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Cool-Season Turfgrass Reaction To A Newly Developed Plant Growth Regulator

Supervisor
Prof. **Dr. Stefano Macolino**
Co-supervisor
Dr. Cristina Pornaro

Submitted by
Mahsa Ghanavati
Student n. **2072128**

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Abstract:

Plant growth regulators (PGRs) are turfgrass management agents that have a very significant impact. They mainly serve to cut down on mowing and enhance the grass's overall attractiveness. Through the years, PGRs have been used to keep the grass healthy, with the main focus on the attractive look of it. The objective of this research was to compare the effectiveness of two PGRs, Primo Maxx II and ATTRAXOR, in reducing vertical growth in Lolium perenne/Poa pratensis and controlling the seedhead development of *Poa annua*. The findings of the research indicated that ATTRAXOR was equal to the effect of Primo Maxx II, a common PGR used for turf. The experiment determined parameters like turf color, turf quality, NDVI values, germination rates, daily growth patterns, and environmental factors such as temperature, precipitation, and biomass production. The experiment compared both PGRs in the spring and fall seasons. Results revealed that the treatments had a notable impact on the growth of *Lolium perenne/Poa* pratensis and the suppression of *Poa annua* seedheads.

Introduction

1. PLANT GROWTH REGULATORS

Phytohormones are the chemical means by which higher plants control their metabolism, growth, morphogenesis, and thus provide a way of communication among plant cells. These work just like hormones in all animals. These are plant growth regulators, also called PGR, involved in key physiological processes such as root development, flowering, expression of sex, delaying senescence, and enhancing latex yield in rubber trees. They also hasten the ripening process in sugarcane, inhibit sprouting in onions and potatoes, shorten wheat internodes, prevent early senescence, and assist in harvest timing as a method of enhancing yields. As farming activities around the globe continue to take on workable sustainable practices, PGRs are becoming increasingly critical in crop productivity and energy conservation. Historically, their main use has been in the regulation of plant growth and development ("Plant Growth Regulators," n.d.).

Although the term "phytohormone" specifically refers to chemicals synthesized naturally within plants, it is usually used synonymously with "plant growth regulators" (Overbeek, 1944; Rademacher, 2015). Phytohormones are an integral part of the regulation of many processes, including Auxins, Cytokinins, Gibberellins, Abscisic acid, and Ethylene, which take part in the process of root growth, flowering, and fruit ripening. Recently gained scientific knowledge disclosed new chemical entities displaying plant hormone properties through Hasan et al. (2018) and Gancheva et al. (2019). Supplementing the naturally existing phytohormones, there are synthetic and biotechnologically produced PGRs commercially available for new ways of applying in the development processes of plants according to Andresen & Cedergreen (2010).

This includes substances like naphthalene acetic acid (ANA), which encourages root development (Ortolá et al., 1991; Sanower & Urbi, 2016), as well as bacterial inoculants that aid in nitrogen fixation and enhance the rhizosphere (Tsavkelova et al., 2006; Garces et al., 2017; Lerma et al., 2018). PGRs, or phytoregulators, are chemicals that replicate the effects of phytohormones when applied externally for targeted agricultural applications. These compounds boost plant growth, regulate flowering, manage fruit ripening, and support agricultural practices such as crop management and phytoremediation (Overbeek, 1944; Rademacher, 2015). Unlike phytohormones, phytoregulators are produced outside the plant, and when used beyond their natural biological function, they are generally called bioregulators (Agudelo-Morales et al., 2021). In contrast to animal hormones, phytohormones can be generated throughout the plant since plants do not have specialized hormone-producing organs. Classical phytohormones include Auxins, Gibberellins, Cytokinins, Ethylene, and Abscisic acid (Davies, 2010), but other signaling molecules like brassinosteroids, jasmonic acid, and salicylic acid also play crucial roles in plant defense (Smith et al., 2017). Nitric oxide (NO), an essential signaling molecule, is not categorized as a phytohormone due to its inorganic nature (Arc et al., 2013). These phytohormones are transported through the plant's phloem and xylem, facilitating communication among various plant organs (Vanneste & Friml, 2009).

- **Auxins (AUXs)**

Auxins were initially investigated by Charles Darwin in 1881 for their involvement in phototropism. In 1926, Frits Went discovered the first auxin to be a growth-inducing compound (Darwin, 1880; Thimann, 1940). Indole-3-acetic acid (IAA), the most important auxin, was at first obtained from human urine (Kögl et al., 1934), amongst the compounds are indole-3-butyric acid (IBA) and naphthalene acetic acid (NAA), which are also auxins (Enders & Strader, 2015). AUX, both natural and synthetic, including seedling elongation, stem stretching, adventitious root formation, and cell division, which cause physiological effects similar to IAA (Enders & Strader, 2015). Thus, AUX is a functional concept that reflects a wider range of substances that affect plant physiology (Ferro et al., 2007).

- **Gibberellins (GBRs)**

Gibberellins are plant products that belong to a class of tetracyclic diterpenoids which comprise the growth regulators. Many gibberellins are unreactive precursors of active substances, which were first associated with rice's "foolish seedling" disease in Japan in the 1930s (Gupta & Chakrabarty, 2013). The chemical secretions of the fungus Gibberella fujikuroi led to the discovery of gibberellins, which were later identified as the main factors governing plant height and seed production (Salazar-Cerezo et al., 2018). Genetic studies found that GA3 is the most bioactive and is used in agriculture for increasing productivity in semi-dwarf rice and wheat varieties (Cowling et al., 1998; MacMillan, 2001). The metabolism of GBRs is strongly influenced by factors such as light, temperature, and water availability (Toyomasu et al., 1998).

- **Cytokinins (CTKs)**

The discovery of cytokinins in the 1950s by Skoog and his colleagues showed that they are phytohormones that govern cell division, differentiation, and growth (Durmuş & Kadioğlu, 2005). Along with their main function of promoting leaf development and facilitating the photosynthesis process, they are also capable of reducing senescence and controlling nutrient uptake (Stirk & van Staden, 2010). The most famous natural cytokinin, trans-Zeatin, is characterized by its strong receptor affinity, whereas its cis isomer is less preferred. (Oshchepkov et al. 2020). In plant defense, they also help to deal with environmental stresses. CTKs have important effects in this respect too (Durmuş & Kadioğlu 2005).

- **Ethylene (ETH)**

Ethylene, a very light hydrocarbon ($CH_2=CH_2$), is a key player in the regulation of plant growth, senescence and fruit ripening. It was the first naturally occurring growth regulator identified, which was just the beginning, and the player has been leading the plant development stage since then (Grierson, 2012). ETH is one of the plant hormones, which are known to be interacting with other hormones like auxins and abscisic acid, and they are overseeing the operations such as leaf growth (Iqbal et al. 2017).

- **Abscisic acid (ABSAc)**

Abscisic acid (ABSAc) regulates various growth facets, for example, seed dormancy, germination, and responses to stress like drought and salinity. ABSAc, first isolated in the 1960s, has been demonstrated to be a fundamental contributor to the control of plant stress responses and the maintenance of metabolic balance (Ohkuma et al., 1963; Xiong & Zhu, 2003). The ability to regulate stomatal closure is of crucial importance during water stress conditions (Xiong & Zhu, 2003).

1.1. Mechanisms of Plant Growth Regulators: Physiological and Biochemical Perspectives

- **Physiological Processes Influenced by Plant Growth Regulators**

Plant growth regulators, including auxins, gibberellins, cytokinins, abscisic acid, and ethylene influence the different physiological processes of plants (Biochemical Mechanisms Involved in Plant Growth Regulation, 1994). Auxins regulate cell elongation, gravitropism, phototropism, and apical dominance. (Cowan, 2006) Similarly, gibberellins regulate cell division, stem elongation, seed germination, as well as fruit development. (Farré, 2012) These hormones work synergistically with other hormones in regulating various developmental processes (Ismail, 2003). While cytokinins promote cell division, shoot growth, and delay senescence, abscisic acid modulates plant responses to environmental stress, and ethylene plays a major role in fruit ripening, seed germination, and plant growth regulation (Verizhnikova & Prudnikova, 2022). Besides growth and developmental processes, plant growth regulators also play an important role in the biochemical aspect of plants (Cowan, 2006).

- **Biochemical Pathways in Plant Growth Regulation**

These biochemical pathways play an important role in the regulation of growth and development within the complex world of plant growth regulation (Kundu & Vadassery, 2022). The growth-limiting biochemical pathways represent a wide array of enzymes, hormones, and other growth-promoting substances that contribute to orchestrating plant growth based on environmental factors such as light, temperature, and nutrient levels(Blázquez et al., 2020). By investigating these pathways and the function of plant growth regulators within them, the biochemical mode of action of plant growth regulators can be better understood (Biochemical Mechanisms Involved in Plant Growth Regulation, 1994).

One of the better-studied plant growth regulators is the auxin family of hormones. Auxins promote cell elongation and division, which is important for root growth, elongation of stems, and branching (Kundu & Vadassery, 2022). Auxins are synthesized in apical meristems of stems and roots and transported down the plant in the phloem, where they promote cell division and elongation (Kundu & Vadassery, 2022). This leads to an increased length of the plant. Auxins also contribute to apical dominance, a phenomenon where shoot tips of plants inhibit the development of lateral shoots (Biddington & Dearman, 1987). Activities at shoot tips ensure that the plant grows taller with a well-developed root system (Biochemical Mechanisms Involved in Plant Growth Regulation, 1994).

Another class of plant growth regulators known to be at the forefront of plant development are cytokinins. They are responsible for cell division and differentiation in various plant tissues, playing a crucial role in the growth of plant stems (Tohge et al., 2015). Cytokinins are synthesized in the roots and transported to the shoots, where they promote shoot elongation and branching (Cowan, 2006). Additionally, cytokinins help delay aging in plant tissues by protecting them from stressful environmental conditions, such as high temperatures and drought (Jin et al., 2022) .

Moreover, other classes of hormones known as giberrellins are importantly involved in the growth of plants through the regulation of the rate of cell division and differentiation. This occurs mainly in root tips and in the movement of plant cells (Khatoon et al., 2020). These hormones regulate the growth in the region of elongation; this region increases the length of plant organs such as the stems, roots, and leaves through elongation (Farré, 2012). They also promote breaking dormancy in seeds and germinating, enhancing stem growth in small seed lings (Fraser & Whenham, 1982). However, they grow too tall to the extent that they can't stand under their weight and with time may fall if not controlled by the presence of a chemical called strigolactone (Kundu & Vadassery, 2022). This hormone acts to suppress the biosynthesis of gibberellins beneath the elongation region, preventing further elongation of plant organs and balancing their growth (Kerr & Bennett, 2007).

Besides gibberellins, auxins are the key players in the process of the elongation of plant cells. After all, auxins are found in the cells that elongate plant pole to pole, as well as in the formation of roots and shoots, and in the direction of growth (Tripathi, 2023). Auxins can be produced in many parts such as apical meristems and quickly transported to the sites where they are needed by means of active processes (Jin et al., 2022). One of the most important aspects of auxin action is that it can be transported polar through plant tissue which is essential for the formation of the directional growth (Nelissen et al., 2010). Auxins play a role in cell elongation by causing the cell walls to expand by various mechanisms (Harris et al., 2011). The cells can be more sensitive to mechanical stimuli such as gravity, light gradients, and touch so as to induce behavior (Ross et al., 2001). Besides that, auxins can promote the expression of genes in a local area in a very rapid manner that is in accordance with the growth-regulating stimuli (Ross et al., 2001). The latter refers to the activation of receptor proteins located on the membrane surface that in turn activate and sequester specific intracellular signaling proteins which then go on to alter hormone levels (Mishra et al., 2021). One such example is auxin accumulation in response to touch which would lead to the activation of a membrane-bound receptor. This receptor would then connect to and activate the auxin responsive kinase(auxin responsive kinase) to perform the operation of phosphorylation (addition of a phosphate group) of target proteins (Kundu & Vadassery, 2022). One of the functions of these target proteins is to change their activity or stability which then can be translated into changes in gene expression thus regulating plant growth and development (Khatoon et al., 2020).

2. USING PLANT GROWTH REGULATORS (PGRS) IN TURFGRASS MANAGEMENT

Plant Growth Regulators (PGRs) are biochemical compounds that influence various facets of plant growth, development, and health (Głąb et al., 2023), such as germination, root development, seed formation, and respiration. They are categorized into two primary types: synthetic and natural (Beard & Green, 1994), or more specifically into groups like Auxins, Gibberellins, Cytokinins, Ethylene, ABA (abscisic acid), and Jasmonic Acid. These substances can either promote or suppress particular aspects of turfgrass health and are commonly applied to lawns to regulate growth rates and foster optimal root development (Cisar, 2013).

- **Benefits of Using PGRs in Turfgrass Management**

Plant Growth Regulators (PGRs) play a significant role in managing various physiological and developmental processes in plants (“Plant Growth Regulators,” n.d.). These synthetic compounds are extensively used in turfgrass management across diverse environments, including lawns, golf courses, and roadside landscapes (Nickell, 1994).

PGRs help regulate plant growth by shortening stems, minimizing lodging, and preserving grain yield (Fahad et al., 2016). They are also effective in mitigating the adverse effects of high temperatures on plant growth (Fahad et al., 2016). For instance, studies have highlighted an increase in α-tocopherol under drought conditions when PGRs are applied (Fahad et al., 2016).

In addition to stress mitigation, PGRs enhance the overall quality of turfgrass (Watschke et al., 2015). Specifically, trinexapac-ethyl has been identified as delivering the highest visual quality assessments for turf (Roberts et al., 2016). This offers a reliable and objective measure of turfgrass health and aesthetic appeal (Głąb et al., 2020). Consequently, PGRs serve as an essential risk management tool in turfgrass maintenance strategies (Głąb et al., 2020).

However, it is crucial to recognize that PGRs can affect different turfgrass species in distinct ways (Zhang, 2016), requiring precise application to achieve optimal results (Fahad et al., 2016). Research suggests that PGRs can slow the deterioration of turf quality (Watschke et al., 2015), whereas excessive nitrogen use may elevate disease risk and reduce turf quality (Zhang, 2016). By enhancing overall grass health, PGRs help maintain superior-quality turf (Drake et al., 2023; “PGR Effects on Turf under Heat and Salt Stress - GCMOnline.com,” n.d.).

Certain PGRs, such as Poast and Oust, also function as growth retarders and seedhead suppressors in turfgrass systems (Wells, 1989). Additionally, they contribute to increasing the root mass and improving the quality of turf stands (Long, 2006). Widely utilized in contemporary agricultural, horticultural, and turfgrass practices (Baldwin et al., 2009), PGRs play an indispensable role in enhancing turfgrass management and advancing overall turf culture (Baldwin et al., 2009; Long, 2006).

Notably, PGRs have been shown to enhance the efficacy of fungicides (Burpee et al., 1996) and are particularly beneficial in shaded turf conditions (Steinke & Stier, 2003). Further research highlights their potential for improving water-use efficiency and drought tolerance, especially in subsurface drip-irrigated turf systems (Schiavon et al., 2014). Additionally, certain PGRs can increase photosynthesis efficiency (Elansary &

Yessoufou, 2015) and improve the effectiveness of fungicides against diseases such as dollar spot in creeping bentgrass (Burpee et al., 1996).

However, there are associated risks, as some PGRs may disrupt hormonal balance in plants, potentially affecting growth and flower production (March et al., 2013). Despite these risks, PGRs play a key role in enhancing turfgrass resistance to environmental stresses, including extreme temperatures, drought, and diseases (Datnoff, 2005). They also bolster turfgrass resilience against pests and insects (Gourichon & Nangle, 2023).

For example, cytokinins promote the production of tillers in turfgrass, increasing density and reducing disease spread (Kang et al., 2013), while abscisic acid helps mitigate water loss during drought conditions (Głąb et al., 2023). These attributes underline the importance of PGRs in advanced turfgrass management practices.

- **Controlling Growth**

Plant Growth Regulators (PGRs) are highly effective tools for managing turfgrass growth, significantly reducing maintenance requirements. Compounds such as trinexapac-ethyl and mefluidide slow growth rates while maintaining the aesthetic appeal of the turf (Głąb et al., 2023). This reduction in growth frequency minimizes mowing needs and decreases the likelihood of pest infestations and disease outbreaks (Braun et al., 2023).

Additionally, the use of PGRs enables turf managers to optimize maintenance schedules, which can lead to reduced costs associated with turf upkeep. However, improper application of PGRs can result in adverse effects such as stunted growth or weakened root systems (Braun et al., 2023). To ensure the desired outcomes, it is essential to follow manufacturer guidelines closely and seek advice from professionals (Carlson et al., 2022; Gourichon & Nangle, 2023).

Furthermore, regular monitoring of turfgrass and adjusting PGR application rates as necessary are critical for achieving the best outcomes. Plant Growth Regulators (PGRs) offer numerous advantages, making them a valuable tool in turfgrass management to enhance the health and appearance of lawns and sports fields (Cowan, 2006). By controlling overgrowth and promoting robust root development, PGRs contribute to creating sustainable and aesthetically pleasing turfgrass (Curci et al., 2022).

However, caution is essential, as improper application can lead to harmful effects on the plants. Following correct procedures and application guidelines is vital to avoid such issues (Cowan, 2006; Acuña et al., 2022). PGRs have emerged as one of the most effective solutions for maintaining sustainable and visually attractive turfgrass systems (Lai & Han, 2022).

3. *POA ANNUA* CHARACTERISTICS

Poa annua L., an allotetraploid species, has a chromosome count of 2n = 28 (Tutin, 1952). This classification is supported by morphological evidence, as annual varieties of *Poa annua* typically have fewer leaves, nodes, secondary tillers, and adventitious roots compared to perennial forms (Gibeault, 1970). Furthermore, annual plants tend to reach reproductive maturity more quickly than their perennial counterparts (Gibeault, 1970). Perennial types are primarily found in areas with moderate to high levels of supplemental irrigation. Research from Oregon and the Northern Pacific Coastal regions of Western Washington found that more than half of the turfgrass samples collected exhibited perennial traits, with both annual and perennial varieties distributed evenly (Gibeault, 1970).

When it comes to *Poa annua*, its diploid forefathers, namely *P. infirma* H.B.K. and *P. supina* Schrad., have 2n = 14 chromosomes each (Tutin, 1952). The attempts to hybridize these species through cross-pollination have not been successful, thus, further supporting the idea of *Poa annua* being an allotetraploid plant (Tutin, 1952). Studies on *Poa annua* have ranged from its genetic diversity, polymorphism, to its evolutionary relationships (Chwedorzewska, 2007).

This grass species is no doubt a versatile one being both annual and perennial types that have different morphology and germination requirements (Chwedorzewska et al., 2015; Gibeault, 1970). The earliest naming of the species by Carl von Linné in 1753 is the root of the currently about 50 taxa within the species been recorded (Carroll et al., 2021). By the way, it is referred to as annual meadow grass and is one of the most popular grass types used for turf management (Jr & Turgeon, 2003).

This is a newly described species that likely came into existence through hybridization of two diploid species – Poa infirma and Poa supina (Mao & Huff, 2012; Tutin, 1952). It is a plant you can find in a city and it usually starts by having its roots in the cracks in the pavement (Hutchinson & Seymour, 1982). The plant is an allotetraploid and as such, it can propagate through many vectors (Chwedorzewska, 2007). Moreover, it has been found that *Poa annua* can additionally promote the growth of other plant species; for example, the presence of P. annua caused a four- to sixfold increase in the number of seedlings for Capsella and Senecio in the next generation (Bergelson, 1990).

3.1. Plant Growth Regulators Applied To *Poa annua*

PGRs, for instance, trinexapac-ethyl and paclobutrazol, are quite useful in the process of eropbhatheating the production of gibberellic acid (GA), which is a pivot for the growth of cells and elongation in *Poa annua* (McCullough et al., 2005; Woosley et al., 2003). Not only in terms of shorter shoots, they also cause flowering to be late which is a very good aspect in the VQ of the turfgrass through the reduction of the seedhead multiplication (McCullough et al., 2006). The use of another PGR, ethephon, for its activity in flowering has been found to obstruct the formation of flowers and the whole-grown stem that is the major causer of *Poa annua* (Dernoeden & Pigati, 2009). The skillful handling of these PGRs brings a more leveled and prettier turf, and additionally, it is also a mowing and costs cutting device (Dernoeden & Pigati, 2009), especially in operations where mowing is done.

The interaction between PGRs and environmental conditions is complex. For example, it is very well targeted that the limited supply of light and the amount of nutrients are quite a vital point in the growth response of *Poa annua* in PGR applications. In conditions of low light, *Poa annua* demonstrate compensatory growth mechanisms such as increased leaf area (SLA), which could be damaged by the cutting (Irving & Mori, 2021). This means while PGRs can be quite useful in inhibiting the growth of these

(PGRs) plants their (PGRs) activities may be interfered with by certain environmental stresses, thereby pointing out the need to integrate management approaches that consider both PGR application and the proper environmental conditions.

Furthermore, the competitive interaction between *Poa annua* and other plant species also affects its growth and response to PGRs significantly. Apart from this, the competition between the species and the Plantago and Trifolium, which are some of the important species, has been found to be negatively correlated with the biomass of *Poa annua*, so it is clear that competition can have a negative impact on the effects of PGRs (Schädler et al., 2007).

The physiological and biochemical responses of *Poa annua* to PGRs are also important. Transcriptomic analyses show that selected gene pathways are turned on as a result of PGR treatment, which in turn causes a complex regulatory network that controls growth and development under PGR influence (Sun et al., 2023). For instance, genes that are connected with the glutathione metabolism, which is an essential function for protecting the plant from oxidative stress, have been found to be upregulated in *Poa annua* under certain chemical treatments (Sun et al., 2023).

Besides the obvious effects of PGR, the role of soil nutrients and microbial interactions must not be underestimated. On the other hand, a study revealed that phosphorus fertilization and soil type affect the growth and seedhead production of *Poa annua*, thus indicating that nutrient management is a requirement within PGR application strategies (Guertal & McElroy, 2018). Moreover, the individual visible phases (AMF) growth that make up the structure of this term have a different effect on the plants' metabolic responses and provide improved growth of *Poa annua* in some condition (Stallmann & Schweiger, 2021).

Besides this, growth suppression is not only the consequences of these findings. The use of PGRs in the program for the management of *Poa annua*, however, must be based on a deep analysis of the long-term ecological consequences, which, in particular, may include the possible shifts in the composition of plant community as well as the development of herbicide resistance. *Poa annua* has demonstrated its ability to set up resistance to multiple herbicide modes of action, thus, it would be neither efficient nor safe to use chemical control methods alone (Benson et al., 2023).

To sum up, the application of plant growth regulators to *Poa annua* is a string of strategies that include not only the pondering of environmental factors but also the competition among the *Poa annua* roots and physiological responses. After properly studying the complex network of these entities, the turf managers may be able to come up with effective strategies to control *Poa annua* populations (turf managers while maintaining the health and aesthetic quality of turfgrass systems) that are not only effective but also sustainable. Future research must continue to discover the molecular processes that are linked to PGRs reactions and the environmental effects of their use, and this way, management practices would be both efficient and sustainable.

3.2. Impact of PGRs on Seed Head Development in *Poa annua*

Research on the management of *Poa annua* in the turfgrass area has been increasingly shifting towards the application of plant growth regulators (PGRs) due to their effectiveness in seedhead suppression which is significantly better than the natural herbicides that can often be unpredictable (McCullough et al., 2005). PGRs such as paclobutrazol and mefluidide are being used more by turf managers to control *Poa annua*, as herbicides are less consistent in their control (Williams, 2014). According to the research conducted, the growth regulators have been the main cause of seedhead cover reduction with the early application of Ethephon in January in the before spring program being the icing on the cake (McMahon & Hunter, 2012).

Several studies have shown the importance of paclobutrazol in preventing *Poa annua*, including one where a dosage of 0.3 kg/ha across four applications achieved good weed control (Johnson & Murphy, 1995). Likewise, the two growth regulators, flurprimidol, and paclobutrazol have been known to control the perennial subspecies of *Poa annua* (McCullough et al., 2013). Literature advocates for the application of mefluidide at rates 0-1.2kg/ha which has affected the growth of Agrostis stolonifera and *Poa annua* (Brown,

2013) with different effects reported at different growth stages (McMahon & Hunter, 2012). Likewise, Jackson et al. (1986) along with several others reported the effects of mefluidide on the growth of *Poa annua* in places such as road verges and parks, which might use mefluidide as an effective treatment of the weed.

In spite of the suboptimal outcomes and inconsistent control achieved with both herbicides and plant growth regulators (PGRs), more recent studies suggest that PGRs are the most widely utilized techniques for controlling *Poa annua*, golf course superintendents being the most notable example of those who utilize PGRs (Williams, 2014). Use of plant growth regulators such as trinexapac-ethyl such as Moddus and Primo Maxx as well as Mefluidide such as Embark Lite have been proven to be very effective with reduction of *Poa annua* population primarily seen four months post-treatment (McMahon & Hunter, 2012). Furthermore, research has explored how PGRs impact pollen quality and seed viability in annual bluegrass, adding another layer to their usefulness in turfgrass management (Askew, 2017). Overall, PGRs offer a promising alternative for controlling seedhead formation in *Poa annua* and managing its population in turfgrass.

3.3. Methods For Evaluating The Impact Of Plant Growth Regulators On *Poa annua*

Poa annua, or annual bluegrass, is a problem in which turf managers must consider a wide variety of physiological, biochemical and ecological aspects. Plant growth regulators (PGRs) are of a paramount importance in vegetative modifications of *Poa annua* such as vertical growth regulation density promotion and seedhead suppression. Such adjustments focused on improving our putting greens and sport fields quality standards (Simard et al., 2021; Guertal & McElroy, 2018). It has been reported in previous studies that PGRs can affect the pattern of growth and the distribution of biomass of plants and the degree of light and nutrients can determine how *Poa annua* distribution their growth. They may also have the ability to alter these growth responses since the plant shows different growth responses to various environmental factors (Irving & Mori, 2021; Bezemer & Jones, 2012).

The biochemical interaction of the *Poa annua* with PGRs enhances understanding its stress tolerance. Transcriptomic analyses revealed that certain transcriptional PGR compounds can induce the expression of genes showing stress-response, which could expand the ability of the plant to resist unfavorable conditions. In the case of herbicide resistance, however, it is vital to know about the molecular mechanisms that allow *Poa annua* to respond to PGRs (Sun et al., 2023; Laforest et al., 2021). Apart from biochemical and physiological interactions, PGRs act in interaction with soil biota, for instance arbuscular mycorrhizal fungi, affecting also plant growth and nutrient resources in plants. These symbiosis may enhance the nutrient status and therefore the overall efficiency of PGRs in promoting the growth of *Poa annua* in the presence of competition (Stallmann & Schweiger, 2021).

4. AIM OF THE EXPERIMENT

Plant growth regulators are chemical substances that influence the different features of plant growth, such as branching, shoot elongation, flower production, fruit thinning, and fruit maturation. In the year 2023, a test has been conducted concerning the efficiency of ATTRAXOR by BASF-Italia, which is an esteemed company in the field of plant-related chemicals. These studies researched the action of ATTRAXOR on seedhead development in Lolium perenne, *Poa pratensis*, and *Poa annua*. ATTRAXOR was compared against Primo Max II, one of the commercially available PGRs in the management of turf. The following was mapped or recorded in the study: turf color, turf height, and vertical growth rate. Additional measurements were made for the *Poa annua* plots, including the number of seed heads formed and their height of inflorescence; local weather data was recorded for adding context. Furthermore, a laboratory experiment was conducted to assess the impact of PGRs on the germination rate of *Poa annua* seed.

4.1. Materials And Methods

The experiment was conducted at the Agricultural Experimental Farm of Padua University, located in Legnaro (45°20' N, 11°57' E, altitude 8 m a.s.l.). The area in question comes within the humid subtropical climate according to the Köppen-Geiger classification, characterized by an average annual rainfall of 831 mm recorded between April and November. The area has an annual average temperature of 12.3°C, with a minimum of 8.0°C and a maximum of 17.4°C. Soil type of the experimental area is coarse-silty, mesic Oxyaquic Eutrudept with loamy texture.

The experiment was established in March 2023, however the present work reports findings of the period from April 2024 to November 2024. The experiment involves the comparison of the use of Attraxor a new PGR for turfgrass versus Primo MAXX II a growth regulator already widely used in the turfgrass market. The experimentation consisted of two fields and one laboratory experiment.

The target of the first experiment (Experiment 1) was a *Lolium perenne*/*Poa pratensis* turfgrass mixture; the target of the second experiment (Experiment 2) was a *Poa annua* monostand, and that of the third experiment (Experiment 3) was *Poa annua* seed. The first two experiments were set up as a randomized complete block with three replicates. In Experiment 1, plots measured 4 m × 2.5 m, and in Experiment 2, an area of 60 cm × 60 cm was sown with *Poa annua*. The Experiment 3 consisted on *Poa annua* seed germination performance and was conducted in growth chamber. Throughout the research, turfgrass plots of Exp. 1 were mowed using a rotary mower machine. During the growing season, it is usually performed once a week. Vertical mowing or aeration was done once in spring based on recommended practices and schedules. Irrigation management was according to the requirements in the different experiments.

Before the emergence of seedlings, irrigation at 6-7 mm/day was applied daily to provide optimum moisture for germination. After the emergence of plants, irrigation was carried out weekly in June, July, and August months, applying 30 mm of water . Weed management in respect to both grassy and broadleaf weeds was done. Grassy weeds were uprooted manually upon sighting, while the broadleaf weeds were managed through a post-emergence application of herbicides (Dicamba + Mecoprop) 40 DAS. Later on, when the plants attained suitable establishment, the uprooting of broadleaf weeds was done manually. Selection of herbicide and its method of application were considered for its efficacy and following safety precautions.

4.2. Climatic Characterization

Legnaro is a tiny town within the municipality of Padua, which is only 7 meters above sea level at coordinates 45.3473° N, 11.9522° E. The climate here is multifarious, with well-marked seasons that well denote the typical characteristics of the Mediterranean and the geographic features of northern Italy, which ensure an environment where different agricultural and outdoor activities can be performed during the year. In terms of the trend of temperatures over the year 2024, the pattern of monthly average, daily extremes, and general annual conditions of weather is strikingly contrasting.

Seasonal Temperature Trends

The weather in Legnaro is rather transitional in its seasonal changes. Winter, however, is cold and ranges from December to February, with the temperature averaging -0.4°C in January and plummeting to as low as -5.0°C on occasions. In February, though, one can experience daytime highs up to 13.6°C, showing that winter slowly disappears. Spring-March to May-comes with relatively higher temperatures, which is fairly good for outdoor action and fieldwork. Highs rise from 15.4°C in March to 22.7°C in May, bringing a refreshing change. Summer-actually, from June to August-is characterized by long, hot days; therefore, the average temperatures rise as high as 31.6°C in July, reaching even higher than 35.0°C and making it the hottest period of the year. During autumn, from September to November, the temperatures gradually cool down. Average high temperatures drop from 25.4°C in September to 19.7°C in November and pave the way for winter chills.

Annual Climate Insights

Legnaro has a climate with considerable variability in temperatures during each day and each month in transitional seasons such as spring and autumn. For example, during the month of April, temperature can also have a wide variability during a single day, for example on April 1, with 9.5°C low to 14.5°C high. Whereas on August 1, the summer culmination was fully felt in the temperature fluctuation from as early as morning at 23.2°C to the scorching afternoon temperatures of 33.6°, such variability is already peculiar for the local climatic features that are determined by the intersection of the Mediterranean and continental factors of influence upon the weather over the region.

4.3. Data Collection

Weather Data Collection at the Legnaro Weather Station (2024)

Situated at 45°20' N and 11°57' E, and standing at a height of 10 meters above sea level, the Legnaro Weather Station is quite instrumental in recording meteorological information within its vicinity. The station hosts different types of instruments meant for measuring such weather variables as temperature, pressure, wind, and rainfall. Most of the equipment is calibrated and maintained on a regular basis to ensure that the data provided is reliable and factual.

Experiment 1. Visual evaluation of turfgrass quality

A visual scoring system was followed in turfgrass quality evaluation, rating turfgrass on various criteria such as texture, uniformity of texture, density, color, and general appearance. The rating for each plot is from 1 to 9, with 6 being the rating considered acceptable, according to Morris and Shearman (1998). While the texture varied with the species, evenness dealt with uniformity in grass growth within the plot. Density was a measure of the tillering of grass, which was specified by species characteristics and environmental as well as management variables. Color rating depended on the darker shades of the grass; the merit grade was rated based on a general subjective assessment of all the above parameters.

Experiment 1. Visual evaluation of turfgrass color

Turfgrass color was visually assessed on the standard 1–9 scoring system, with 1 being the poorest quality-yellowish or pale and 9 being the best quality-dark green with a vibrant color. Turfgrass color is one of the most important features; it usually shows the physiological status of the plant, nutrient supply, and health of the plant.

The color rating was given as per the following scores:

1. Colour of Green: Darker shades got higher marks.
2. Evenness of Colour: The more even the colour over the plot, the higher was the rating.
3. Stress Symptoms: Chlorosis, discoloration, and drought stress lowered the rating.

Observations were recorded in the same light conditions as variability in lighting conditions can result in inconsistency in observations. This is a relatively subjective measurement but gives a fast, qualitative indication of the general health and beauty of turf grasses.

Experiment 1: Assessment of turfgrass condition using NDVI

In this experiment, NDVI was employed tpo asses the physiological state of turfgrass. The RapidSCAN CS-45 Handheld Trim Sensor was used to take one reading above every plot. This is more objective than the subjective visual ratings, which are usually prone to personal bias. It calculates the light reflected by the vegetation: the healthier the plants, the more near-infrared light is reflected, while stressed plants reflect less, hence returning a lower NDVI value. A total of 19 biweekly readings were made for each plot.

The RapidSCAN CS-45 is designed to function independently of surrounding light conditions, given its internal polychromatic light source, to produce reliable biomass estimates throughout the day. It can measure vegetation from 0.3 to over 3 meters in distance. The sensor outputs a number of signals that include NDVI, NDRE vegetation indices, sample measurements, geographic coordinates, and critical reflectance data. The three optical channels used in the sensor for the measurement of reflectance are at wavelengths of 670 nm, 730 nm, and 780 nm, recorded at the very same time data capture is taking place on both the vegetation and the soil beneath it.

One of the unique features of the RapidSCAN CS-45 is its capability to measure height-nonsensitive spectral reflectance, herein referred to as pseudo-solar reflectance (PSR). This allows the sensor to standardize all values of spectral reflectance as percent, thus providing consistent output regardless of the sensor's height over vegetation.

Experiment 1. Vertical growth rate and clipping production

Vertical growth rate were evaluated using a plate meter to measure canopy height. Plate meter readings were taken biweekly by gently setting the apparatus over the turfgrass canopy. Displacement of the plate was a function of the plate height, where taller grass resulted in increased displacement. Multiple measurements within each plot were averaged to minimize variability.

The dry weight of clippings was measured as follows:1. the turf was mowed using a cylindrical mower;2. clippings were collected and appropriately labeled.3. wet weight of the clippings was recorded; 3. samples were then set on aluminum plates and dried in a hot air oven at 100°C for 48 hours; 5. after drying, clippings were removed from the oven, and their dry weight was measured.

This method ensures an accurate measure of biomass by providing a standard unit of measurement that allows for the effective comparison of different PGR treatments in relation to turfgrass growth.

Experiment 2: Monitoring *Poa annua* seed head Development

This experiment counted the number of *Poa annua* seed heads on a week-to-week basis on a mature *Poa annua* turf (60 x 60 cm) subjected to Attraxor and Primo Maxx II applications. In addition, the height of the seed head was measured to monitor its development over time.

Experiment 3. Germination rate of *Poa annua* seeds

A germination test was performed to assess the seed germination in various treatment conditions arranged in a complete random design with two groups and five replications of each treatment. In all, there were 30 Petri dishes for 50 seeds each. The treatments consisted of water, Attraxor, and Primo Maxx II. Each of the treatments had five dishes within each group. The seeds were then spread evenly over the dishes that were lined with moistened filter paper, sealed with parafilm to prevent moisture loss, and incubated in a thermal chamber for a continuous period of 10 days, alternating between 25°C during the day and 50°C at night. Each dish was treated with 3.5 mL of the respective treatment solution. Seeds were counted every 2 days as germinated when the radicle had reached at least 2 mm in length. Data from the replicates were used for determination of the percentage germination and assessment of differences in germination dynamics between the treatments and the control.

4.4. Statistical Analysis

Data collected were analyzed by ANOVA using R software-R Development Core Team (2021). Meanwhile, the following assessed parameters were turfgrass color, overall aesthetic quality, NDVI, number, and height of *Poa annua* seed heads, which were analyzed using a mixed-effects linear model to assess the fixed effects of 'Treatment,' 'Measurement date,' and 'Treatment×Measurement date.'For the rest of the variables, clippings dry weight and vertical growth rate, the linear model was taken into consideration by itself to evaluate the effect of 'Treatment'. Each variable was evaluated against its respective model to ensure appropriateness of statistical evaluation of each.

Figure 1. Measurement of turfgrass height prior to mowing using a grass plate meter

Figure 2. Counting the germination rate of Poa annua seeds

Figure 3. Visual assessment of turf color and overall turf quality

Figure 4. Using the NDVI with the RapidSCAN CS-45 to assess the physiological condition of the turfgrass and monitor its overall health

5. Results & Discussion

5.1. Resutls of Analysis of Variance

The following table presents the results of ANOVA for the turfgrass parameters: turfgrass quality, turfgrass color, NDVI, vertical growth rate, and clippings production rate.

Table 1. ANOVA results for the parameters Turfgrass quality, color, NDVI, clippings dry weight, and vertical growth rate.

Source of variation	Turf quality	Turf color	NDVI	Clippings production	Vertical growth rate
treat.	*	*	NS	**	***
date	**	**	*	_	_
treat x date	**	*	NS	_	_

* Significant F test at the 0.05 level of probability. ** Significant F test at the 0.01 level of probability. *** Significant F test at the 0.001 level of probability. NS †, nonsignificant at the 0.05 probability level.

5.2. Turf Quality

Statistical analysis revealed a significant interaction between treatment and dates ($p < 0.05$), indicating a different behavior of treatments over time. The results of ANOVA further pointed out a significant date effect, showing that seasonal changes in turf quality have occurred. This perhaps could be due to climatic influences, where the coolseason species normally go dormant when the soil temperature rises excessively, or probably with sudden shifts within the microclimate. The poorest recorded quality was done between July and September 2024, a period characterized by higher temperatures and increased sunlight exposure unfavorable for growth. A very remarkable recovery of turf quality, however, became apparent in the post-summer period with the return of more favorable conditions.

Both treatments remained ahead of the control through the term of the trial, starting with mature plants in June, where Attraxor had the highest effect; however, the opposite happened the following month, with Primo Maxx II having the highest impact. Attraxor also continued to be ahead of Primo Maxx II from August through November. These findings show that the effectiveness of these growth regulators is expressed variably under different environmental conditions and on the aspect of timing of application. The explanation of seasonal variability of Primo Maxx II and Attraxor on turf health opens further ways to optimize turf management practices that should ensure superior quality maintenance across diverse climatic conditions.

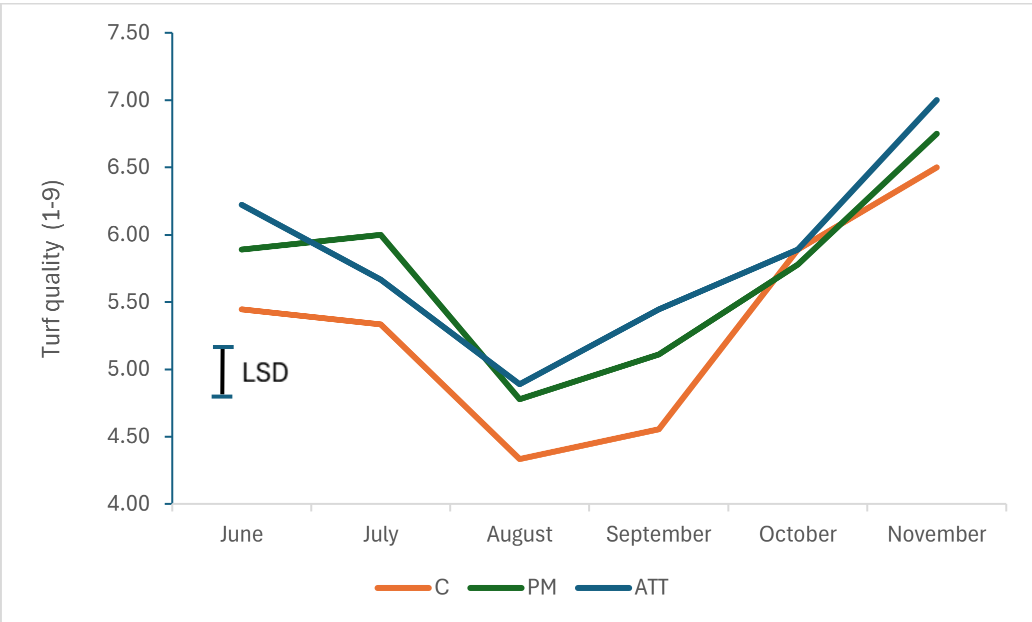

Figure 5. Turfgrass quality in response to different growth regulators during the experimental period. (ATT = Attraxor, PM = Primo Maxx II, and C = control).

5.3. Turf Colour

In June, the color of turf starts to decline as temperatures increase, but usually begins a recovery in August as temperatures start to moderate. This is largely a function of the regional climatic conditions, as this cool-season turf species tends to go dormant during periods of high soil temperatures. From July to August 2024, color intensity exhibited a rather noticeably lower level, perhaps explained by the high temperature of the soil and scarce sunlight since both conditions inhibit growth and impede pigment production.

By late August, when temperatures finally cooled, turf color greatly improved to indicate recovery from the summer stress. Through this period, applications of Primo Maxx II demonstrated consistently higher levels of enhancement in turf color compared with Attraxor; each was above the control. The greatest difference in the enhancement of turf color between Primo Maxx II and Attraxor occurred by August. By September, however, the effects of both treatments started to converge, resulting in similar improvements in turf color.

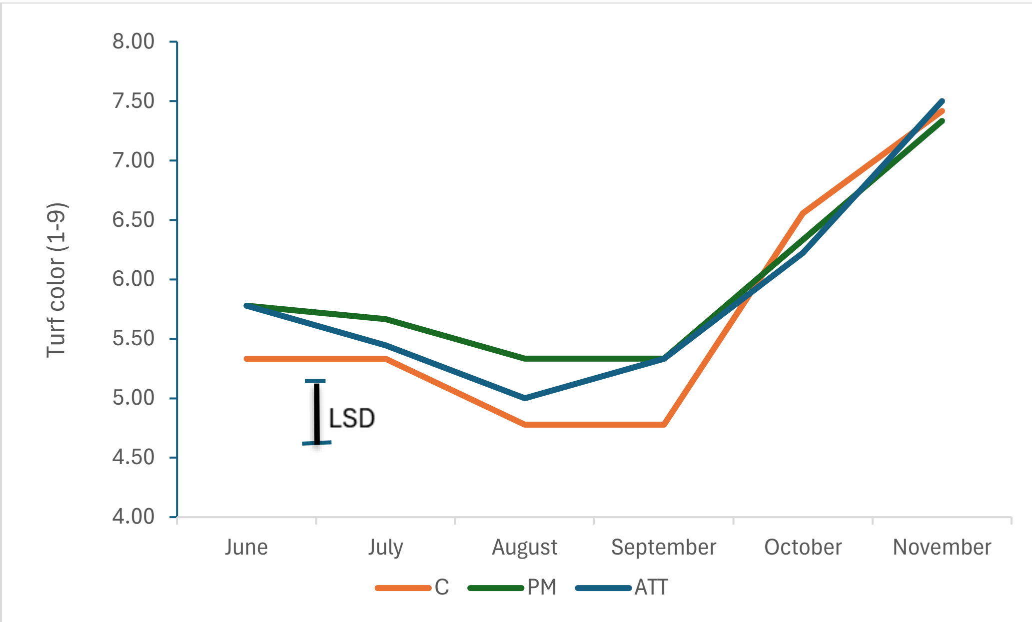

Figure 6. Turf colour in response to different growth regulators during the experimental period. (ATT = Attraxor, PM = Primo Maxx II, and C = control).

5.4. NDVI

The NDVI variation in a month, ranging from June to November, is represented by this graph. It follows a similar pattern for all treatments, and no significant differences can be seen among them. Such consistency in the monthly pattern may indicate that treatments consistently affected vegetation health during the observed period.

A striking feature in this graph is the NDVI progressive decline from June to August, further staying low in August and September. This corresponds with the summer season, which normally is unfavorable for most cool-season turf species. High temperatures and possible drought stress during this period likely reduced photosynthetic activity and overall vegetation health.

From September to November, NDVI values increased sharply, then stabilized, indicating recovery with the environmental conditions becoming more suitable for cool-season turf. The consistent NDVI pattern across treatments would suggest that external factors-climatic conditions-were more influential upon vegetation health compared to the treatments themselves.

This absence of significant variation among the treatments underscores the importance of environmental factors in managing cool-season turf during summer stress periods. This tendency points out the need to adapt seasonal changes in management practices for maintaining turf health.

The winter is expected to have stable vegetation conditions with no significant stress, as indicated by the steady NDVI values in November.

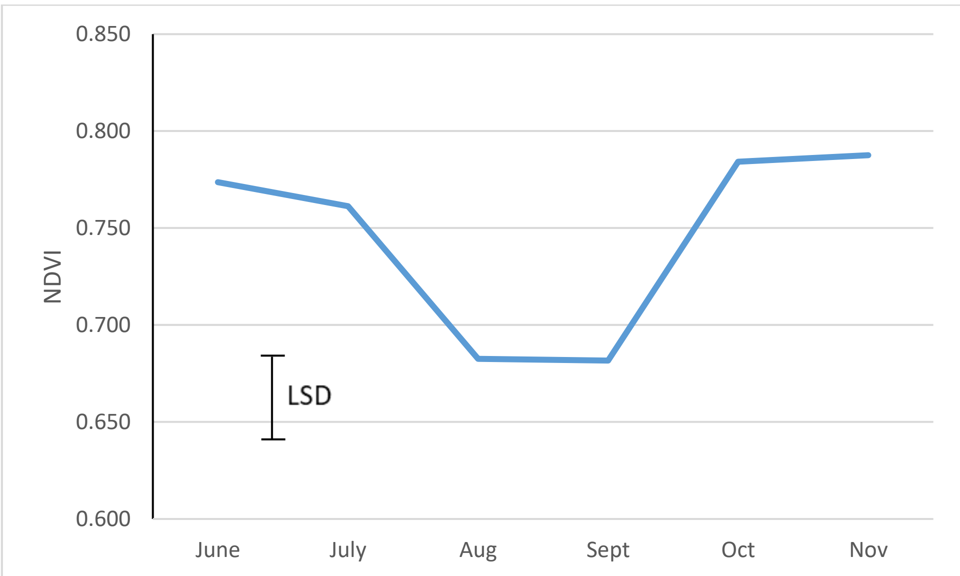

Figure 7. Index NDVI variation during the experimental period.

5.5. Vertical growth rate

Figure 8: Growth curves showing the cumulative turfgrass growth from April to the final mowing in October. Mowing was done on a weekly basis with the date being varied by approximately ±1 day due to weather conditions. Average turf height before mowing was measured as an average daily growth and product efficiency. This was subtracted from the standard cutting height of about 6.27 cm to get the difference, which is taken as a measure of the cumulative growth over the season, hence estimating the product's effect on the turfgrass development.

ANOVA showed a significant treatment effect at $P < 0.01$. Below is Figure 9, which compares daily growth rates of the three turf plots treated with various PGRs, versus one which was left as a control. The latter had the highest daily growth rate at 4.18 mm/day, Primo Maxx II came in at 3.76 mm/day, while ATTAXOR ranked the lowest at 3.62 mm/day.

These findings have implications for practical turf management. Such understanding of growth patterns and responses to different PGRs will help turfgrass managers and landscapers in choosing an appropriate PGR that will bring maximum reductions in the growth of turf, thereby reducing the frequency of mowing and hence saving time and costs. Biomass production associated with each PGR, obtained from growth curve analysis, will assist in assessing the potential savings in mowing and labor costs. Because Figure 0 illustrates growth trends, the curves delineate the clear distinction among the three test plots of the applied PGRs.

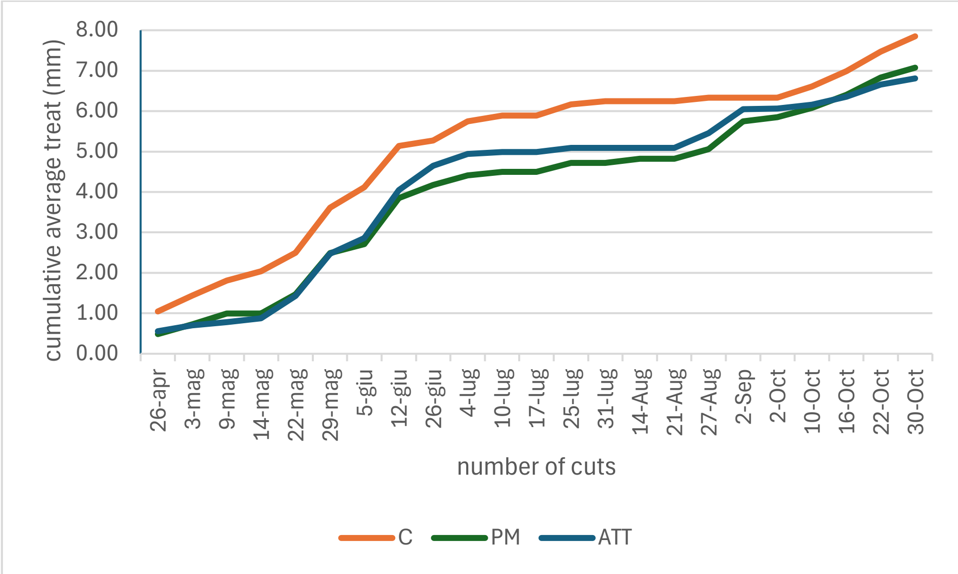

Figure 8. Cumulative vertical growth of the turfgrass using the three plant growth regulators (ATT = Attraxor, PM = Primo Maxx II, and C = control).

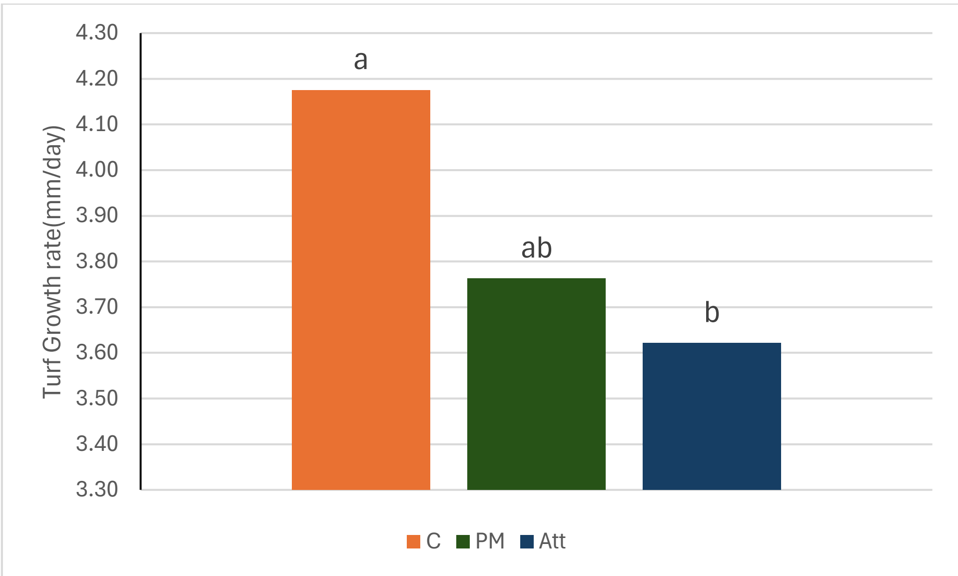

Figure 9. Average daily growth rate of turfgrass subjected to different PGRs (ATT = Attraxor, PM = Primo Maxx II, C = Control).

5.6. Clippings dry mass

Figure 10 shows cumulative clippings mass produced during the fall period (October). The clippings production initially decreased and subsequently increased, and differences among treatments became apparent. In the course of the experimental period, the control always had the highest dry weight, whereas Primo Maxx II colleted a better performance than ATTAXOR after its initial performance. First mowing session:

all treatments had similar dry weights. However, from the second cut onwards, ATTAXOR began to outperform Primo Maxx II since it produced less biomass overall. The total biomass from the sums of five cuts of dry weights recorded the highest total biomass production for the control plot.

Initially, ATTAXOR and Primo Maxx II were releasing similar trends in terms of dry weight production until from the last cut its sum of dry weights becomes almost identical. This result reflects a positive outcome for the test. Since plants contain lots of water, these may vary with the immediate surroundings, in say, climatic conditions; dry weight measures give a better estimate of biomass, in that it eliminates the variable conditions presented by water content. The total dry weight is one of the best indices of plant performance and hence taken to represent photosynthetic capacity, nutrient uptake, and other environmental conditions.

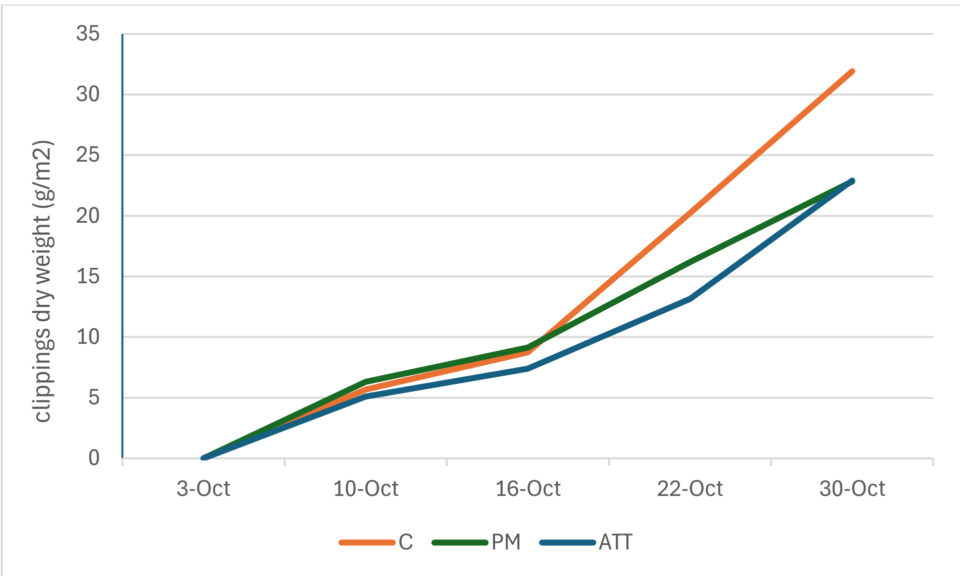

Figure 10. Cumulative dry mass of turfgrass clippings from five autumn cuts, comparing treatments: ATT (Attraxor), PM (Primo Maxx II), and C (Control).

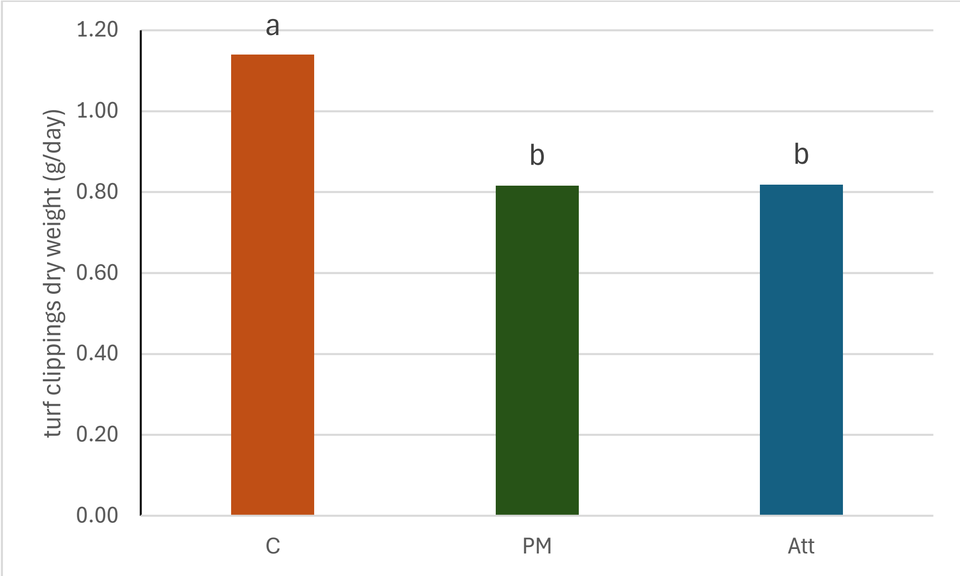

Figure 11. Average daily biomass growth rate of turfgrass subjected to different PGRs (ATT = Attraxor, PM = Primo Maxx II, C = Control).

5.7. Germination

Germination refers to the transformation of seeds into seedlings, which occurs when dormancy is disrupted by favorable environmental conditions. The factors that most influence germination are water, oxygen, and temperature. This experiment examined the actual percentages of germinated *Poa annua* seeds after different treatments: water (control), Attraxor (ATT), and Primo Maxx II (PM). A total of 50 seeds were assigned to each of the 30 Petri dishes, divided into two experimental groups, with five replicates being subjected to each treatment. The Petri dishes were incubated in a thermal chamber at 25°C during daylight hours and at 15°C at nighttime for 10 successive days. Each dish was treated with 3.5 mL of the appropriate solution. These results showed that germination for seeds treated with Attraxor or Primo Maxx II exhibited 0%, which means the complete inhibition of germination by the treatments. The experiment was repeated under same conditions. The control seeds germinated at percentages of 42.0, 29.6, and 9.6% from Experiment 1 and 32.8, 16.0, and 15.2% from Experiment 2 on the dates of November 18, 20, and 22, respectively.

These findings provide insights for predicting germination rates in field conditions and the potential application of these treatments in the management of seed germination.

Table 2. Germination Percentages of Poa annua Seeds in Experiment 1 Under Control, Attraxor, and Primo Maxx II Treatments

Treat	18-Nov	20-Nov	22-Nov
C	42.0	29.6	9.6
PM	0	0	0
ATT	0	0	0

Table 3. Germination Percentages of Poa annua Seeds in Experiment 2 Under Control, Attraxor, and Primo Maxx II Treatments

Treat	18-Nov	20-Nov	22-Nov
C	32.8	16.0	15.2
PM	0	0	0
ATT	0	0	0

(ATT = Attraxor, PM = Primo Maxx II, and C = control).

5.8. Poa annua Seed Head Development

The figure above shows the quantity of seed heads produced by Poa annua under the same three treatments. The control plants (C) underwent a natural reproductive cycle, their seed head numbers reaching a peak of 250 on May 14 before declining sharply. This would indicate that unmanaged *Poa ann*ua invests much in reproduction during mid-spring. Although the high seed head count in the control group presents a chance of infestation, taller seed heads would be more easily located and removed during mowing. More frequent mowing during periods of peak production could reduce the amount of seed dispersion and limit future infestations.

Plants treated with Primo Maxx II (PM) produced the most seed heads, reaching a high of 450 on 14 May. This unexpected outcome could be due to a compensatory trade-off from the suppression of height. The presence of a reduced height of the inflorescence is more aesthetically pleasing in turf, but the significant increase in seed head number greatly increases the risk for long-term dissemination of Poa annua. This highlights the need for more frequent mowing or supplementary management practices when using PM to minimize the risk of seed dispersal. Despite these challenges, PM may still be useful for short-term aesthetic improvements in highly visible turfgrass areas.

Attraxor-treated plants had the fewest seed heads throughout the study and never exceeded 100 on May 14. This shows that Attraxor can provide very effective suppression of reproductive output, and thus it can be an excellent choice for reducing Poa annua spread. Limiting both inflorescence height and seed head numbers, Attraxor effectively reduces the reproductive potential of Poa annua, an essential component of long-term control of the species. Because it is so strongly suppressed, seed heads may remain low and less obvious, thereby escaping mowing if the blades are set too high. To maximize the impact of Attraxor, its application should be supplemented with spot mowing during the reproductive period and subsequent overseeding with desirable grasses for a more thorough management approach.

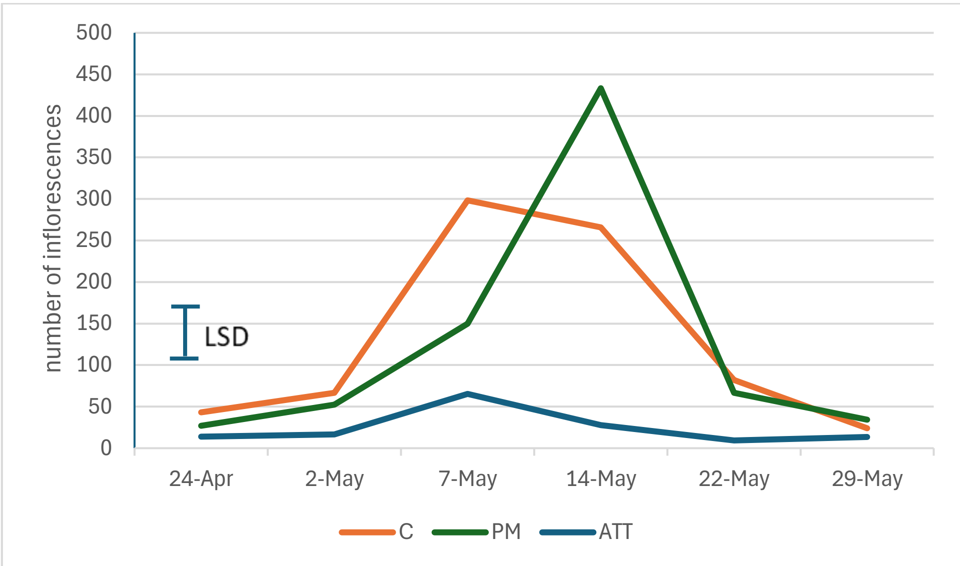

Figure 12. Poa annua seed head development in response to different growth regulators during the experimental period. (ATT = Attraxor, PM = Primo Maxx II, and C = control).

5.9. Average Height of Poa annua Inflorescences

The graph illustrates the results of applying Control (C), Primo Maxx II (PM), and Attraxor (ATT) on the average height of Poa annua inflorescences. In the control group, C showed a natural unfolding of inflorescences, which increased in height gradually, reached its peak of 8.4 cm on May 22nd, and then declined slightly. Taller inflorescences, like those in the control treatment, are beneficial for management because they are more likely to be removed during periodic mowing. The trade-off is that the taller inflorescences were highly reproductive and could achieve much higher seed dispersal if mowing did not occur on a frequent enough basis.

The plants treated with Primo Maxx II clearly reduced their height of inflorescence to 5.2 cm by May 7, with a slight recovery during the later weeks. This would therefore mean that PM effectively inhibits the vertical growth within its active period but tends to lose potency with time. Such height reduction decreases the showiness of the inflorescence, thus improving the aesthetics of turf and decreasing competition with desirable grasses. However, the partial regrowth in height indicates that consistent re-application or mowing is required to maintain the suppression of the grass. For areas where aesthetics is a priority, PM could be a dependable alternative; careful timing of mowing during its window of efficacy would enhance its effectiveness.

Attraxor-treated plants had the most consistent and greatest reduction in inflorescence height, reaching a low of 3.8 cm by May 7, then sustaining the suppression for the remainder of the experiment. This gives Attraxor considerable potential as an active ingredient for the control of Poa annua. On the contrary, such extreme height reduction could be problematic because very short inflorescences may not be captured by mowers at standard heights and would allow seed maturity. Under the best conditions, benefits from Attraxor may be maximized by adjusting mowing heights to remove all of the inflorescences. Supplemental overseeding or fertilization may also enhance the effects of Attraxor by encouraging desirable turf species growth and reducing the opportunity for resurgence of *Poa annua*.

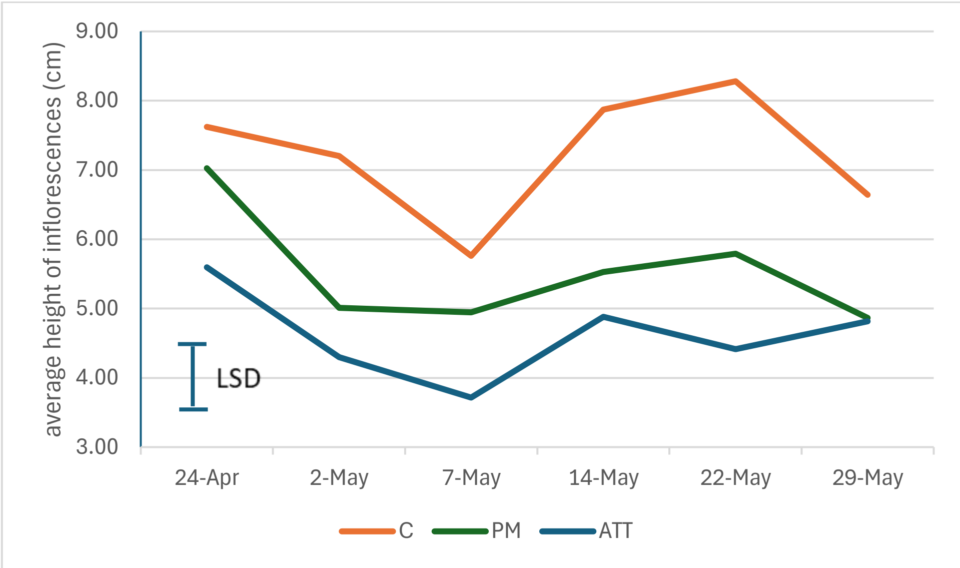

Figure 13. Average height of Poa annua inflorescences in response to different growth regulators during the experimental period. (ATT = Attraxor, PM = Primo Maxx II, and C = control).

6. Conclusion

The objective of this project was to comprehensively evaluate the plant growth regulators Attraxor and Primo Maxx II for their potential in controlling growth, improving aesthetic quality, and providing seedhead suppression in *Lolium perenne*/*Poa pratensis* mixtures and *Poa annua* during the period. Both PGRs displayed efficacy in lowering vertical growth and increasing turfgrass quality when compared with the untreated controls. Attraxor was a very effective chemical for suppressing seedheads, which reduced the reproductive potential of *Poa annua*, and, in some cases, reduced inflorescence height with minimal mowing. Primo Maxx II proved superior in its ability to maintain turf color through high-stress times of the year and was, therefore, best suited for situations where maintaining pleasing aesthetics was important.

The season was a key factor in influencing PGRs. For example, the higher temperatures during the summer reduced turfgrass quality overall for all treatments and showed that PGR application timing should be related to weather conditions. The germination studies developed during the project also pointed out the complete inhibition of *Poa annua* seed germination by both PGRs, a hopeful result regarding the pre-emergent weed control strategies. However, biomass production and regrowth patterns differed among treatments, suggesting that a management strategy relying solely on PGRs may not be entirely adequate. Instead, complementary management practices such as precise mowing schedules, irrigation management, and overseeding with more competitive turfgrass species can help to maximize the efficacy of PGRs without engendering ecological imbalances.

Therefore, the overall results provide evidence that PGRs are useful, yet a crucial tool for contemporary sustainable management in turfgrasses. Their ability to enhance health in turfgrasses, reduce the cost of maintenance of golf courses, sports fields, and ornamental lawns, and suppress weed populations represents several important benefits. Avenues for future research involve developing more intricate application protocols that will enhance the efficacy of PGRs under environmental conditions, including searching for the long-term impacts on soil health and plant ecosystems.

Furthermore, the study of the use of PGRs in combination with biological controls or eco-friendly practices would further enhance turfgrass management for sustainability. With this knowledge, practitioners may achieve aesthetic excellence with environmental responsibility in turfgrass systems.

SOURCES

1. Plant Growth Regulators. (n.d.). In link.springer.com. Retrieved August 22, 2022, from https://link.springer.com/book/97836426820632. **Overbeek, 1944**
2. Rademacher W. Plant growth regulators: backgrounds and uses in plant production. Journal of Plant Growth Regulation. 34 (2015) 845–72. https://doi.org/10.1007/s00344-015-9541-6
3. Hasan M., Razvi S., Kuerban A., Balamash K., Al-Bishri W., et al. Strigolactones-A Novel Class of Phytohormones as Anti-Cancer Agents. Journal of Pesticide Science. Pesticide Science Society of Japan. 43 (2018) 168-172. https://doi.org/10.1584/jpestics.D17-090
4. Gancheva S., Malovichko Y., Poliushkevich L., Dodueva I., Lutova L. Plant Peptide Hormones. Russian Journal of Plant Physiology. 66 (2019) 171-189. https://doi.org/10.1134/S1021443719010072
5. Andresen M., Cedergreen N. Plant growth is stimulated by tea-seed extract: A new natural growth regulator? HortScience 45 (2010) 1848-1853. https://doi.org/10.21273/hortsci.45.12.1848
6. Ortolá, A., Monerri C., Guardiola JL. The use of naphthalene acetic acid as a fruit growth enhancer in Satsuma mandarin: a comparison with the fruit thinning effect. Scientia Horticulturae. 47 (1991) 15-25. https://doi.org/10.1016/0304-4238(91)90023-R
7. Sanower M., Urbi Z. Effect of Naphthalene Acetic Acid on the adventitious rooting in shoot cuttings of Andrographis Paniculata (burm.f.) wall. ex nees: an important therapeutical herb. International Journal of Agronomy. (2016) 1-6. https://doi.org/10.1155/2016/1617543
8. Tsavkelova E., Klimova S., Cherdyntseva, T., Netrusov A. Microbial producers of plant growth stimulators and their practical use: A review. Applied Biochemistry and Microbiology. 42 (2006) 117-126. https://doi.org/10.1134/S0003683806020013
9. Garcés V., Palencia M., Combatt, E. Development of bacterial inoculums based on biodegradable hydrogels for agricultural applications. Journal of Science with Technological Applications. 2 (2017) 13-23. https://doi.org/10.34294/j.jsta.17.2.11
10. Lerma T., Combatt E., Palencia M. 2018. Soil-mimicking hybrid composites based on clay, polymers and nitrogen-fixing bacteria for the development of remediation systems of degraded soil. Journal of Science with Technological Applications. 4 (2018) 17-27. https://doi.org/10.34294/j.jsta.18.4.27
11. Agudelo-Morales, C. E., Lerma, T. A., Martínez, J. M., Palencia, M., & Combatt, E. M. (2021). Phytohormones and Plant Growth Regulators - A Review. *Journal of Science with Technological Applications*, *10*, 27–65. https://doi.org/10.34294/j.jsta.21.10.66
12. Davies, P. J. Their nature, occurrence, and functions. Plant Hormones. Springer. (2010). 1–15. https://doi.org/10.1007/978-1-4020-2686-7_1
13. Smith S., Li C., Li J. Hormone Function in Plants. In hormone metabolism and signaling in plants. Elsevier Inc. (2017) 1-38. https://doi.org/10.1016/B978-0-12-811562-6.00001-3

14. Arc E., Sechet J., Corbineau F., Rajjou L., Marion-Poll L. ABA Crosstalk with Ethylene and Nitric Oxide in Seed Dormancy and Germination. Frontiers in Plant Science 4 (2013) 1-19. https://doi.org/10.3389/fpls.2013.00063
15. Vanneste S., Friml J. Auxin: a trigger for change in plant development. Cell. 136 (2009) 1005-1016. https://doi.org/10.1016/j.cell.2009.03.001
16. Darwin, C. General considerations on the movements and growth of seedling plants. In the Power of Movement in Plants (Cambridge Library Collection - Darwin, Evolution and Genetics. (1880) 67-128. https://doi.org/10.1017/CBO9780511693670.003
17. Thimann K., Growth hormones in plants. Journal of the Franklin Institute. 229 (1940) 337–346. https://doi.org/10.1016/S0016-0032(40)90872-9
18. Kögl F., Haagen-Smit A., Erxleben H. Über Ein Neues Auxin ('Hetero-Auxin') Aus Harn. 11. Mitteilung Über Pflanzliche Wachstumsstoffe. Hoppe-Seyler's Zeitschrift Fur Physiologische Chemie. 228 (1934) 90–103. https://doi.org/10.1515/bchm2.1934.228.1-2.90
19. Enders T., Strader L. Auxin Activity: Past, Present, and Future. American Journal of Botany 102 (2015) 180–96. https://doi.org/10.3732/ajb.1400285
20. Ferro N., Bultinck P., Gallegos A., Jacobsen H., Carbo-Dorca R., et al. Unrevealed structural requirements for auxin-like molecules by theoretical and experimental evidences. Phytochemistry. 68 (2007) 237–250. https://doi.org/10.1016/j.phytochem.2006.10.006
21. Gupta R., Chakrabarty S. Gibberellic Acid in Plant: Still a Mystery Unresolved. Plant Signaling and Behavior. 8 (2013) 255041-255045. https://doi.org/10.4161/psb.25504
22. Salazar-Cerezo S., Martínez-Montiel N., García-Sánchez J., Pérez-Terrón R., Martínez-Contreras R. Gibberellin biosynthesis and metabolism: a convergent route for plants, fungi and bacteria. Microbiological Research. 208 (2018) 85-98. https://doi.org/10.1016/j.micres.2018.01.010
23. Cowling R., Kamiya Y., Seto H., Harberd P. Gibberellin Dose-Response Regulation of GA4 Gene Transcript Levels in Arabidopsis. Plant Physiology. 117 (1998) 1195–1203. https://doi.org/10.1104/pp.117.4.1195
24. MacMillan J. Occurrence of gibberellins in vascular plants, fungi, and bacteria. Journal of Plant Growth Regulation. 20 (2001) 387–442. https://doi.org/10.1007/s003440010038
25. Toyomasu T., Kawaide H., Mitsuhashi W., Inoue Y., Kamiya Y. Phytochrome regulates gibberellin biosynthesis during germination of photoblastic lettuce seeds. Plant Physiology. 118 (1998) 1517–23. https://doi.org/10.1104/pp.118.4.1517
26. Durmuş, N., Kadioğlu A. Reduction of Paraquat Toxicity in Maize Leaves by Benzyladenine. Acta Biologica Hungarica. 56 (2005) 97–107. https://doi.org/10.1556/ABiol.56.2005.1-2.10
27. Stirk W., van Staden J. Flow of Cytokinins through the environment. plant growth regulation. Springer. 62 (2010) 101-116. https://doi.org/10.1007/s10725-010-9481-x
28. Oshchepkov M., Kalistratova A., Savelieva E., Romanov G., Bystrova N., et al. Natural and synthetic cytokinins and their applications in biotechnology, agrochemistry and medicine. Russian Chemical Reviews. 89 (2020) 787–810. https://doi.org/10.1070/rcr4921
29. Grierson D. 100 Years of Ethylene - A Personal View. In the plant hormone ethylene, Wiley-Blackwell. 44 (2012) 1–17. https://doi.org/10.1002/9781118223086.ch1

30. Iqbal N., Khan N., Ferrante A., Trivellini A., Francini A., et al. Ethylene role in plant growth, development and senescence: interaction with other phytohormones. Frontiers in plant science. 8 (2017) 475-503. https://doi.org/10.3389/fpls.2017.00475
31. Ohkuma K., Lyon J, Addicott F., Smith O. Abscisin II, an abscission-accelerating substance from young cotton fruit. Science. 142 (1963) 1592–1593. https://doi.org/10.1126/science.142.3599.1592
32. Xiong L., Zhu J. Regulation of Abscisic Acid biosynthesis. Plant Physiology. American Society of Plant Biologists. 133 (2003) 29-36. https://doi.org/10.1104/pp.103.025395
33. (1994). Biochemical mechanisms involved in plant growth regulation.. https://doi.org/10.1093/oso/9780198577645.001.0001
34. Cowan, A. K. (2006). Phospholipids as plant growth regulators. Plant Growth Regulation, 48(2), 97-109. https://doi.org/10.1007/s10725-005-5481-7
35. Farré, E. M. (2012). The regulation of plant growth by the circadian clock. Plant Biology, 14(3), 401-410. https://doi.org/10.1111/j.1438-8677.2011.00548.x
36. Ismail, A. M. (2003). Physiological studies on the influence of cytokinin or ga3 in the alleviation of salt stress in sorghum plants. Acta Agronomica Hungarica, 51(4), 371-380. https://doi.org/10.1556/aagr.51.2003.4.1
37. Verizhnikova, A. A. and Prudnikova, E. Y. (2022). Influence of innovative plant growth regulators on physiological and biochemical parameters and yield of solanum tuberosum. Vegetable Crops of Russia, (4), 86-90. https://doi.org/10.18619/2072-9146-2022-4-86-90
38. Kundu, A. and Vadassery, J. (2022). Molecular mechanisms of piriformospora indica mediated growth promotion in plants. Plant Signaling &Amp; Behavior, 17(1). https://doi.org/10.1080/15592324.2022.2096785
39. Blázquez, M. Á., Nelson, D. C., & Weijers, D. (2020). Evolution of plant hormone response pathways. Annual Review of Plant Biology, 71(1), 327-353. https://doi.org/10.1146/annurev-arplant-050718-100309
40. Biddington, N. L. and Dearman, A. S. (1987). The effects of mechanically-induced stress and plant growth regulators on the growth of lettuce, cauliflower and bean (phaseolus vulgaris l.) plants. Plant Growth Regulation, 5(3), 183-194. https://doi.org/10.1007/bf00024694
41. Tohge, T., Scossa, F., & Fernie, A. R. (2015). Integrative approaches to enhance understanding of plant metabolic pathway structure and regulation. Plant Physiology, 169(3), 1499-1511. https://doi.org/10.1104/pp.15.01006
42. Jin, S., Zhang, M., Leng, Y., Xu, L., Jia, S., Wang, S., ... & Gao, J. (2022). Osnac129 regulates seed development and plant growth and participates in the brassinosteroid signaling pathway. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.905148
43. Khatoon, A., Rehman, S. U., Aslam, M. W., Jamil, M., & Komatsu, S. (2020). Plant-derived smoke affects biochemical mechanism on plant growth and seed germination. International Journal of Molecular Sciences, 21(20), 7760. https://doi.org/10.3390/ijms21207760
44. Fraser, R. S. S. and Whenham, R. J. (1982). Plant growth regulators and virus infection: a critical review. Plant Growth Regulation, 1(1), 37-59. https://doi.org/10.1007/bf00024221
45. Kerr, I. D. and Bennett, M. J. (2007). New insight into the biochemical mechanisms regulating auxin transport in plants. Biochemical Journal, 401(3), 613-622. https://doi.org/10.1042/bj20061411

46. Tripathi, D., Yadav, N., Shahi, S., & Yadav, R. K. (2023). Effect of seed priming with plant growth regulators on growth parameters, biochemical changes of rice (oryza sativa l.). International Journal of Plant &Amp; Soil Science, 35(19), 464-472. https://doi.org/10.9734/ijpss/2023/v35i193572
47. Nelissen, H., Groeve, S. D., Fleury, D., Neyt, P., Bruno, L., Bitonti, M. B., ... & Lijsebettens, M. V. (2010). Plant elongator regulates auxin-related genes during rna polymerase ii transcription elongation. Proceedings of the National Academy of Sciences, 107(4), 1678-1683. https://doi.org/10.1073/pnas.0913559107
48. Harris, J. C., Hrmová, M., Lopato, S., & Langridge, P. (2011). Modulation of plant growth by hd-zip class i and ii transcription factors in response to environmental stimuli. New Phytologist, 190(4), 823-837. https://doi.org/10.1111/j.1469-8137.2011.03733.x
49. Ross, J. J., O'Neill, D., Wolbang, C. M., Symons, G. M., & Reid, J. B. (2001). Auxin-gibberellin interactions and their role in plant growth. Journal of Plant Growth Regulation, 20(4), 346-353. https://doi.org/10.1007/s003440010034
50. Mishra, B. S., Sharma, M., & Laxmi, A. (2021). Role of sugar and auxin crosstalk in plant growth and development. Physiologia Plantarum, 174(1). https://doi.org/10.1111/ppl.13546
51. Beard, J. B. and Green, R. L. (1994). The role of turfgrasses in environmental protection and their benefits to humans. Journal of Environmental Quality, 23(3), 452-460. https://doi.org/10.2134/jeq1994.00472425002300030007x
52. Cisar, J. O. (2013). Development of turfgrass management systems for green roof-type applications. Ats, 10(1), 0. https://doi.org/10.2134/ats-2013-0016bc
53. Nickell, L. G. (1994). Plant Growth Regulators in Agriculture and Horticulture. *ACS Symposium Series*, 1–14. https://doi.org/10.1021/bk-1994-0557.ch001
54. Fahad, S., Hussain, S., Saud, S., Hassan, S., Chauhan, B. S., Khan, F., Ihsan, M. Z., Ullah, A., Wu, C., Bajwa, A. A., Alharby, H., Amanullah, Nasim, W., Shahzad, B., Tanveer, M., & Huang, J. (2016). Responses of Rapid Viscoanalyzer Profile and Other Rice Grain Qualities to Exogenously Applied Plant Growth Regulators under High Day and High Night Temperatures. *PLOS ONE*, *11*(7), e0159590. https://doi.org/10.1371/journal.pone.0159590
55. Watschke, T. L., Prinster, M., & Breuninger, J. M. (2015). Plant Growth Regulators and Turfgrass Management. *Agronomy*, 557–588. https://doi.org/10.2134/agronmonogr32.c16
56. Roberts, J. A., Ritchie, D. F., & Kerns, J. P. (2016). Plant Growth Regulator Effects on Bacterial Etiolation of Creeping Bentgrass Putting Green Turf Caused by Acidovorax avenae. *Plant disease*, *100*(3), 577–582. https://doi.org/10.1094/PDIS-04-15-0419-RE
57. Głąb, T., Szewczyk, W., Gondek, K., Knaga, J., Tomasik, M., & Kowalik, K. (2020). Effect of plant growth regulators on visual quality of turfgrass. *Scientia Horticulturae*, *267*, 109314. https://doi.org/10.1016/j.scienta.2020.109314
58. Zhang, X. (2016). *Influence of Plant Growth Regulators on Turfgrass Growth, Antioxidant Status, and Drought Tolerance*.
59. Drake, A. M., Petrella, D. P., Blakeslee, J. J., Danneberger, T. K., & Gardner, D. S. (2023). Effect of Plant Growth Regulators on Creeping Bentgrass during Heat, Salt, and Combined Stress. *HortScience*, *58*(4), 410-418. Retrieved Dec 18, 2023, from https://doi.org/10.21273/HORTSCI16978-22

60. PGR effects on turf under heat and salt stress - GCMOnline.com. (n.d.). Gcmonline.com. https://gcmonline.com/course/environment/news/PGR-turf-heat-stress-salt-stress
61. Wells, D. W. (1989, January 1). Plant Growth Regulator Evaluations in Warm Season Turfgrasses. https://core.ac.uk/works/63378428
62. Long, S. (2006). TigerPrints THATCH CONTROL, WINTER PAINTING, AND PLANT GROWTH REGULATOR MANAGEMENT ON GOLF COURSE PUTTING GREENS. https://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=1009&context=all_theses.
63. Baldwin, C. M., Liu, H., McCarty, L. B., Luo, H., & Toler, J. E. (2009). Nitrogen and plant growth regulator influence on 'Champion'bermudagrass putting green under reduced sunlight. Agronomy journal, 101(1), 75-81.10.2134/agronj2008.0004x.
64. *Burpee, L. L., Green, D. E., & Stephens, S. L. (1996). Interactive Effects of Plant Growth Regulators and Fungicides on Epidemics of Dollar Spot in Creeping Bentgrass. Plant Disease, 80(12), 1245–1250. https://doi.org/10.1094/PD-80-1245*
65. Steinke, Kurt & Stier, J.. (2003). Nitrogen Selection and Growth Regulator Applications for Improving Shaded Turf Performance. Crop Science - CROP SCI. 43. 10.2135/cropsci2003.1399.
66. Schiavon, M., Leinauer, B., Serena, M., Maier, B., & Sallenave, R. (2014). Plant Growth Regulator and Soil Surfactants' Effects on Saline and Deficit Irrigated Warm-Season Grasses: I. Turf Quality and Soil Moisture. *Crop Science*, *54*(6), 2815. https://doi.org/10.2135/cropsci2013.10.0707
67. Elansary, H. O., & Yessoufou, K. (2015). Growth regulators and mowing heights enhance the morphological and physiological performance of Seaspray turfgrass during drought conditions. Acta Physiologiae Plantarum, 37(11). https://doi.org/10.1007/s11738-015-1986-5
68. March, S. R., Martins, D., & McElroy, J. P. (2013). Growth inhibitors in turfgrass. *Planta Daninha*, *31*(3), 733–747. https://doi.org/10.1590/s0100-83582013000300025
69. Datnoff, L. E. (2005). Silicon in the life and performance of turfgrass. Applied Turfgrass Science, 2(1), 1-6. https://doi.org/10.1094/ats-2005-0914-01-rv
70. Gourichon, D. and Nangle, E. (2023). Advances in plant growth regulation in turfgrass. Burleigh Dodds Series in Agricultural Science, 389-426. https://doi.org/10.19103/as.2022.0110.12
71. Kang, J. Y., Kim, D. H., Lee, D. G., Kim, I. S., Jeon, M. G., Lee, J. D., ... & Lee, S. (2013). Screening of antifungal activities of medicinal plants for the control of turfgrass fungal disease. Weed &Amp; Turfgrass Science, 2(1), 70-75. https://doi.org/10.5660/wts.2013.2.1.070
72. Głąb, T., Szewczyk, W., & Gondek, K. (2023). Response of kentucky bluegrass turfgrass to plant growth regulators. Agronomy, 13(3), 799. https://doi.org/10.3390/agronomy13030799
73. Braun, R. C., Straw, C. M., Soldat, D. J., Bekken, M. A. H., Patton, A. J., Lonsdorf, E. V., ... & Horgan, B. P. (2023). Strategies for reducing inputs and emissions in turfgrass systems. Crop, Forage &Amp; Turfgrass Management, 9(1). https://doi.org/10.1002/cft2.20218
74. Carlson, M. P., Gaussoin, R. E., & Puntel, L. A. (2022). A review of precision management for golf course turfgrass. Crop, Forage &Amp; Turfgrass Management, 8(2). https://doi.org/10.1002/cft2.20183
75. Cowan, A. K. (2006). Phospholipids as plant growth regulators. Plant Growth Regulation, 48(2), 97-109. https://doi.org/10.1007/s10725-005-5481-7

76. Curci, P. L., Zhang, J., Mähler, N., Seyfferth, C., Mannapperuma, C., Diels, T., ... & Vandepoele, K. (2022). Identification of growth regulators using cross-species network analysis in plants. Plant Physiology, 190(4), 2350-2365. https://doi.org/10.1093/plphys/kiac374
77. Acuña, A., Gardner, D., Villalobos-González, L., & Danneberger, K. (2022). Effects of plant biostimulants on seedling root and shoot growth of three cool-season turfgrass species in a controlled environment. International Turfgrass Society Research Journal, 14(1), 416-421. https://doi.org/10.1002/its2.97
78. Lai, J. and Han, L. (2022). Progress and challenges in china turfgrass abiotic stress resistance research. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.922175
79. Tutin, T. G. (1952). Origin of *Poa annua* L. *Nature*, *169*(4291), 160–160. https://doi.org/10.1038/169160a0
80. Gibeault, V. A. (n.d.). *Perenniality in Poa annua L.* Ir.library.oregonstate.edu. Retrieved December 18, 2023, from https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/xk81jq45h?locale=en
81. Chwedorzewska, K. J. (2007). *Poa annua* L. in Antarctic: searching for the source of introduction. Polar Biology, 31(3), 263–268. https://doi.org/10.1007/s00300-007-0353-4
82. Chwedorzewska, K. J., Giełwanowska, I., Olech, M., Molina-Montenegro, M. A., Maciej Wódkiewicz, & Galera, H. (2015). *Poa annua*L. in the maritime Antarctic: an overview. 51(6), 637–643. https://doi.org/10.1017/s0032247414000916
83. Carroll, D. E., Brosnan, J. T., Trigiano, R. N., Horvath, B. J., Shekoofa, A., & Mueller, T. C. (2021). Current understanding of the *Poa annua* life cycle. Crop Science, 61(3), 1527–1537. https://doi.org/10.1002/csc2.20441
84. Jr, J. M. V., & Turgeon, A. J. (2003). *Poa annua*: Physiology, Culture, and Control of Annual Bluegrass. In Google Books. John Wiley & Sons. https://books.google.it/books?id=PtnRMlhbbaoC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false
85. Mao, Q., & Huff, D. R. (2012). The Evolutionary Origin of *Poa annua* L. Crop Science, 52(4), 1910–1922. https://doi.org/10.2135/cropsci2012.01.0016
86. Hutchinson, C. S., & Seymour, G. B. (1982). *Poa annua* L. The Journal of Ecology, 70(3), 887. https://doi.org/10.2307/2260111
87. Bergelson, J. (1990). Life After Death: Site Pre-Emption by the Remains of *Poa annua*. Ecology, 71(6), 2157–2165. https://doi.org/10.2307/1938629
88. McCullough, P., Hart, S., & Lycan, D. (2005). Plant growth regulator regimens reduce *Poa annua* populations in creeping bentgrass. Applied Turfgrass Science, 2(1), 1-5. https://doi.org/10.1094/ats-2005-0304-01-rs
89. Woosley, P., Williams, D., & Powell, A. (2003). Postemergence control of annual bluegrass (*Poa annua* spp. reptans) in creeping bentgrass (agrostis stolonifera) turf1. Weed Technology, 17(4), 770-776. https://doi.org/10.1614/wt02-153
90. McCullough, P., Li, H., McCarty, L., & Toler, J. (2006). Ethephon and trinexapac-ethyl influence creeping bentgrass growth, quality, and putting green performance. Applied Turfgrass Science, 3(1), 0. https://doi.org/10.1094/ats-2006-0324-01-rs https://acsess.onlinelibrary.wiley.com/doi/10.1094/ATS-2006-0324-01-RS

91. Dernoeden, P. and Pigati, R. (2009). Scalping and creeping bentgrass quality as influenced by ethephon and trinexapac-ethyl. Applied Turfgrass Science, 6(1), 1-7. https://doi.org/10.1094/ats-2009-0601-01-rs
92. Irving, L. and Mori, S. (2021). Effects of light, n and defoliation on biomass allocation in *Poa annua*. Plants, 10(9), 1783. https://doi.org/10.3390/plants10091783
93. Schädler, M., Brandl, R., & Haase, J. (2007). Antagonistic interactions between plant competition and insect herbivory. Ecology, 88(6), 1490-1498. https://doi.org/10.1890/06-0647
94. Sun, Q., Wang, W., Huang, J., Gu, X., Dong, Y., Yang, Y., ... & He, Y. (2023). Transcriptome analysis reveals the response mechanism of digitaria sanguinalis, arabidopsis thaliana and *Poa annua* under 4,8-dihydroxy-1-tetralone treatment. Plants, 12(14), 2728. https://doi.org/10.3390/plants12142728
95. Guertal, E. and McElroy, J. (2018). Soil type and phosphorus fertilization affect *Poa annua* growth and seedhead production. Agronomy Journal, 110(6), 2165-2170. https://doi.org/10.2134/agronj2018.02.0139
96. Stallmann, J. and Schweiger, R. (2021). Effects of arbuscular mycorrhiza on primary metabolites in phloem exudates of plantago major and *Poa annua* and on a generalist aphid. International Journal of Molecular Sciences, 22(23), 13086. https://doi.org/10.3390/ijms222313086
97. Benson, C., Sheltra, M., Maughan, J., Jellen, E., Robbins, M., Bushman, B., ... & Huff, D. (2023). Homoeologous evolution of the allotetraploid genome of *Poa annua* l... https://doi.org/10.21203/rs.3.rs-2729084/v1
98. Askew, S. D. (2017). Plant Growth Regulators Applied in Winter Improve Annual Bluegrass (*Poa annua*) Seedhead Suppression on Golf Greens. *Weed Technology*, *31*(5), 701–713. https://doi.org/10.1017/wet.2017.73
99. Johnson, B. J., & Murphy, T. R. (1995). Effect of Paclobutrazol and Flurprimidol on Suppression of *Poa annua* spp. reptans in Creeping Bentgrass (Agrostis stolonifera) Greens. Weed Technology, 9(1), 182–186. https://www.jstor.org/stable/3987842?read-now=1&seq=4#page_scan_tab_contents
100. McMahon, G. and Hunter, A. (2012). DETERMINATION OF THE EFFECTS OF PLANT GROWTH REGULATORS ON AGROSTIS STOLONIFERA AND *POA ANNUA*. Acta Hortic. 937, 161-168DOI: 10.17660/ActaHortic.2012.937.19https://doi.org/10.17660/ActaHortic.2012.937.19
101. Williams, A. (2014). PLANT GROWTH REGULATORS AND HERBICIDES FOR MANAGEMENT OF *POA ANNUA*: IMPACT OF BIOTYPES AND BEHAVIOR OF FLURPRIMIDOL IN TURFGRASS SPECIES. Theses and Dissertations--Plant and Soil Sciences. https://uknowledge.uky.edu/pss_etds/45/
102. Brown, J. (2013). Changes in *Poa annua* Populations in Response to Herbicides and Plant Growth Regulators. Department of Agronomy and Horticulture: Dissertations, Theses, and Student Research. https://digitalcommons.unl.edu/agronhortdiss/69/
103. McCullough, P. E., Barreda, D. G. de, & Yu, J. (2013). Selectivity of Methiozolin for Annual Bluegrass (*Poa annua*) Control in Creeping Bentgrass as Influenced by Temperature and Application Timing. *Weed Science*, *61*(2), 209–216. https://doi.org/10.1614/WS-D-12-00135.1
104. Haguewood, J. B. (2014). Management of annual bluegrass (*Poa annua* L.) using post-emergence herbicides and plant growth regulators. Mospace.umsystem.edu. https://mospace.umsystem.edu/xmlui/handle/10355/45821
105. Jackson, I., O'connor, B., Jacobson, D. *Mefluidide: a plant growth regulator.*. (n.d.) Retrieved December 15, 2023, from www.cabdirect.org/cabdirect/abstract/19800712800

106. Simard, A., Czyzewski, B., Price, G., & McGraw, B. (2021). Evaluation of nitrogen fertility and plant growth regulator impacts on annual bluegrass weevil (listronotus maculicollis) oviposition and larval survivorship. International Turfgrass Society Research Journal, 14(1), 815-822. https://doi.org/10.1002/its2.72
107. Bezemer, T. and Jones, T. (2012). The effects of co2 and nutrient enrichment on photosynthesis and growth of *Poa annua* in two consecutive generations. Ecological Research, 27(5), 873-882. https://doi.org/10.1007/s11284-012-0961-5
108. Laforest, M., Soufiane, B., Patterson, E., Vargas, J., Boggess, S., Houston, L., … & Brosnan, J. (2021). Differential expression of genes associated with non-target site resistance in *Poa annua* with target site resistance to acetolactate synthase inhibitors. Pest Management Science, 77(11), 4993-5000. https://doi.org/10.1002/ps.6541
109. Morris, K. and Shearman R.C. 1998. National Turfgrass Evaluation Program (NTEP) Turfgrass Evaluation Guidelines. https://www.ntep.org/pdf/ratings.pdf . Accessed August 10, 2021. Google Scholar