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Performance of Different Cool-Season Species and Cultivars Overseeded on Bermudagrass and Managed with Autonomous Mower

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Abstract: With global warming, the cultivation area of bermudagrass is moving northwards in the Mediterranean area despite its winter dormancy and loss of green color. The most common solution is overseeding with perennial ryegrass, which can be complicated to remove in spring. DLF breeders have released a new cultivar of annual ryegrass that is stress tolerant and easy to transition in spring. A trial was carried out on a sod farm in Pisa, Italy. Twenty-nine varieties of cool-season grasses, encompassing both forage and turf species, were overseeded on a hybrid bermudagrass variety 'Tifway' (*Cynodon dactylon* x *transvaalensis*). The aim of this trial was to compare the overseeding potential of various cool-season turfgrass species and cultivars and to identify which ones perform best in terms of cleanness of cut when overseeded on hybrid bermudagrass in autumn and maintained at a mowing height of 25 mm. Moreover, the following parameters were also assessed: actual turf height (cm); cumulated height (cm); turf visual color and quality (1–9 scale); and visual ground cover (%). Plots were managed with an autonomous mower, which adopted a daily mowing frequency and was set to work with systematic trajectories. The results showed differences between cultivars, and the annual ryegrass showed the best spring transition (scoring a mean value of 96% green cover in July 2023) compared to the other entries. The best result of CoC was measured for rough-stalked meadow grass 'Sabrena 1' and tall fescue 'Turfway' with 0.9 mm.

Keywords: robotic mower; overseeding; transition zone; bermudagrass; cleanness of cut; autonomous mowing

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1. Introduction

Species of the genus Cynodon have long been considered crop weeds in tropical and subtropical areas. *Cynodon dactylon* (L.) Pers. is the most prevalent, with a range of latitudes from 45° N to 45° S [1]. Hybrid bermudagrass (*Cynodon dactylon* x *C. transvaalensis*) is of superior quality compared to common bermudagrass. However, it requires vegetative propagation due to its sterility. Several cultivars of *Cynodon* spp. have shown high quality in evaluations carried out in Italy [2].

The broader adoption of warm-season turfgrasses in the coastal regions of the Mediterranean area holds significant technical and environmental promise [3]. Utilizing warm-season turfgrass species offers a myriad of benefits compared to cool-season varieties [4]. These advantages include reduced water requirements, the ability to irrigate with saline or reclaimed water sources, heat tolerance [5,6] and heightened resistance to some fungal infections [7].

Although these areas lie within the turfgrass transition zones where warm-season varieties can thrive, they may experience winter dormancy during cooler months when soil temperatures drop below 10 °C [8].

As studied by Fontanier and Steinke, 2017 [4], also in the USA, overseeding has become standard practice for golf courses and sports fields with heavy winter traffic. Thus, bermudagrass holds a prominent position as a turfgrass in various regions of the transitional zones of the United States to tropical areas worldwide. Its resilience, durability, and ability to thrive in different climates make it a preferred choice for sports fields, golf courses, and other landscape applications [9,10]. In the Mediterranean area, attaining turf management with minimal inputs could involve adopting a bermudagrass/cool-season polystand turfgrass, maintained with an autonomous mower. This approach could provide a more sustainable solution, addressing issues such as bermudagrass winter dormancy and loss of green color, the use of smaller quantities of water and fertilizers, and higher playability of the field in all periods of the year.

Overseeding of warm-season grasses with cool-season grasses is therefore essential for technical or aesthetic reasons to maintain a green, actively growing turf during winter. Overseeding is used to establish either a permanent [11] or, more commonly, a temporary polystand. Cool-season grasses can be overseeded in late summer or early autumn [3]. This approach facilitates the establishment of a temporarily actively growing green cover, particularly when alternatives like turf covers or painting are deemed less effective remedies for warm-season turfgrass dormancy during winter [12,13].

The overseeding is usually carried out on turfgrass that is professionally maintained to ensure that it receives an adequate supply of water and nutrients. In this context, the availability of light and space become critical factors influencing the switch of bermudagrass with cool-season grasses, usually perennial ryegrass [14,15]. The process of removing the overseeded cool-season turfgrass from the bermudagrass in spring is referred to as the spring transition [16]. Ideally, this transition should coincide with the full green-up of the bermudagrass [15,17]. Thus, the choice of cool-season turfgrass for overseeding plays a crucial role in determining the outcome of the process. Several transitional stages need to be considered when selecting a cool-season turfgrass for overseeding, particularly the ease of establishment of the overseeded turfgrass in the autumn and the transition back to the warm-season turfgrass in the spring [18]. The optimal overseeding scenario involves rapid establishment, high-quality turf, and a seamless transition back to the warm-season turf species [19]. In a world where herbicides are less and less authorized and used, having cool-season varieties that disappear almost by themselves is crucial. The success of overseeding depends on factors such as the selection of cool-season turf varieties that are compatible with the existing turf, adequate seedbed preparation, optimum timing, appropriate seeding rate, post-planting maintenance, and proper management of the spring transition [20,21].

Traditionally, turfgrass mowers are categorized into three primary groups: rotary mowers, reel mowers, and flail mowers [13]. However, lightweight autonomous mowers (LAMs) have recently demonstrated superior turf quality compared to traditional walk-behind rotary mowers [22–24]. Technological progress is leading the market to more and more efficient machines able to enhance cutting quality. Although there is no clear definition in the literature of 'mowing quality' and 'cleanness of cut', these terms are commonly used to define turfgrass quality. In particular, greater or lesser cleanness of cut is often used as a means of comparison between different species or cultivars [25,26].

An early attempt to assess mowing quality was made by Gibeault and Hanson (1977) [27] who defined a 0 to 10 rating scale for mowing quality. According to this scale, 0 was considered a very poor-quality cut, while 10 was considered a superior-quality cut ('. . .a clean leaf cut'). The need to develop objective measurements with a high degree of accuracy is therefore a crucial process in developing a measurement protocol. One solution being explored is the use of digital technologies, which can be helpful. Karcher and Richardson (2003) [28] wondered how to quantify turfgrass green cover using an objective method that did not entail high time and labor costs in its realization. Also, Horst et al.,

(1984) [29] demonstrated how different evaluators led to a variation in ratings that was related to different operators rather than the cultivars analyzed.

The trial was carried out to simulate a low-maintenance warm-season soccer field overseeded with cool-season turfgrasses managed with a lightweight autonomous mower. Thus, the aim of the present trial was to compare the overseeding potential of different cool-season turfgrass species and cultivars and to determine the best performance in terms of cleanness of cut when overseeded on hybrid bermudagrass in autumn mown at 25 mm.

2. Material and Methods

The trial was carried out in a sod farm in Pisa, Italy (43°39′ N 10°21′ E, 2 m a.s.l.), which belongs to a Mediterranean climatic area and falls into the turfgrass transition zone.

Twenty-nine varieties of cool-season grasses, including forage and turf species, were overseeded on bermudagrass variety 'Tifway' (*Cynodon dactylon x transvaalensis*) established in a soil characterized by the following physical–chemical properties: 91% sand, 5% silt, 4% clay, pH 6.6, and 1.4 g kg^{-1} of organic matter; EC 0.51 dS m^{-1}. Cool-season grass species used for the trial were perennial ryegrass (*Lolium perenne*), annual ryegrass (*Lolium multiflorum*), smooth-stalked meadow grass (*Poa pratensis*), rough-stalked meadow grass (*Poa trivialis*), and tall fescue (*Festuca arundinacea*). On 21 September 2022, a severe scalping was carried out to prepare an adequate soil surface for the cool-season species to germinate and grow. One day after the scalping, on 22 September 2022, all the cool-season varieties were manually seeded with a seed rate of 66.7 g m^{-2} for all the ryegrasses and tall fescues, and 15 g m^{-2} for smooth-stalked meadow grass and rough-stalked meadow grass (Table 1). At seeding time, 72 kg ha^{-1} of N and 184 kg ha^{-1} of $(NH_4)_2HPO_4$ (biammonium phosphate) were applied.

Table 1. List of species and cultivars overseeded on Bermudagrass.

Species	Cultivar	Seed Rate (g m^{-2})	Species Classification
Diploid annual ryegrass	Axcella	66.7	Turf
Diploid annual ryegrass	Grazer nova	66.7	Forage
Diploid annual ryegrass	Magloire	66.7	Forage
Diploid annual ryegrass	Quickston	66.7	Turf
Diploid annual ryegrass	Surrey nova	66.7	Forage
Diploid Italian ryegrass	Itaka	66.7	Forage
Diploid perennial ryegrass	Aspire	66.7	Turf
Diploid perennial ryegrass	Bandalore	66.7	Turf
Diploid perennial ryegrass	Centurion	66.7	Turf
Diploid perennial ryegrass	Mercitwo	66.7	Turf
Hybrid ryegrass	Transist 2600	66.7	Turf
Tetraploid annual ryegrass	Jivet	66.7	Forage
Tetraploid annual ryegrass	Logics	66.7	Forage
Tetraploid annual ryegrass	Nival/Torero	66.7	Forage
Tetraploid annual ryegrass	Prompt	66.7	Forage
Tetraploid annual ryegrass	N°1 22411/12	66.7	Turf
Tetraploid annual ryegrass	N°2 22413/14	66.7	Turf
Tetraploid annual ryegrass	N°3 22415/16	66.7	Turf
Tetraploid annual ryegrass	N°4 22417/18	66.7	Turf
Tetraploid perennial ryegrass	Fabian	66.7	Turf
Tetraploid perennial ryegrass	Tetradark	66.7	Turf
Tetraploid perennial ryegrass	Tetradry	66.7	Turf
Tetraploid perennial ryegrass	Tetragreen	66.7	Turf
Smooth-stalked meadow grass	SR2100	15.0	Turf
Smooth-stalked meadow grass	340/40296	15.0	Turf
Rough-stalked meadow grass	Sabrena 1	15.0	Turf
Tall fescue	Essential	66.7	Turf
Tall fescue	Granditte	66.7	Turf
Tall fescue	Turfway	66.7	Turf
Bermudagrass (control)		-	-

Monthly fertilization, from October to March, consisted of 50 kg ha^{-1} of N, 12.5 kg ha^{-1} of P_2O_5, and 25 kg ha^{-1} of K_2O (EUROCHEM, Cesano Maderno, MB, Italy, Nitrophoska super, NPK 20-5-10 + 3 MgO + 12.5 SO_3). From April to June, 50 kg ha^{-1} of $(NH_4)_2SO_4$ (ammonium sulphate) was applied monthly. No fungicide, herbicide, or insecticide applications were performed during the trial.

The total size of the experimental area measured 360 m^2, with the elementary plot of 3 m^2 (2 m × 1.5 m). A complete randomized block experimental design with four replications was adopted for this trial. To improve seed germination, the entire experimental area was covered with Edilfloor Thermofelt geotextile (30 g m^{-2} specific weight) for 20 days after seeding and irrigated to achieve adequate seedling germination. The evaluation of the performance is based on the determination of the characteristics affecting fall–winter establishment, winter growth and appearance, spring transition, and bermudagrass green-up.

Mowing management of the experimental area was initially performed with an electric walk-behind rotary mower (Honda mod. HRG466 XB; 36 C; Honda France manufacturing; Ormes, France), on 6 October 2022 with a weekly mowing frequency, gradually reducing the mowing height to 25 mm. Subsequently, the experimental area was managed with a lightweight Husqvarna EPOS 550 autonomous mower (Husqvarna, Stockholm, Sweden) on 25 January 2023 (Figure 1).

Figure 1. Autonomous mower systematically managing the experimental plots (mod. EPOS 550, Husqvarna, Stockholm, Sweden).

When mowing with the autonomous mower, a daily mowing frequency was adopted (every day, seven days per week), with a set mowing height of 25 mm (Figure 2). The mower was set to work at 65 cm s^{-1} ground speed, with a 2500 rpm blade speed, and with systematic trajectories to increase the working efficiency.

On 4 April 2023, a scalping with a self-propelled reel mower (20-3.5 RP-7; McLane, Paramount, CA, USA) was performed to encourage spring transition. The scalping was performed only on half of each plot with the aim of collecting data both on the scalped and no scalped half of the plot to determine spring transition differences among varieties (Figure 3).

Assessments conducted in this trial were:

(a) Actual turf height (cm): measurement before each mowing with a grass meter (400 g m^{-2} density);
(b) Cumulated height (cm): reported as monthly average from October 2022 through March 2023;
(c) Turf visual color (monthly): rated on a scale of 1 to 9, where 1 = light green and 9 = dark green, with a rating of 6 = acceptable [30];
(d) Turf visual quality (monthly): rated on a scale of 1 to 9, where 1 = poorest and 9 = best [30];

(e) Visual ground cover (monthly): expressed as the percentage of ground covered by the overseeded species or by bermudagrass;
(f) Cleanness of cut (CoC), which is the effect of mowing at single-leaf scale measured after cutting with an autonomous mower at 25 mm.

Figure 2. Drone image of the entire experimental area acquired after mowing at 25 mm with the autonomous mower.

Figure 3. Scalping on half plot at 10 mm with a self-propelled reel mower, 4 April 2023 (McLane).

To determine the cleanness of cut, a prototype instrument was built to allow the acquisition of images (Figure 4), which were later processed and evaluated using graphics processing software. The image capture apparatus consists of a glass plate (66.0 × 26.0 cm) with a metal ruler graduated in millimeters fixed to the camera's focusing plane and a column stand with standard camera support. The digital camera used was the Ricoh mod. R10 (Ricoh Company Ltd., Tokyo, Japan). Two suction cup handles attached to the glass were used to press down the glass plate into the turf canopy in order to lodge the leaves on a single plane. Subsequently, the pictures were processed using open-source graphics processing software (GIMP, version 2.10.34), distributed under the GPLv3+ license, (https://www.gimp.org/downloads/, accessed on 12 February 2024). Measurements were carried out on 40 randomly collected leaves per entry and reported in mm. The measure tool function of the software was used to determine the length (mm) of the fringed necrotic or desiccated tissues. The shorter the length of the necrotic tissues, the higher the cleanness of cut. Specifically, the cleanness of cut was determined as the average length (mm) of the necrotic leaf tip and/or desiccated veins. The reference ranges of values are reported as follows: 0–1 mm = excellent; 1–3 mm = acceptable; and >3 mm = unacceptable cleanness of cut.

Figure 4. Cleanness of cut prototype instrument.

Statistical analysis was performed with the statistical software COSTAT (version 6.4 CoHort Software, Monterey, CA, USA) testing the effect of twenty-nine cool-season varieties on the measured parameters of actual turf height, cumulated actual height, turf visual color and quality, visual ground cover, and cleanness of cut. Data were analyzed by a one-way analysis of variance. Means were separated with Fisher's protected least significant difference at a 0.05 probability level, and LSD values were reported in the tables.

3. Results

3.1. Cumulative Actual Height

During the six-month trial period, field test results showed that the highest cumulative actual heights were reached by forage tetraploid annual ryegrass 'Jivet' (71 cm), 'Logics' (73 cm), and Nival/Torero (75.7 cm). The same trend was measured also for the forage diploid annual ryegrass 'Magloire' (71.1 cm). In contrast, the lowest cumulative actual height values were observed for smooth-stalked meadow grass 'SR2100' and '340/40296' showing values of 13.3 cm and 18.0 cm, respectively (Table 2). Significant differences were also detected for tall fescue varieties, which showed lower cumulative actual height values than tetraploid and diploid annual ryegrasses.

3.2. Turf Visual Color

Concerning turf color, mean higher values were observed for tetraploid perennial ryegrass 'Tetradark' (7.5) and diploid perennial ryegrass 'Bandalore' (7.4). Diploid annual ryegrasses 'Axcella', forage 'Grazer nova', and 'Magloire'; forage diploid Italian ryegrass 'Itaka', forage tetraploid annual ryegrass 'Jivet', 'Logics', 'Nival/Torero', and 'Prompt'; smooth-stalked meadow grass 'SR2100', '340/40296', and rough-stalked meadow grass

'Sabrena 1' showed values lower than or equal to 5, significantly different from the highest recorded values (Table 3).

Table 2. Cumulated monthly height (cm) and cumulated height over six months (cm) from October 2022 to March 2023 (average across 4 replications).

Species	Cultivar	Oct	Nov	Dec	Jan	Feb	Mar	Cumulative 6 Months
					(cm)			
Diploid annual ryegrass	Axcella	12.6	8.2	4.5	7.3	5.2	6.7	44.4
Diploid annual ryegrass	Grazer nova	22.1	11.7	5.9	8.9	6.7	8.0	63.3
Diploid annual ryegrass	Magloire	24.0	14.7	6.8	7.7	6.1	11.8	71.1
Diploid annual ryegrass	Quickston	11.6	9.8	4.7	5.3	5.0	6.9	43.1
Diploid annual ryegrass	Surrey nova	20.3	10.0	4.9	5.8	5.2	8.7	54.8
Diploid Italian ryegrass	Itaka	21.4	16.0	6.6	9.4	5.2	8.6	67.1
Diploid perennial ryegrass	Aspire	10.1	8.5	2.6	3.7	3.2	4.7	32.8
Diploid perennial ryegrass	Bandalore	10.5	8.7	4.4	4.3	2.9	3.8	34.6
Diploid perennial ryegrass	Centurion	13.6	10.8	4.7	6.8	3.8	4.8	44.6
Diploid perennial ryegrass	Mercitwo	13.7	9.9	5.6	5.8	4.8	6.2	46.1
Hybrid ryegrass	Transist 2600	17.5	11.0	5.1	7.5	5.3	6.4	53.0
Tetraploid annual ryegrass	Jivet	23.9	14.8	5.7	8.6	7.8	10.3	71.0
Tetraploid annual ryegrass	Logics	26.3	13.5	5.6	8.5	7.6	11.4	73.0
Tetraploid annual ryegrass	Nival/Torero	24.3	13.6	6.1	9.8	8.4	13.5	75.7
Tetraploid annual ryegrass	Prompt	22.0	12.5	5.4	7.0	6.0	9.7	62.5
Tetraploid annual ryegrass	N°1 22411/12	13.8	9.9	4.2	6.0	4.6	7.2	45.7
Tetraploid annual ryegrass	N°2 22413/14	15.5	10.2	4.9	4.9	5.3	7.0	47.9
Tetraploid annual ryegrass	N°3 22415/16	15.0	10.5	4.2	7.0	6.4	8.1	51.1
Tetraploid annual ryegrass	N°4 22417/18	15.7	10.6	5.4	8.2	5.6	6.1	51.6
Tetraploid perennial ryegrass	Fabian	13.7	10.2	5.7	4.7	4.3	5.9	44.6
Tetraploid perennial ryegrass	Tetradark	13.6	9.9	3.5	4.3	2.9	4.5	38.7
Tetraploid perennial ryegrass	Tetradry	15.3	11.0	4.6	4.3	3.6	4.9	43.8
Tetraploid perennial ryegrass	Tetragreen	12.1	10.0	3.7	3.6	3.3	5.9	38.7
Smooth-stalked meadow grass	SR2100	5.8	2.9	0.3	2.4	0.7	1.2	13.3
Smooth-stalked meadow grass	340/40296	2.8	3.3	1.4	3.5	2.7	4.3	18.0
Rough-stalked meadow grass	Sabrena 1	6.2	4.4	3.9	5.4	5.5	6.5	31.9
Tall fescue	Essential	9.0	6.0	2.6	4.6	2.5	3.5	28.2
Tall fescue	Granditte	11.4	6.1	2.3	4.9	1.7	3.5	29.9
Tall fescue	Turfway	9.2	5.2	2.4	2.8	2.2	3.5	25.2
Bermudagrass (control)		1.8	0.0	0.0	0.0	0.0	0.1	1.9
LSD 0.05		8.3	4.7	2.3	3.4	8.8	4.0	28.3

Means are significantly different at the 0.05 probability level as determined by Fisher's protected LSD.

Table 3. Turf visual color (1–9 scale: 1 = light green; 9 = dark green) from October 2022 to March 2023 (average across 4 replications).

Species	Cultivar	26 Oct	21 Nov	20 Dec	16 Jan	14 Feb	15 Mar	Mean
Diploid annual ryegrass	Axcella	4.3	3.9	4.0	5.6	5.6	6.6	5.0
Diploid annual ryegrass	Grazer nova	3.5	4.0	3.9	6.0	5.6	6.3	4.9
Diploid annual ryegrass	Magloire	3.5	3.6	3.9	5.6	5.6	7.0	4.9
Diploid annual ryegrass	Quickston	5.9	5.0	5.0	6.1	5.6	7.4	5.8
Diploid annual ryegrass	Surrey nova	4.0	4.0	4.9	6.1	5.9	6.8	5.3
Diploid Italian ryegrass	Itaka	3.5	3.9	4.0	6.1	5.9	6.5	5.0
Diploid perennial ryegrass	Aspire	7.5	6.8	6.4	7.1	7.0	8.0	7.1
Diploid perennial ryegrass	Bandalore	7.6	7.4	6.5	7.6	7.4	8.0	7.4
Diploid perennial ryegrass	Centurion	6.8	5.8	6.1	7.3	6.8	7.8	6.7
Diploid perennial ryegrass	Mercitwo	5.1	5.1	5.4	6.5	6.0	7.6	6.0
Hybrid ryegrass	Transist 2600	5.1	5.3	5.8	6.4	6.0	7.0	5.9

Table 3. *Cont.*

Species	Cultivar	26 Oct	21 Nov	20 Dec	16 Jan	14 Feb	15 Mar	Mean
Tetraploid annual ryegrass	Jivet	3.9	3.9	4.8	5.5	5.5	6.8	5.0
Tetraploid annual ryegrass	Logics	3.6	3.9	3.6	5.8	5.3	6.3	4.7
Tetraploid annual ryegrass	Nival/Torero	3.5	3.8	3.6	5.6	5.4	6.6	4.8
Tetraploid annual ryegrass	Prompt	3.8	3.9	4.3	5.6	5.4	6.8	4.9
Tetraploid annual ryegrass	N°1 22411/12	6.8	5.8	5.6	6.8	6.8	7.5	6.5
Tetraploid annual ryegrass	N°2 22413/14	6.6	5.9	5.6	7.0	6.8	7.6	6.6
Tetraploid annual ryegrass	N°3 22415/16	6.5	6.0	6.1	7.6	7.0	7.5	6.8
Tetraploid annual ryegrass	N°4 22417/18	6.5	5.8	5.6	7.3	7.0	7.3	6.6
Tetraploid perennial ryegrass	Fabian	6.1	5.9	5.3	6.5	6.3	7.9	6.3
Tetraploid perennial ryegrass	Tetradark	8.3	7.1	6.1	7.8	7.6	8.0	7.5
Tetraploid perennial ryegrass	Tetradry	6.6	5.9	5.6	6.6	6.4	7.9	6.5
Tetraploid perennial ryegrass	Tetragreen	6.9	6.5	6.0	7.3	6.9	8.0	6.9
Smooth-stalked meadow grass	SR2100	0.0	4.3	5.0	6.3	6.0	7.4	4.8
Smooth-stalked meadow grass	340/40296	0.0	4.6	4.5	5.8	5.6	6.5	4.5
Rough-stalked meadow grass	Sabrena 1	0.0	5.1	4.4	5.8	5.5	7.5	4.7
Tall fescue	Essential	7.3	6.6	5.3	7.1	6.6	7.9	6.8
Tall fescue	Granditte	7.4	7.0	5.5	7.8	7.4	7.9	7.1
Tall fescue	Turfway	7.5	6.9	5.6	7.8	7.1	8.0	7.1
Bermudagrass (control)		5.5	3.8	0.0	0.0	0.0	0.0	1.5
LSD 0.05		3.2	2.2	2.0	2.2	1.5	2.0	2.0

Means are significantly different at the 0.05 probability level as determined by Fisher's protected LSD.

3.3. Turf Visual Quality

Turf visual quality mean higher values have been observed for tetraploid perennial ryegrass 'Tetragreen', tetraploid annual ryegrass 'N°4 22417/18', and diploid perennial ryegrasses 'Aspire' and 'Bandalore' (6.8). In contrast, the lowest significantly different values detected were for 'SR2100' and '340/40296' smooth-stalked meadow grass (4.0 and 4.1, respectively) (Table 4).

Table 4. Turf visual quality (1–9; 1 = poorest; 9 = best) from December 2022 to March 2023 (average across 4 replications).

Species	Cultivar	20 Dec	16 Jan	14 Feb	15 Mar	Mean
Diploid annual ryegrass	Axcella	6.4	6.1	6.8	7.0	6.6
Diploid annual ryegrass	Grazer nova	6.1	4.5	5.5	6.9	5.8
Diploid annual ryegrass	Magloire	6.0	5.3	5.6	7.4	6.1
Diploid annual ryegrass	Quickston	6.4	6.0	6.1	7.3	6.4
Diploid annual ryegrass	Surrey nova	6.5	5.8	6.5	7.3	6.5
Diploid Italian ryegrass	Itaka	6.3	5.8	6.3	6.9	6.3
Diploid perennial ryegrass	Aspire	6.4	6.3	6.4	8.0	6.8
Diploid perennial ryegrass	Bandalore	6.3	6.4	6.8	7.6	6.8
Diploid perennial ryegrass	Centurion	6.4	5.9	6.4	7.8	6.6
Diploid perennial ryegrass	Mercitwo	6.5	5.0	6.0	7.6	6.3
Hybrid ryegrass	Transist 2600	6.3	5.6	5.9	7.3	6.3
Tetraploid annual ryegrass	Jivet	6.0	4.4	4.9	7.3	5.6
Tetraploid annual ryegrass	Logics	5.6	4.6	5.0	6.6	5.5
Tetraploid annual ryegrass	Nival/Torero	5.4	4.0	4.6	7.1	5.3
Tetraploid annual ryegrass	Prompt	6.0	4.5	5.4	7.3	5.8
Tetraploid annual ryegrass	N°1 22411/12	6.1	6.0	6.3	7.6	6.5
Tetraploid annual ryegrass	N°2 22413/14	6.3	6.1	6.4	7.4	6.5
Tetraploid annual ryegrass	N°3 22415/16	6.4	5.6	6.4	7.5	6.5
Tetraploid annual ryegrass	N°4 22417/18	6.6	6.4	6.6	7.6	6.8

Table 4. *Cont.*

Species	Cultivar	20 Dec	16 Jan	14 Feb	15 Mar	Mean
Tetraploid perennial ryegrass	Fabian	6.4	5.6	5.8	7.8	6.4
Tetraploid perennial ryegrass	Tetradark	5.6	6.0	5.8	7.3	6.2
Tetraploid perennial ryegrass	Tetradry	6.1	5.5	5.6	7.8	6.3
Tetraploid perennial ryegrass	Tetragreen	6.1	6.5	6.9	7.6	6.8
Smooth-stalked meadow grass	SR2100	2.8	4.0	3.9	5.4	4.0
Smooth-stalked meadow grass	340/40296	3.3	3.6	3.6	6.0	4.1
Rough-stalked meadow grass	Sabrena 1	5.8	5.4	6.1	7.3	6.1
Tall fescue	Essential	5.8	5.9	5.9	7.6	6.3
Tall fescue	Granditte	5.4	5.6	5.6	7.6	6.1
Tall fescue	Turfway	4.8	5.5	5.5	7.4	5.8
Bermudagrass (control)		0.0	0.0	0.0	0.0	0.0
LSD 0.05		1.9	1.8	1.9	1.9	1.8

Means are significantly different at the 0.05 probability level as determined by Fisher's protected LSD.

3.4. Ground Visual Cover

Regarding ground cover and spring transition, the effect of scalping carried out on 4 April was not decisive in encouraging spring transition. As demonstrated in Figure 5, in April temperatures were not optimal to stimulate the complete transition of the bermudagrass; such low average temperatures stimulated the recovery of the cool-season species after scalping (Table 5). Bermudagrass green-up started in March 2023 (21 March 2023: 19% of bermudagrass on control plots). Scalping at 10 mm on half plot was carried out on 4 April 2023. Bermudagrass recovery was assessed starting from 16 May. No significant difference was observed between scalped and non-scalped subplots; therefore, the bermudagrass ground cover percentage is reported as an average value. Assessments were performed until ground cover was assumed complete (>95%) for some of the cultivars.

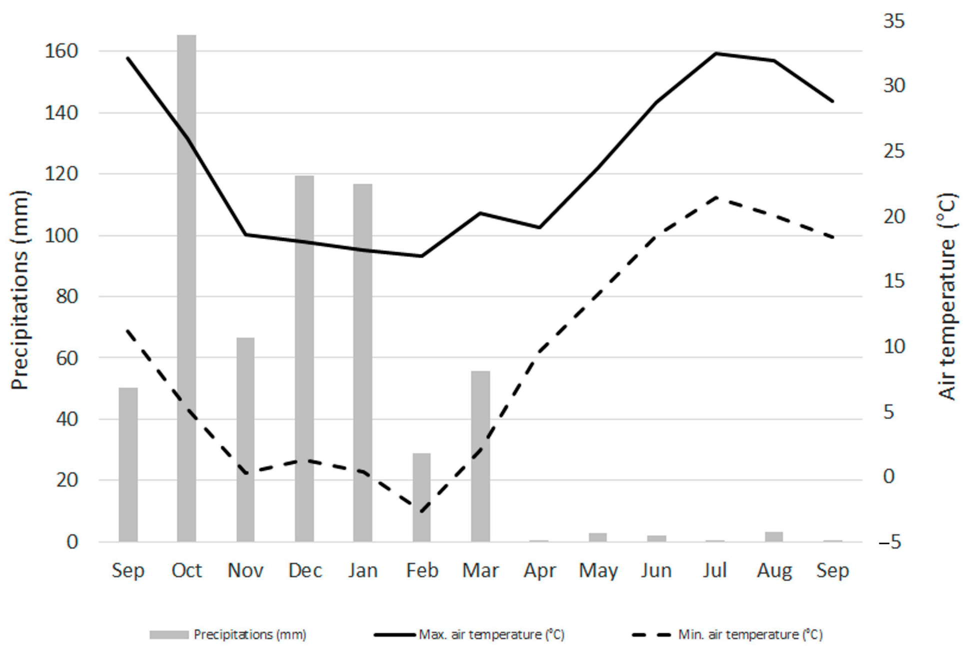

Figure 5. Monthly mean maximum and minimum air temperatures and monthly rainfall of the study period (September 2022-September 2023) at the sod farm in Pisa (Italy).

Table 5. Ground visual cover (%) from December 2022 through July 2023. expressed monthly as the percentage of ground covered by the overseeded species and by bermudagrass (%) (average across 4 replications).

Species	Cultivar	*Overseeded* sp. (%)			Bermudagrass (%)			
		20 Dec	16 Jan	17 Apr	16 May	30 May	13 Jun	11 Jul
Diploid annual ryegrass	Axcella	79	100	79	44	54	66	98
Diploid annual ryegrass	Grazer nova	74	100	68	61	68	75	91
Diploid annual ryegrass	Magloire	73	99	64	54	63	69	89
Diploid annual ryegrass	Quickston	78	100	84	40	45	51	99
Diploid annual ryegrass	Surrey nova	76	100	61	48	56	63	99
Diploid Italian ryegrass	Itaka	78	100	76	44	51	58	91
Diploid perennial ryegrass	Aspire	70	98	91	24	38	45	83
Diploid perennial ryegrass	Bandalore	70	100	90	23	39	48	89
Diploid perennial ryegrass	Centurion	76	100	86	21	30	41	76
Diploid perennial ryegrass	Mercitwo	78	98	91	33	40	46	88
Hybrid ryegrass	Transist2600	75	100	83	48	53	59	99
Tetraploid annual ryegrass	Jivet	70	99	59	66	74	79	98
Tetraploid annual ryegrass	Logics	70	98	49	74	79	84	95
Tetraploid annual ryegrass	Nival/Torero	68	98	55	79	84	90	96
Tetraploid annual ryegrass	Prompt	69	99	79	41	49	58	94
Tetraploid annual ryegrass	N°1 22411/12	68	99	75	69	73	83	98
Tetraploid annual ryegrass	N°2 22413/14	69	96	64	60	68	75	99
Tetraploid annual ryegrass	N°3 22415/16	76	100	78	58	65	75	96
Tetraploid annual ryegrass	N°4 22417/18	75	100	74	58	66	76	98
Tetraploid perennial ryegrass	Fabian	70	94	91	16	30	39	79
Tetraploid perennial ryegrass	Tetradark	65	85	84	26	36	44	70
Tetraploid perennial ryegrass	Tetradry	69	98	88	29	39	46	84
Tetraploid perennial ryegrass	Tetragreen	74	98	90	23	35	41	79
Smooth-stalked meadow grass	SR2100	25	66	44	63	75	83	94
Smooth-stalked meadow grass	340/40296	31	65	74	51	60	74	89
Rough-stalked meadow grass	Sabrena 1	59	100	58	44	58	69	86
Tall fescue	Essential	70	91	93	26	35	40	65
Tall fescue	Granditte	71	95	91	20	30	41	73
Tall fescue	Turfway	66	88	73	23	35	54	70
Bermudagrass (control)		-	-	83	95	100	100	100
LSD 0.05		24	25	24	12	11	11	13

Means are significantly different at the 0.05 probability level as determined by Fisher's protected LSD.

On 11 July 2023, assessment bermudagrass reached complete recovery in most of the cool-season entries. Specifically, as shown in Table 5, bermudagrass showed the best spring recovery when overseeded with diploid and tetraploid annual ryegrass varieties, showing an average ground cover percentage of 94.5% in association with diploid and 96.8% with tetraploid annual ryegrasses. In contrast, tetraploid perennial ryegrasses, rough-stalked meadow grass, and tall fescue entries appeared as the most competitive during the warm period, together with 'Aspire' and 'Centurion' among the diploid perennial ryegrasses.

3.5. Cleanness of Cut (CoC)

Among CoC, significant differences were only observed in April (Figure 4). The best result of CoC has been measured for rough-stalked meadow grass 'Sabrena 1' and tall fescue 'Turfway' with 0.9 mm. In contrast, the worst recorded values of CoC of cut have been observed for diploid annual ryegrass 'Axcella' (5.7), forage 'Magloire' (5.0), hybrid ryegrass 'Transist 2600' (4.9), and forage tetraploid annual ryegrass 'Nival/Torero' (4.9) and 'N°4 22417/18' (4.8) (Table 6).

Table 6. Cleanness of Cut (CoC) measured after autonomous mower (AM) cutting at 25 mm: measurements on 10 randomly collected leaves per plot and reported in mm (0–1 mm excellent, 1–3 mm acceptable, >3 mm unacceptable cleanness of cut) (average across 4 replications). Autonomous mowing started on 25 January 2023 and CoC evaluations have been carried out on February, March, and April 2023.

Species	Cultivar	22 Feb	22 Mar	18 Apr
		(mm)		
Diploid annual ryegrass	Axcella	1.0	1.1	5.7
Diploid annual ryegrass	Grazer nova	0.7	0.8	3.2
Diploid annual ryegrass	Magloire	0.6	0.8	5.0
Diploid annual ryegrass	Quickston	0.6	0.7	3.4
Diploid annual ryegrass	Surrey nova	0.6	0.8	4.6
Diploid Italian ryegrass	Itaka	0.6	0.7	4.1
Diploid perennial ryegrass	Aspire	0.6	0.8	1.1
Diploid perennial ryegrass	Bandalore	0.6	0.6	1.1
Diploid perennial ryegrass	Centurion	0.7	0.9	2.1
Diploid perennial ryegrass	Mercitwo	0.9	1.1	1.1
Hybrid ryegrass	Transist 2600	0.6	0.8	4.9
Tetraploid annual ryegrass	Jivet	0.8	0.9	3.0
Tetraploid annual ryegrass	Logics	0.5	0.7	4.1
Tetraploid annual ryegrass	Nival/Torero	0.5	0.7	4.9
Tetraploid annual ryegrass	Prompt	1.0	1.1	4.4
Tetraploid annual ryegrass	N°1 22411/12	0.7	0.9	2.2
Tetraploid annual ryegrass	N°2 22413/14	0.6	0.8	2.8
Tetraploid annual ryegrass	N°3 22415/16	0.6	0.7	4.1
Tetraploid annual ryegrass	N°4 22417/18	0.8	0.9	4.8
Tetraploid perennial ryegrass	Fabian	0.9	1.1	2.4
Tetraploid perennial ryegrass	Tetradark	0.5	0.7	1.4
Tetraploid perennial ryegrass	Tetradry	0.7	0.8	1.5
Tetraploid perennial ryegrass	Tetragreen	0.7	0.8	1.5
Smooth-stalked meadow grass	SR2100	0.8	0.9	1.4
Smooth-stalked meadow grass	340/40296	0.6	0.8	1.0
Rough-stalked meadow grass	Sabrena 1	0.7	0.8	0.9
Tall fescue	Essential	0.9	1.0	1.2
Tall fescue	Granditte	0.8	0.9	1.2
Tall fescue	Turfway	0.7	0.9	0.9
LSD 0.05		ns	ns	1.0

Means are significantly different at the 0.05 probability level as determined by Fisher's protected LSD. ns not significant at the 0.05 level of probability.

4. Discussion and Conclusions

The results of the present research show that annual ryegrass is suitable for use as temporary overseeded winter turf when bermudagrass turfgrass is established as a permanent lawn. Annual ryegrass seeds germinate rapidly and withstand relatively low winter mowing heights, and their vigorous winter growth facilitates the repair of damaged areas. Forage species showed a quicker and higher cumulative growth compared to the turf species, which resulted in a quicker establishment during autumn. Furthermore, forage species showed low competition with the warm-season grass during the spring transition. However, forage species showed a lighter green color. As demonstrated by Grossi et al., 2019 [13], autumn overseeding also allows effective weed control on dormant warm-seasons during winter, making the football field playable and always green with vigorous plants.

According to all the measured parameters during this trial, as also demonstrated by Grossi et al., 2019 [13], smooth-stalked meadow grasses have shown the worst performance when overseeded on bermudagrass ('Tifway') recording the lowest values.

As with many other factors, objective measurement of cutting quality might be a useful tool for researchers, cutting equipment developers, and the turfgrass genetic enhancement sector. The significance is highlighted further by the ongoing expansion of the market for autonomous mowers, which necessitate different cutting apparatus designs as compared to regular mowing machines.

Cleanness of cut results showed how the innovative method used in this trial is able to objectively detect values sufficiently accurate and representative of the actual cutting quality. Moreover, the new method has proven to be advantageous because it offers the possibility of collecting samples in situ without causing damage to the turf.

The results obtained from this research have shown that among all variables affecting the cleanness of cut, other than the sharpness of the blade itself, the species, the cultivar within the same species, and the period in which the mowing event is performed are of greatest interest. Specifically, as shown in Table 6, mowing the same species and cultivars in different periods led to different cleanness of cut results (significant differences in CoC values were observed only in April 2023). Moreover, the results obtained suggested that different cleanness of cut results can be obtained when mowing different cultivars of the same species, particularly regarding diploid and tetraploid annual ryegrasses.

Autonomous mowers may represent an innovative approach in sports field mowing management. As observed in this research, although autonomous mowers are equipped with a rotative mowing apparatus, they can still provide an excellent cleanness of cut which is comparable to the one provided by conventional mowers equipped with a reel mowing apparatus. Based on the results obtained from this trial, the authors believe that further studies should be carried out more accurately on different turfgrass species and varieties, taking into account different seasonal periods and extending the trial duration.

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References

1. Taliaferro, C.M.; McMaugh, P. Development in warm-season turfgrass breeding/genetics. *Int. Turfgrass Soc. Res. J.* **1993**, *7*, 14–26.
2. Volterrani, M.; Grossi, N.; Pardini, G.; Miele, S.; Gaetani, M.; Magni, S. Warm season turfgrass adaptation in Italy. *Int. Turfgrass Soc. Res. J.* **1997**, *8*, 1344–1354.
3. Magni, S.; Gaetani, M.; Grossi, N.; Caturegli, L.; La Bella, S.; Leto, C.; Virga, G.; Tuttolomondo, T.; Lulli, F.; Volterrani, M. Bermudagrass adaptation in the Mediterranean climate: Phenotypic traits of 44 accessions. *Adv. Hort. Sci.* **2014**, *28*, 29–34.
4. Fontanier, C.; Steinke, K. Performance of Annual and Perennial Ryegrass Mixtures for Winter Overseeding into Three Warm-Season Turfgrass Species. *Int. Turfgrass Soc. Res. J.* **2017**, *13*, 305–311. [CrossRef]
5. Carrow, R.N.; Duncan, R.R. Salt-affected turfgrass sites. In *Assessment and Management*; Ann Arbor Press: Ann Arbor, MI, USA, 1988.
6. Harivandi, M.A. *Effluent Water for Turfgrass Irrigation*; University of California Cooperative Extension Leaflet 21500; Division of Agriculture and Natural Resources: Oakland, CA, USA, 1991.
7. Gullino, M.L.; Mocioni, M.; Zanin, G.; Alma, A. *La Difesa dei Tappeti Erbosi*; Ed. L'Informatore Agrario s.r.l.: Verona, Italy, 2000.
8. Magni, S.; Gaetani, M.; Caturegli, L.; Leto, C.; Tuttolomondo, T.; La Bella, S.; Virga, G.; Ntoulas, N.; Volterrani, M. Phenotypic traits and establishment speed of forty four turf bermudagrass accessions. *Acta Agric. Scand.* **2014**, *64*, 722–733.
9. Richardson, M.D. Morphology, turf quality, and heat tolerance of intermediate ryegrass. *HortScience* **2004**, *39*, 170–173. [CrossRef]
10. Serensits, T.; Cutulle, M.; Jeffrey, J.F. Persistence of overseeded cool-season grasses in Bermudagrass Turf. *Int. J. Agron.* **2011**, *2011*, 496892. [CrossRef]
11. Dunn, J.H.; Minner, D.D.; Fresenburg, B.F.; Bughrara, S.S. Bermudagrass and cool season turfgrass mixtures: Response to simulated traffic. *Agron. J.* **1994**, *86*, 10–16. [CrossRef]

12. Volterrani, M.; Magni, S. Bermudagrass autumn overseeding with annual ryegrass. In Proceedings of the I International Conference on Turfgrass Management and Science for Sports Fields, Athens, Greece, 2–7 June 2003; 661; pp. 353–356.
13. Grossi, N.; Fontanelli, M.; Frasconi, C.; Martelloni, L.; Raffaelli, M.; Peruzzi, A.; Gaetani, M.; Magni, S.; Caturegli, L.; Volterrani, M.; et al. Effects of close cutting on ground cover and quality of a polystand of Manilagrass and cool season turfgrasses. *Ital. J. Agron.* **2019**, *14*, 59–65. [CrossRef]
14. Yelverton, F. Spring transition: Going, going, gone: Removal of overseeded perennial ryegrass from bermudagrass is a must. *USGA Green Sect. Rec.* **2005**, *43*, 22–23.
15. Peppers, J.M.; Mittlesteadt, T.L.; Askew, S.D. Effects of perennial ryegrass competition on bermudagrass and hybrid bermudagrass cover, biomass, and total nonstructural carbohydrate accumulation. *Crop Sci.* **2021**, *61*, 3179–3186. [CrossRef]
16. Green, R.L.; Klein, G.J.; Merino, F.; Gibeault, V. Influence of fall-applied treatments on spring transition of a bermudagrass green. *Hortic. Sci.* **2004**, *39*, 424–428.
17. Horgan, B.P.; Yelverton, F.H. Removal of perennial ryegrass from overseeded bermudagrass using cultural methods. *Crop Sci.* **2001**, *41*, 118–126. [CrossRef]
18. Johnson, B.J. Transition from overseeded cool-season to warm-season grass with pronamide. *Weed Sci.* **1975**, *24*, 309–311. [CrossRef]
19. Mazur, A.R.; Rice, J.S. Impact of overseeding bermudagrass with various amounts of perennial ryegrass for winter putting turf. *HortScience* **1999**, *34*, 864–870. [CrossRef]
20. Kopec, D.; Umeda, K. Overseeding Winter Grasses into Bermudagrass Turf. The University of Arizona Cooperative Extension. az1683, 2p. 2015. Available online: https://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1683-2015.pdf (accessed on 20 April 2024).
21. McCarty, L. *Golf Turf Management*; CRC Press: Boca Raton, FL, USA, 2018.
22. Grossi, N.; Fontanelli, M.; Garramone, E.; Peruzzi, A.; Raffaelli, M.; Pirchio, M.; Martelloni, L.; Frasconi, C.; Caturegli, L.; Gaetani, M.; et al. Autonomous mower saves energy and improves quality of tall fescue lawn. *HortTechnology* **2016**, *26*, 825–830. [CrossRef]
23. Pirchio, M.; Fontanelli, M.; Frasconi, C.; Martelloni, L.; Raffaelli, M.; Peruzzi, A.; Caturegli, L.; Gaetani, M.; Magni, S.; Volterrani, M.; et al. Autonomous rotary mower versus ordinary reel mower—Effects of cutting height and nitrogen rate on Manila grass turf quality. *HortTechnology* **2018**, *28*, 509–515. [CrossRef]
24. Pirchio, M.; Fontanelli, M.; Frasconi, C.; Martelloni, L.; Raffaelli, M.; Peruzzi, A.; Gaetani, M.; Magni, S.; Caturegli, L.; Volterrani, M.; et al. Autonomous mower vs. rotary mower: Effects on turf quality and weed control in tall fescue lawn. *Agronomy* **2018**, *8*, 15. [CrossRef]
25. BSPB Turfgrass Seed 2022—The Buyers Guide to Quality Amenity Turfgrasses. Available online: https://www.manualzz.com (accessed on 20 April 2024).
26. Christians, N.E.; Patton, A.J.; Law, Q.D. *Fundamentals of Turfgrass Management*; John Wiley & Sons: Hoboken, NJ, USA, 2017.
27. Gibeault, V.A.; Hanson, D. Perennial ryegrass mowing quality and appearance response to three nitrogen regimes. In *Proceedings of the Third International Turfgrass Research Conference*; American Society of Agronomy, Crop Science Society of America, Soil Science Society of America: Madison, WI, USA, 1980; pp. 39–43.
28. Karcher, D.E.; Richardson, M.D. Quantifying turfgrass color using digital image analysis. *Crop Sci.* **2003**, *43*, 943–951. [CrossRef]
29. Horst, G.L.; Engelke, M.C.; Meyers, W. Assessment of visual evaluation techniques. *Agron. J.* **1984**, *76*, 619–622. [CrossRef]
30. Morris, K.N.; Shearman, R.C. NTEP Turfgrass Evaluation Guidelines. In Proceedings of the NTEP Turfgrass Evaluation Workshop, Beltsville, MD, USA, 1998; pp. 1–5. Available online: https://www.ntep.org/pdf/ratings.pdf (accessed on 20 April 2024).