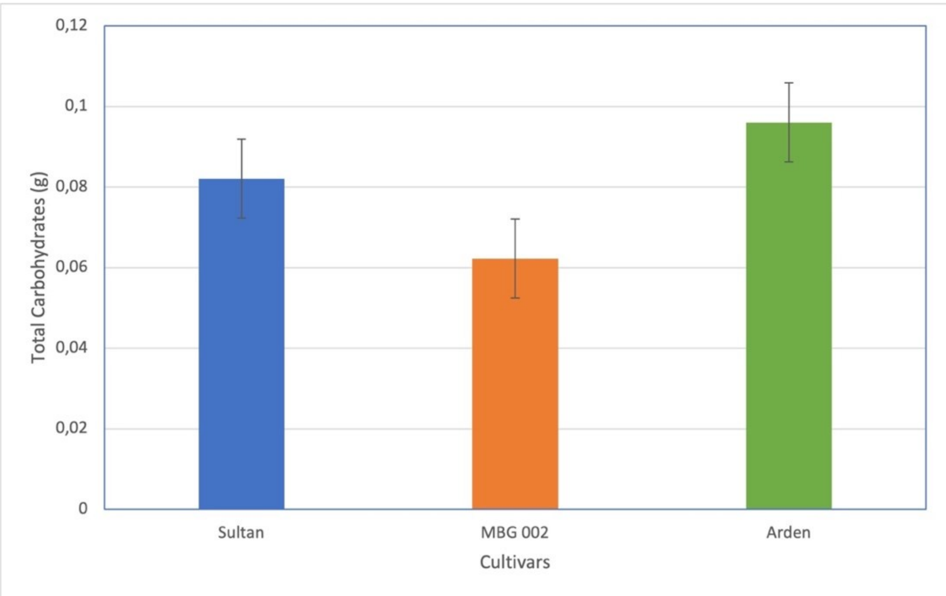

Figure 28. Total nonstructural carbohydrates content in three different cultivars of bermudagrass. Vertical bars indicate standard error.

5. Conclusions

The findings of this study provide valuable insights into the performance of three bermudagrass cultivars under various biostimulant and fertilization programs during the fall and spring seasons. The results demonstrate that the treatment effect had a significant impact on all three bermudagrass varieties, as indicated by the statistical analysis. Regarding the color of the bermudagrass, there was no significant difference observed among the three varieties, namely Sultan, MBG002, and Arden. However, Sultan and MBG002 exhibited better color performance compared to Arden, suggesting that these varieties may be more suitable for achieving desirable color outcomes. The quality of bermudagrass was significantly influenced by the treatments, with P2 treatment showing higher quality compared to P1 and P2 treatments. Further, it indicates the importance of appropriate treatment application in enhancing turfgrass quality. Moreover, the study confirmed the significant impact of both cultivar selection and treatment application on turfgrass quality, consistent with previous research in the field. The NDVI (Normalized Difference Vegetation Index) analysis revealed that both cultivar and treatment exerted significant effects on the bermudagrass. The interaction between cultivar and treatment also demonstrated a significant effect on the NDVI. These findings suggest that careful consideration of cultivar selection and treatment application is crucial for achieving desirable vegetation density and health. Regarding green-up, cultivar selection had a significant effect, while treatment application did not exhibit a significant impact. This indicates that the choice of bermudagrass variety plays a crucial role in achieving optimal green-up, while treatment programs may not have a substantial influence on this aspect. Dormancy, an important characteristic of bermudagrass, was significantly influenced by the treatments for all three cultivars. This finding highlights the potential of biostimulant and fertilization programs in managing dormancy and promoting active growth in bermudagrass during the fall and spring seasons. Starch content did not differ significantly among cultivars, treatments, or their interaction, indicating that these factors may not have a notable effect on starch accumulation in bermudagrass. However, both carbohydrate content and total non-structural carbohydrate levels were significantly affected by the cultivar choice. Arden exhibited higher levels of both carbohydrates compared to Sultan and MBG002, suggesting that Arden may have a greater capacity for carbohydrate storage and utilization.

In summary, the results of this study emphasize the importance of cultivar selection and treatment application in optimizing bermudagrass performance cultivar performance in temperate regions, including color, quality, NDVI, dormancy, and carbohydrate levels. These findings contribute to the understanding of how biostimulant and fertilization programs can be tailored to specific bermudagrass varieties to enhance their overall performance during the fall and spring seasons.

6. Future Scope

Based on the findings of this study, there are several important avenues for future research that can enhance our understanding and management of bermudagrass performance during the fall and spring seasons. Firstly, further investigation is needed to explore the underlying physiological and biochemical mechanisms responsible for the observed differences in bermudagrass performance among cultivars and treatment programs. Understanding these mechanisms can provide valuable insights into the specific factors influencing color, quality, NDVI, dormancy, and carbohydrate levels in bermudagrass. Further, there is a need to optimize treatment programs by refining biostimulant and fertilization strategies. This involves determining the most effective application rates, timing, and combinations of nutrients for maximizing bermudagrass performance. Studying the effects of different nutrient formulations, application methods, and frequencies can help in developing optimal treatment protocols tailored to specific cultivars and environmental conditions.

Additionally, long-term studies are warranted to assess the sustained effects of different treatment programs on bermudagrass performance. Monitoring the color, quality, NDVI, dormancy, and carbohydrate levels over multiple growing seasons can provide insights into the durability and consistency of treatment effects. Understanding the influence of environmental factors such as temperature, humidity, rainfall, and light availability on bermudagrass performance under different treatment programs is another important aspect to explore. This knowledge can help in adapting management strategies to varying environmental conditions. Moreover, incorporating additional performance indicators beyond color, quality, NDVI, dormancy, and carbohydrate levels is crucial. Factors such as disease resistance, heat tolerance, water-use efficiency, and overall stress tolerance should be investigated to gain a comprehensive understanding of bermudagrass performance.

Lastly, genetic studies can be pursued to identify genetic markers associated with desirable bermudagrass performance traits. This can contribute to the development of improved bermudagrass cultivars through selective breeding or genetic modification. By exploring these future research directions, we can further enhance our understanding of bermudagrass performance and develop more effective and sustainable strategies for turfgrass maintenance during the fall and spring seasons.

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