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Response of Perennial Ryegrass/Kentucky Bluegrass Mixture to Mulching Mower Under Different Nitrogen Fertilisation Levels

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ABSTRACT

Mowing is a fundamental turfgrass management practice where grass clippings are either removed or returned to the canopy. The process of clipping return is referred to as mulching, which can create several advantages for low-maintenance/sustainable turfgrass systems. The objective of this research was to evaluate the effect of mulching on a perennial ryegrass (*Lolium perenne* L.) and Kentucky bluegrass (*Poa pratensis* L.) turfgrass mixture under four different nitrogen fertility rates (0, 80, 120, and 200 kg N ha⁻¹ year⁻¹). Turfgrass quality and colour, as well as NDVI and percent green turfgrass cover, were evaluated bi-weekly. Turfgrass canopy height was measured before and after mowing in order to determine clipping dry matter (DM) production and clipping nitrogen (N) content. Mulching had a positive effect on turfgrass visual quality and colour, NDVI, and percent green turfgrass cover. The impact of mulching was more noticeable during reduced growth periods (summer and winter). The largest differences occurred in July 2023, when turfgrass visual quality for mulching and non-mulching was 7 and 4.5, respectively. In January 2023, turfgrass colour, NDVI, and percent turfgrass cover was 7.1 and 6.1, 0.8 and 0.72, and 60% and 50% for mulching and non-mulching, respectively. The N content observed within turfgrass clippings from mulched plots was enhanced by the increase of N fertilisation rates. The difference between mulched and non-mulched plots receiving 200 kg N ha⁻¹ year⁻¹ was 2.5 kg N m⁻², while the difference between non-fertilised mulched and non-mulched plots was 2.2 kg N m⁻². Mulching helps maintain turfgrass quality year-round, especially in winter, with greater benefits under low nitrogen input. It supports reduced fertilisation without affecting performance.

1 | Introduction

Mowing is one of the most common and energy-intensive practices conducted by turfgrass managers. The periodic removal of leaf tissue through mowing is conducted in order to maintain both turfgrass aesthetics and to provide functional, uniform playing surfaces. Tolerant turfgrass species compensate for tissue loss by increasing canopy density below the mowing height (Sheffer et al. 1978, Macolino et al. 2014). However, mowing is

often a stress, causing several negative impacts including temporary root growth cessation, a reduction in photosynthesis and associated carbohydrate production, increased disease potential and water loss from cut leaf ends, and a decrease in water absorption due to root reduction (Fry and Huang 2004; Howieson and Christians 2008). Therefore, certain mowing practices and equipment are often employed to try and reduce some of these effects while simultaneously increasing the sustainability of managed turfgrass systems.

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Mulching lawn mowers are equipped with special blades and a deck design that increase the suspension of grass clippings so they are cut into tiny particles (McLane 1992). It is speculated that smaller pieces allow the clippings to move through the turfgrass canopy, eventually coming into contact with the soil surface below (Pornaro et al. 2022). However, Miller et al. (2019) did not observe a reduction in clipping size when comparing mulching and traditional side-discharge mowers. Collecting clippings can help avoid the formation of unappealing clumps, which often occur when mowing wet or overgrown turf (Law et al. 2016). Collected clippings piled on roadsides may also contribute to eutrophication during runoff events while local landfills are often overwhelmed with bagged clipping deposits (Grégoire et al. 2022). Furthermore, many turfgrass systems experience long-term acidification without the continuous return of alkaline leaf tissue to the soil (Tang et al. 2013).

Turfgrass clippings often contain significant amounts of mineralisable nitrogen (N) (Miltner et al. 1996; Starr and DeRoo 1981). Therefore, mulching can result in numerous environmental impacts. Increased surface area from smaller clipping size can enhance decomposition rates and may result in the release of plant-available nutrients and the addition of organic matter to the soil (Grégoire et al. 2022; Grubbs et al. 2021; Knot et al. 2017). Law et al. (2017) observed a 3.3% increase in total soil carbon (C) and a 4.6% increase in total soil N when clippings were returned compared to when they were removed from Kentucky bluegrass (*Poa pratensis* L.) and tall fescue [*Schedonorus arundinaceum* (Schreb.) Dumort.]. However, clipping management did not affect soil organic matter accumulation (Law et al. 2017). Mulching has also been correlated to an increase in turfgrass growth and quality (Grégoire et al. 2022; Murray and Juska 1977; Schiavon et al. 2021). Although Law et al. (2021) reported that grass clipping management had a negligible impact on greenhouse gas fluxes in both cool- and warm-season turfgrasses, Li et al. (2013) observed an increase in nitrous oxide (N₂O) production under aerobic conditions. Even though clippings are often collected during seed set to reduce the spread of problematic weeds, several investigators have reported long-term reductions in weed pressure when clippings are recycled (Busey 2003). This may be attributed to improvements in soil nutrient content and a subsequent increase in turfgrass competition.

It has been demonstrated that returning clippings to the canopy reduces overall fertility requirements (Grégoire et al. 2022); however, reports on the exact contribution to turfgrass fertilisation can differ greatly and often vary with environment, turfgrass species, and soil type. Starr and DeRoo (1981) estimated that grass clippings from a Kentucky bluegrass/perennial ryegrass (*Lolium perenne* L.) lawn contained about 40 kg ha⁻¹ year⁻¹ of mineralisable N, which was approximately 20% of applied N during the trial. According to Miltner et al. (1996), 35% of N applied through fertiliser was recovered in Kentucky bluegrass clippings during a two-year period. Both Kopp and Guillard (2002) and Heckman et al. (2000) asserted that it was possible to reduce N fertilisation by up to 50% without any significant reduction in turfgrass quality. The historical variability observed with respect to nutrient return warrants further investigation into the amount of supplemental fertility required to maintain turfgrass growth and quality. Therefore, the objective of our research was to examine the effect of mulching/clipping return on a perennial

ryegrass/Kentucky bluegrass mixture managed under different N fertility rates.

2 | Materials and Methods

A field study was conducted at the Experimental Agricultural Farm at the University of Padua in Legnaro, Italy (45°20' N, 11°57' E, 8 m a.s.l.) from April 2022 to March 2024. This region is classified as humid subtropical with a mean annual temperature of 12.3°C and annual rainfall of 820 mm (mostly distributed from April to November) (ARPAV 2021). Monthly precipitation and air temperatures during the study period are reported in Table 1. The soil at the site was a coarse-silty, mixed, mesic, Oxyaquic Eutrupept (Morari 2006) containing 14% clay, 69% silt, and 17% sand, with a pH of 8.1, organic matter content of 2.4%, a C-to-N ratio of 12.2, an Olsen P content of 29 mg kg⁻¹, and an exchangeable K content of 140 mg kg⁻¹.

A mixture of perennial ryegrass ('Adagio' and 'Boker' comprising 50% and 40% of the seed weight, respectively) and Kentucky bluegrass ('Baronial' comprising 10% of the seed weight) cultivars was seeded on 11 September 2021 at a rate of 25 g m⁻². Starter fertiliser (8 N—24 P₂O₅—24 K₂O) (Adriatica SpA—Loreo RO, Italy) was applied at seeding with a rotary spreader at a rate of 50 kg N ha⁻¹. Irrigation was provided through a sprinkler system that applied approximately 0.5 cm of water every other day for 3 weeks until plots were fully established. During summer (June to August), irrigation was provided weekly at 80% reference evapotranspiration (ET) estimated with an ET gauge (Spectrum Technologies Inc., Aurora, IL 60504, USA). Grass weeds were manually removed, while spring broadleaf weeds were controlled using the selective herbicide Joker (21.2% dicamba) at 1 L ha⁻¹ (Joker, Chimiberg SpA—Caravaggio BG, Italy) applied twice from March to May. A single verticutting was performed in April of each experimental year to prevent excessive thatch formation using a Toro To-54610 (The Toro Company, Bloomington, MN 55420, USA).

Plots were mowed at a 5.5 cm height using an electric rotary mower (STIGA COMBI950SQ AE) with clippings removed until plots were fully established. From April 2022 (full establishment), two mowing treatments (with and without clipping return) and four N fertilisation levels (0, 80, 120, and 200 kg N ha⁻¹ year⁻¹) were compared in a split-plot design with three replications. Main plots (4.0 m × 10.5 m) consisted of mowing treatments while sub-plots (4.0 m × 3.5 m) were N fertility rates. Plots were mowed at a 5.5 cm height using the same electric mower, and clippings were either removed (non-mulched plots) or returned to the canopy (mulched plots). Plots were mowed weekly during spring (March to June) and autumn (September to November) and every 2 weeks during summer (July to August) when high temperatures (Table 1) caused a reduction in growth.

The evaluated fertility levels consisted of 0, 80, 120, and 200 kg N ha⁻¹ year⁻¹ (reference N amount), which represent 0%, 40%, 60%, and 100% of the reference amount. The 200 kg N ha⁻¹ year⁻¹ treatment is the ideal N rate for achieving optimal perennial ryegrass performance in this study location (Pornaro et al. 2024); however, this rate is slightly higher than that recommended for Kentucky bluegrass (Fiorio et al. 2012).

TABLE 1 | Monthly mean air temperature and precipitation during the study period and long-term averages (1994–2020) at the Experimental Agricultural Farm at the University of Padua in Legnaro, Italy.

Month	Air temperature (°C)				Precipitation (mm)			
	2022	2023	2024	1994–2020	2022	2023	2024	1994–2020
January	3	6.2	3.6	3.2	20.4	57.8	58	42.5
February	6.2	5.3	9.5	4.9	10.2	0	110.2	50.9
March	8.2	10.4	11.1	9	13.8	26.8	99.6	56.7
April	12	12.3	14.2	13.,2	39.8	77.4	52.0	73.3
May	20	18	—	18	32.8	169.2	—	88.5
June	24.5	23	—	22	11	30	—	73.4
July	26.2	25.1	—	23.9	42.2	100	—	71.9
August	24.6	24.2	—	23.4	105.4	75.4	—	64.7
September	19.3	21.7	—	18.9	94	33.8	—	80.8
October	16.8	17	—	14	6.4	83.2	—	84.2
November	10.2	8.4	—	8.9	189.8	73.8	—	89.3
December	6.5	5.2	—	4.1	57.8	34	—	60.7
Year	14.9	14.8	—	13.7	623.6	761.4	—	836.9

The annual N amount was distributed using urea (46% N) and split into four applications: March (30%), May (20%), September (30%) and December (20%).

Turfgrass quality and colour were visually evaluated every 2 weeks starting in May 2022 in accordance with the rating scale proposed by Krans and Morris (2007). Evaluations range from 1 (worst) to 9 (best), with 6 being the minimum acceptable level. Normalised difference vegetation index (NDVI) was measured using a CS45 RapidScan (Holland Scientific Inc., Lincoln, NE 68516, USA) to further assess the relative greenness of the leaf canopy. Volumetric water content (%VWC) was recorded using a POGO Turf Pro (Stevens Water Monitoring Systems Inc. Portland, OR 97220, USA) equipped with 5.6 cm length metal rods (three measurements per plot), and % green turfgrass cover was determined using digital image analysis in accordance with Richardson et al. (2001). All of these measurements were taken every 2 weeks. Digital images were captured using a digital camera (Canon Powershot G12, Tokyo, Japan) in JPEG (joint photographic experts group) format with an image resolution of 2736 × 3648 pixels. Proper exposure was supplied by selecting an aperture of f/4.0. The camera was mounted to the top of a light box (50 × 55 × 60 cm) internally equipped with four incandescent light bulbs (550 lm; TCP Inc., Aurora, OH 44202, USA) to provide a consistent light source. Digital images were analysed and processed using SigmaScan Pro software (SPSS Inc., Chicago, IL 60606, USA). In March and November of each year, turfgrass canopy height was measured in each plot before weekly mowing using a modified plate metre (mod. EC10; Grasstec Ltd., United Kingdom) (Pornaro et al. 2022) and clippings were collected from a 0.5 × 3.5 m area using the electric rotary mower. Clippings were oven-dried at 65°C for 48 h to estimate daily dry matter (DM) production and to determine total N content (Total Kjeldahl Nitrogen). Before each fertility application, clippings were also collected from each plot, using the

same previously mentioned mower and covering the same area (0.5 × 3.5 m). Clippings were subsequently oven-dried at 65°C for 48 h to determine total N content by the Kjeldahl method. From April to November 2023, turfgrass canopy height was measured in each plot before weekly mowing using the same modified plate metre, and clippings were collected from a 0.5 × 3.5 m plot area and drying oven as previously described to estimate DM and total N content. Clipping DM production and vertical turfgrass growth during mowing intervals were used to calculate the canopy density as the ratio between clipping production and the volume given by the plot surface and the turfgrass canopy height. Densities were averaged over each month from April to November. The N content and clipping DM production from March to November 2023 were utilised to calculate the total N of each plot.

As reported by Pornaro et al. (2018), the daily growing curve of the turfgrass canopy can be described by two curves using the Gaussian equation. Gaussian models in Equation (1) were applied to fit the observed daily DM yields of two growing periods separately in order to obtain daily DM yield production curves from March to July 2023 and from July to November 2023.

$$f(x) = a * e^{-(b-x)^2/c^2} \quad (1)$$

where $f(x)$ is daily DM yield and x is day of the year (DOY). The curve parameters a , b and c have biological interpretations and are used to describe the fitted curves where a is the peak of the curve, b is the DOY in which the maximum DM yield occurred and c is the curve amplitude (Pornaro et al. 2018).

Analysis of variance (ANOVA) was performed using a linear mixed effects model to test the effects of N fertility rate, mulching, sampling date, and their interactions on the measured parameters (turfgrass quality, turfgrass colour, NDVI, % green turfgrass

cover, soil moisture, clipping DM production, clipping N content and turfgrass canopy height) collected during the duration of the experimental period (April 2022 to March 2024). Additional ANOVAs were performed using a linear mixed effects model to test the effects of N fertility rate, mulching, sampling date, and their interactions on canopy density and clipping N content data collected from April 2023 to March 2024. Finally, ANOVAs were conducted using a linear mixed effects model to test the effects of N fertility rate, mulching, and their interactions on the Gaussian curve parameters (*a*, *b* and *c*) of DM clipping production from March 2023 to July 2023. The blocks within sampling date and the main plots within blocks were included as random effects to account for the clustering of observations. An LSD test with Bonferroni correction at a probability of $\alpha=0.05$ was used to identify significant differences among means. All statistical analyses were performed in R version 4.3.2 (R core team 2023).

3 | Results

All investigated parameters, except soil moisture, were affected by the interactions between sampling date and N fertility level and between sampling date and mulching (Table 2). Turfgrass colour was also significantly affected by the interaction between treatment and mulching, while turfgrass canopy height was not affected by the interaction between sampling date and N fertility rate. All single effects significantly impacted the investigated parameters, except for soil moisture, which was not affected by mulching.

Turfgrass performance: From April to October of the first year, no significant differences were observed between the two mulching treatments (Figure 1A). Starting in November 2022, the effect of mulching resulted in greater turfgrass quality than the non-mulched plots. During winter 2023, summer 2023, and winter 2024, this difference increased, with turfgrass quality ratings of non-mulched plots decreasing below sufficiency while the mulched plot ratings were close to 7. All N fertility rates displayed a similar trend during spring,

summer, and fall of 2022. However, starting in November 2022, a drop in turfgrass quality was observed for plots receiving no fertilisation, subsequently reaching insufficient turfgrass quality ratings (<6) in December 2022, January 2023 and February 2023 (Figure 1B). The other N fertility rates displayed acceptable values with no significant differences throughout the duration of the study except for March 2023 where the highest rate was observed in plots fertilised with $200\text{ kg N ha}^{-1}\text{ year}^{-1}$. No significant differences in turfgrass colour were reported between mulched and non-mulched plots until November 2022 (Figure 1C). Starting from November 2022, turfgrass colour ratings for mulched plots stabilised at a rating of 7, with an increase in November 2023, followed by a significant decline in February 2024. The non-mulched plots displayed more variability with respect to turfgrass colour than mulched plots during the study period. Lower ratings were observed in response to no mulching except in April, May and November 2023. As previously observed for turfgrass quality, turfgrass colour ratings were similar across the four N fertility rates until January 2023 (Figure 1D). Starting in January 2023, plots fertilised with $200\text{ kg N ha}^{-1}\text{ year}^{-1}$ reached greater turfgrass colour values than the non-fertilised plots, which displayed unacceptable ratings (<6). The most significant differences with respect to turfgrass colour were observed during the winter of 2023. However, in July 2023, a general decline in turfgrass colour ratings resulted in no significant differences between N fertility rates. After September 2023, plots receiving the highest N fertility rate exhibited similar turfgrass colour ratings as those observed in spring 2023, which were significantly higher than the non-fertilised plots. The interaction between N rate and mulching (data not shown), revealed that mulched plots receiving fertilisation had the highest turfgrass colour ratings, while mulched plots without fertiliser displayed similar ratings as non-mulched plots fertilised with the highest N fertility rate (6.6 and 6.9, respectively). Non-mulched and non-fertilised plots exhibited the lowest turfgrass colour ratings (from 5.8 to 6.1). The NDVI values followed seasonal variability, reaching lower values in summer (Figure 3A). Differences in NDVI values between

TABLE 2 | Results of analysis of variance for the effects of sampling date, nitrogen fertility rate, mulching, and their interaction on turfgrass quality (TQ), turfgrass colour (TC), normalised difference vegetation index (NDVI), percent green turfgrass cover (% Cover), soil moisture, clipping DM production (clipping DM), turfgrass canopy height and clipping nitrogen content.

	TQ	TC	NDVI	% cover	Moisture	Clipping DM	Turfgrass canopy height	Clipping N content
Sampling date (SD)	***	***	***	***	***	***	***	***
N fertility rate (N)	***	***	***	***	*	***	*	N.S.
Mulching (M)	***	***	***	***	N.S.	***	***	***
SD*N	***	*	*	*	N.S.	**	N.S.	**
SD*M	***	***	***	***	N.S.	***	**	***
N*M	N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
SD*N*M	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	**

Note: *Significant at the 0.05 probability level. **Significant at the 0.01 probability level. ***Significant at the 0.001 probability level. Abbreviation: N.S., non-significant.

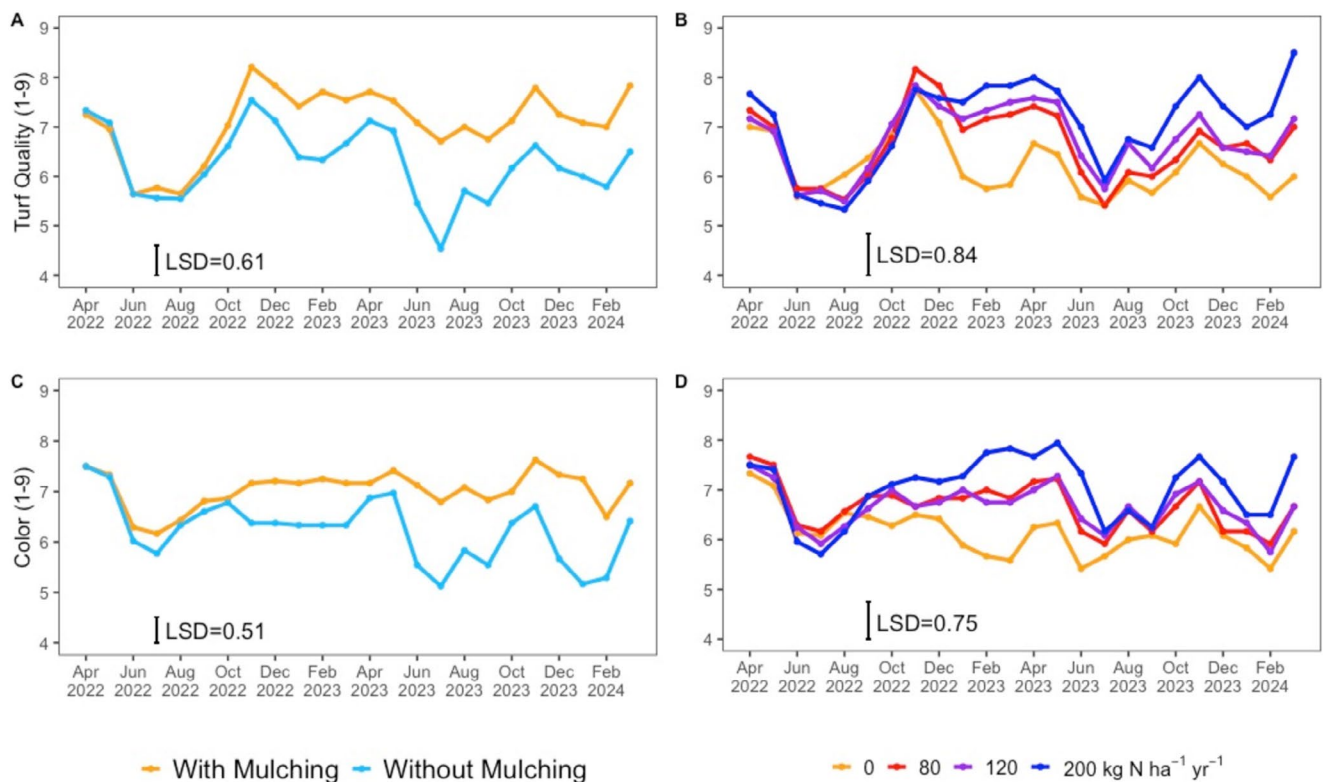


FIGURE 1 | Sampling date effect on visual turfgrass quality (A and C) and turfgrass colour (B and D) on a scale from 1 to 9 (1 = worst, 9 = best, 6 = minimum acceptable quality) at the Agricultural Experimental Farm at the University of Padua in Legnaro, Italy (45°20' N, 11°57' E) from April 2022 to March 2024. Error bars represent the least significant difference (LSD) determined at $p \leq 0.05$.

mulched and non-mulched plots were only observed in the last period of the experiment, with mulched plots displaying higher values during winter 2024 (Figure S1A). Starting in December 2023, a continuous decline in NDVI occurred until summer 2023. Significant differences between the higher N fertility rate and the non-fertilised plots were observed beginning in February 2023 until the end of the experimental period except for November and December 2023 (Figure S1B). During fall 2023, non-fertilised plots exhibited a lower percentage of turfgrass green cover than fertilised plots, while during March 2024, plots receiving the two highest N fertility rates (200 and 120 kg N ha⁻¹ year⁻¹) reached higher coverage than the non-fertilised plots. In June and July 2023, mulched plots displayed higher turfgrass green cover percentages than non-mulched plots; however, this difference was not observed starting from December 2023 (Figure S1C). Turfgrass green cover differences between N fertility rates started in December 2022, where the non-fertilised plots displayed lower percentages than plots receiving the highest N fertility rate, except during August 2023 (Figure S1D).

DM production, canopy growth, and clipping N content: Daily clipping DM production measured in spring and fall was higher in plots fertilised with 200 kg N ha⁻¹ year⁻¹ than in the non-fertilised plots only in May and November 2023 (Figure 2). Differences between mulched and non-mulched plots were first evident in May 2023, when mulched plots exhibited greater clipping DM production (Table 3). Daily turfgrass canopy growth measured in spring and fall was lower in non-fertilised plots (1.30 mm day⁻¹) than plots fertilised

with 200 and 80 kg N ha⁻¹ year⁻¹ (1.44 and 1.50 mm day⁻¹, respectively), while plots fertilised with 120 kg N ha⁻¹ year⁻¹ were not significantly different from the other N fertility rates (1.39 mm day⁻¹) (data not shown). Differences in daily turfgrass canopy growth between mulched and non-mulched plots were significant in all sampling dates except for November 2022 (Table 3).

The N content within clippings collected before fertilisation was higher in March 2022 than any other dates (Figure S2). Furthermore, N content was higher in March and May 2023 than December 2022, with a depletion occurring in September 2023. The difference between the mulched and non-mulched plots was significant for plots fertilised with 80 kg N ha⁻¹ year⁻¹ in March 2022 and May 2023; plots fertilised with 120 kg N ha⁻¹ year⁻¹ in March 2022, March 2023, and May 2023; and plots fertilised with 200 kg N ha⁻¹ year⁻¹ in May 2023 (Figure S2). In such cases, clippings collected in mulched plots displayed higher N content than non-mulched plots.

Turfgrass canopy density during the 2023 growing season was affected by the interactions between sampling date and N fertility rate and between sampling date and mulching treatment, while turfgrass clipping N content was affected by all two-way interactions (Table 4). Differences within N fertility rates were observed during spring 2023 (April and May) and October 2023 (Figure 3). The highest N fertility rate (200 kg N ha⁻¹ year⁻¹) consistently displayed values higher than non-fertilised plots but additionally higher than plots fertilised with 80 kg N ha⁻¹ year⁻¹

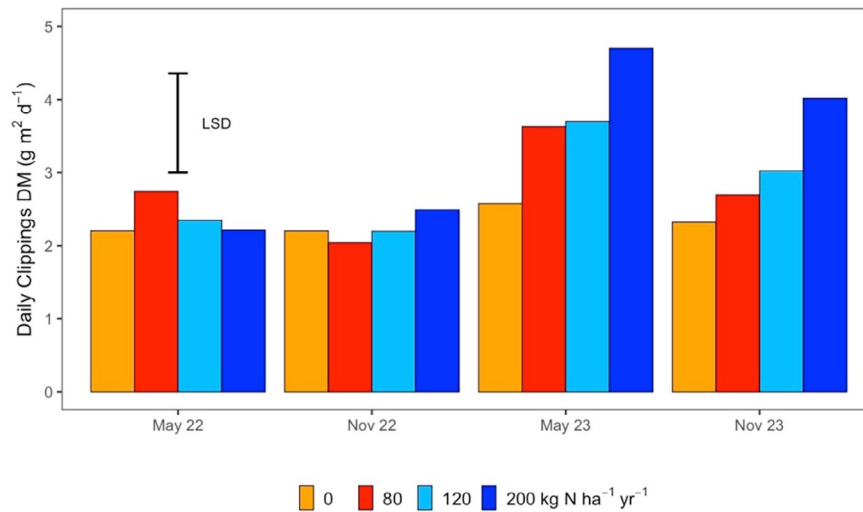


FIGURE 2 | Effect of the interaction between N fertility rate and sampling date on daily clipping dry matter (DM) production in spring (May) and fall (November) of both experimental years (2022 and 2023). Error bars represent the least significant difference (LSD) at $p \leq 0.05$.

TABLE 3 | Effect of the interaction between mulching and sampling date on daily turfgrass clipping dry matter (DM) production in May and November of 2022 and 2023.

	Daily clipping DM ($\text{g m}^{-2} \text{d}^{-1}$)		Daily canopy growth (mm)	
	Mulching	Non-mulching	Mulching	Non-mulching
May 2022	2.37 c	2.38 c	1.46 b	1.25 c
November 2022	2.21 c	2.26 c	0.81 d	0.66 d
May 2023	4.43 a	2.88 bc	1.94 a	1.54 b
November 2023	3.32 b	2.71 bc	2.00 a	1.58 b

Note: Mean values with the same letter are not statistically different at $p \leq 0.05$.

TABLE 4 | Results of analysis of variance for the effects of sampling date, treatment, mulching, and their interaction on turfgrass canopy density and turfgrass clipping N content from March to November 2023 (growing season).

	Canopy density 2023	N content in clipping 2023
Sampling date (SD)	***	***
N rate (N)	*	**
Mulching (M)	***	***
SD*N	*	***
SD*M	*	*
N*M	N.S.	*
SD*N*M	N.S.	N.S.

Note: *Significant at the 0.05 probability level. **Significant at the 0.01 probability level. ***Significant at the 0.001 probability level. Abbreviation: N.S., non-significant.

during October. The practice of mulching enhanced the turfgrass canopy density in months where cool-season grasses typically experience greatest growth (April, May, and September) (Figure 3).

Turfgrass clipping N content was higher in fall than spring and significantly different among N fertility rates and between mulched or non-mulched plots during spring and fall only (Figure S3). Large differences were observed from the end of March (DOY = 90) until the end of July (DOY = 170) and in October. Turfgrass clipping N content was higher in mulched plots during spring and early summer (Figure S3).

The increase in N content within turfgrass clippings of mulched plots was further emphasised by the increase of N fertility rates: the difference between mulched and non-mulched plots receiving the highest N rate was greater than the difference between non-fertilised mulched and non-mulched plots (Figure 4). The annual N content in turfgrass clippings was higher in mulched plots ($198 \text{ kg ha}^{-1} \text{ year}^{-1}$) than in non-mulched plots ($129 \text{ kg ha}^{-1} \text{ year}^{-1}$). The total annual N amount in turfgrass clippings from plots fertilised with 0, 80, 120, and $200 \text{ kg N ha}^{-1} \text{ year}^{-1}$ was 110, 149, 167, and $228 \text{ kg ha}^{-1} \text{ year}^{-1}$, respectively.

The coefficient a of the Gaussian curve obtained from the daily turfgrass clipping DM production displayed significant differences among N fertility rates and mulching treatment, while coefficient c was only affected by mulching treatment (data not shown). The daily DM production was higher where clippings were returned and the amplitude of the estimated curve was higher (Figure 5).

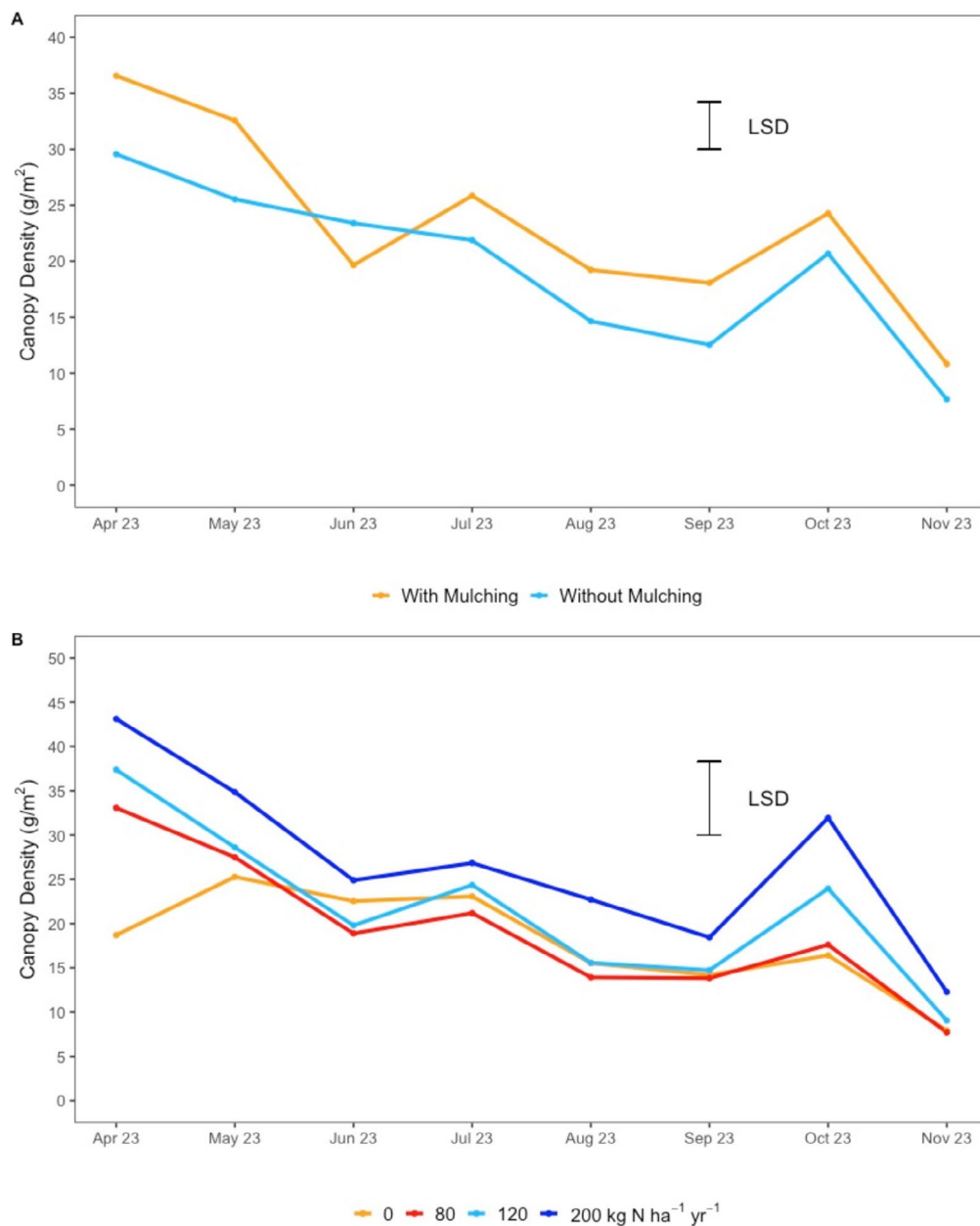


FIGURE 3 | Turfgrass canopy density as affected by mulching (A) or N fertility rates (0, 80, 120, 200 kg ha⁻¹ year⁻¹) (B) during the study period (April 2022 to March 2024). Error bars represent the least significant difference (LSD) determined at $p \leq 0.05$.

4 | Discussion

Most evaluated parameters were unaffected by mulching within the first 9 months following trial initiation. These results agree with most of the previous research investigating clipping return to turfgrass systems (Kopp and Guillard 2002; Schiavon et al. 2021). However, Grégoire et al. (2022) did not observe any differences among evaluated parameters throughout the duration of their research. Accentuation of observed differences over time in response to clipping return can be linked to the decomposition and subsequent mineralisation of supplied nutrients to the soil profile (Knot et al. 2017). Differences with respect to turfgrass quality and colour, NDVI, and turfgrass green colour were observed between mulched and non-mulched plots during the winter of 2023.

Therefore, one positive impact of mulching turfgrass clippings is the stabilisation of seasonal variation observed throughout the study. Decreases in turfgrass quality and colour typically observed during the winter and summer were less severe in mulched plots compared with non-mulched plots. The NDVI values further confirmed better turfgrass health soon after the start of the second year, even though differences in NDVI and turfgrass green cover were more evident during winter than summer. This could be due to an increase in the consistency in available nutrients released from clipping decomposition in the upper soil profile. Several other studies reported an increase in turfgrass quality (Kopp and Guillard 2002; Schiavon et al. 2021) or NDVI (Grégoire et al. 2022) in response to clipping return, especially when turfgrass systems were N deficient (Grégoire et al. 2022).

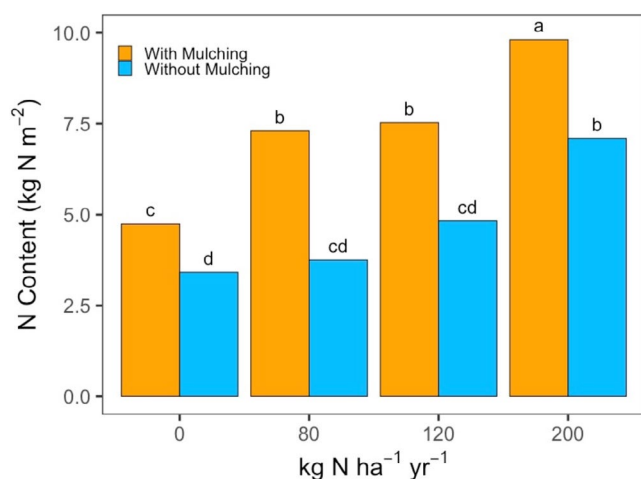


FIGURE 4 | Effect of the interaction between N fertility rate and mulching on turfgrass clipping N content collected before each mowing from April 2023 to November 2023. Error bars represent the least significant difference (LSD) at $p \leq 0.05$.

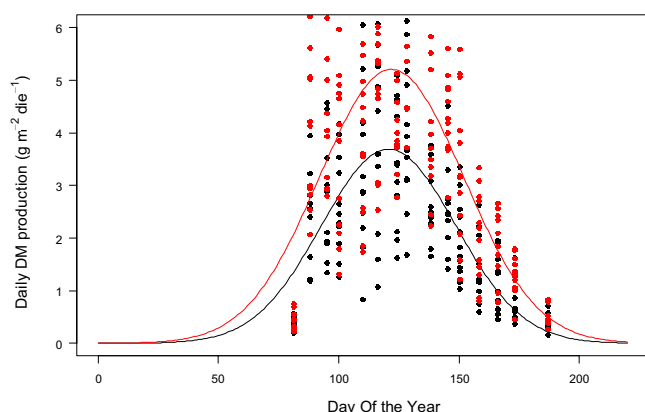


FIGURE 5 | Daily turfgrass clipping dry matter (DM) production from March to July 2023 of mulched and non-mulched plots. Dots are daily turfgrass clipping DM production; lines are estimated Gaussian curves. Red represents mulched plots; black represents non-mulched plots.

No differences were observed among investigated parameters with respect to the addition of fertiliser, regardless of rate, until summer 2022. The major differences were reported between the highest ($200 \text{ kg N ha}^{-1} \text{ year}^{-1}$) and the lowest ($0 \text{ kg N ha}^{-1} \text{ year}^{-1}$) N fertility rate, with the highest rate exhibiting greater values, regardless of the evaluated parameter. The 80 and $120 \text{ kg N ha}^{-1} \text{ year}^{-1}$ fertility rates displayed similar values for all investigated parameters throughout the duration of the experiment. Furthermore, differences between these N fertility rates and the $200 \text{ kg N ha}^{-1} \text{ year}^{-1}$ rate only occurred during spring and fall. The interaction between mulching treatment and N fertility rate was only significant for turfgrass colour, with higher values observed in mulched plots, except for those receiving $0 \text{ kg N ha}^{-1} \text{ year}^{-1}$. Those mulched plots exhibited values similar to non-mulched plots fertilised with $200 \text{ kg N ha}^{-1} \text{ year}^{-1}$. Therefore, our results suggest that the amount of N fertility required annually by turfgrass systems can be reduced when mulching practices are employed. These findings are similar to several previously reported studies (Kopp and Guillard 2002; Law, 2016; Qian et al. 2003). Kopp and Guillard (2002) demonstrated that N fertilisation can be reduced by 50% or more without

decreasing turfgrass quality when clippings are returned to the canopy. Qian et al. (2003) reported that mulching practices could reduce N fertilisation by 33%–60%, but reductions were dependent on the age of the turfgrass system. In our research, turfgrass responded similarly to fertilisation with $80 \text{ kg N ha}^{-1} \text{ year}^{-1}$ as it did to $200 \text{ kg N ha}^{-1} \text{ year}^{-1}$, which could translate into reductions in fertility cost, management requirements, and environmental inputs. Law et al. (2016) estimated that by collecting clippings from a lawn fertilised with $142 \text{ kg N ha}^{-1} \text{ year}^{-1}$, approximately $104 \text{ kg N ha}^{-1} \text{ year}^{-1}$ was withdrawn, which is equivalent to 73% of the N applied annually. Similarly, we determined that mulching resulted in a 63% increase in N compared to non-mulched areas. Grégoire et al. (2022) observed a more positive impact on NDVI from clipping release when N fertilisation was reduced. Contrarily, we only noted a significant interaction between mulching and N fertility rate with respect to turfgrass colour. Furthermore, the observed influence of mulching was more pronounced in non-fertilised plots rather than plots receiving higher fertility rates.

One of the most positive effects attributed to the practice of mulching is an increase in soil moisture in the upper profile due to the intensification of organic matter derived from clipping decomposition (Pornaro et al. 2022). Grégoire et al. (2022) reported a positive impact of turfgrass clippings on soil moisture content. However, we did not observe a significant impact of clipping return on soil moisture. This may have been attributed to the annual verticutting applied in the spring of each year. Removing thatch from the soil surface may have contributed to an increase in water loss since thatch can buffer soil temperature extremes (Beard 1973; Murray and Juska 1977). Some practitioners are concerned that the practice of mulching adds too much fertility to the system and may lead to an increase in clipping production. On the contrary, our research observed that mulching had a stronger influence on vertical growth rate and canopy density than clipping production. This result may be linked to the higher water content within the clippings collected from mulched plots due to the presence of clippings on the soil surface, which reduces water loss from the soil (Pornaro et al. 2022). However, higher vertical growth rates may aid turfgrass recovery from injuries or disease, while denser canopies can increase the competitiveness of turfgrass against weed encroachment (Frank and Guertal 2013; Masin and Macolino 2014).

5 | Conclusion

Our results provide evidence that mulching can stabilise turfgrass quality and colour across seasons, especially in winter. The effects of mulching were stronger in plots without fertilisation compared to those receiving higher nitrogen rates. It also allowed for reduced nitrogen input without compromising turfgrass performance. This may lead to lower costs for fertilisation, reduced maintenance efforts and decreased environmental impact.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

- ARPAV. 2021. "Regional Agency for Environmental Protection of Veneto Region (ARPAV). Dipartimento Per La Sicurezza Del Territorio. Centro Meteorologico: Teolo, Padova, Italy." https://www.arpa.veneto.it/arpavinforma/indicatori-ambientali/indicatori_ambientali/clima-e-rischi-naturali/clima/precipitazione-annua/view.
- Beard, J. B. 1973. *Turfgrass: Science and Culture*. Prentice-Hall, Inc.
- Busey, P. 2003. "Cultural Management of Weeds in Turfgrass: A Review." *Crop Science* 43, no. 6: 1899–1911.
- Fiorio, S., S. Macolino, and B. Leinauer. 2012. "Establishment and Performance of Bluegrass Species and Tall Fescue Under Reduced-Input Maintenance in a Temperate Mediterranean Environment." *HortTechnology* 22, no. 6: 810–816.
- Frank, K. W., and E. A. Guertal. 2013. "Nitrogen Research in Turfgrass." *Turfgrass: Biology, Use, and Management* 56: 457–491.
- Fry, J., and B. Huang. 2004. *Applied Turfgrass Science and Physiology*. John Wiley & Sons.
- Grégoire, G., R. Benjannet, and Y. Desjardins. 2022. "Contribution of Grass Clippings to Turfgrass Fertilization and Soil Water Content Under Four Nitrogen Levels." *Science of the Total Environment* 837: 155765.
- Grubbs, R. A., G. M. Henry, and M. L. Cabrera. 2021. "Effects of Mowing Interval on Turfgrass Clipping Tissue Characteristics and Soil Nitrogen Dynamics." *Soil Science Society of America Journal* 85, no. 4: 1174–1184.
- Heckman, J. R., H. Liu, W. Hill, M. DeMilia, and W. L. Anastasia. 2000. "Kentucky Bluegrass Responses to Mowing Practice and Nitrogen Fertility Management." *Journal of Sustainable Agriculture* 15, no. 4: 25–33.
- Howieson, M. J., and N. E. Christians. 2008. "Carbohydrate Metabolism and Efficiency of Photosystem II in Mown Creeping Bentgrass (*Agrostis stolonifera* L.)." *HortScience* 43, no. 2: 525–531.
- Knot, P., F. Hrabe, S. Hejduk, et al. 2017. "The Impacts of Different Management Practices on Botanical Composition, Quality, Colour and Growth of Urban Lawns." *Urban Forestry & Urban Greening* 26: 178–183.
- Kopp, K. L., and K. Guillard. 2002. "Clipping Management and Nitrogen Fertilization of Turfgrass: Growth, Nitrogen Utilization, and Quality." *Crop Science* 42, no. 4: 1225–1231.
- Krans, J. V., and K. Morris. 2007. "Determining a Profile of Protocols and Standards Used in the Visual Field Assessment of Turfgrasses: A Survey of National Turfgrass Evaluation Program-Sponsored University Scientists." *Applied Turfgrass Science* 4, no. 1: 1–6.
- Law, Q. D., C. A. Bigelow, and A. J. Patton. 2016. "Selecting Turfgrasses and Mowing Practices That Reduce Mowing Requirements." *Crop Science* 56, no. 6: 3318–3327.
- Law, Q. D., J. M. Trappe, R. C. Braun, and A. J. Patton. 2021. "Greenhouse Gas Fluxes From Turfgrass Systems: Species, Growth Rate, Clipping Management, and Environmental Effects." *Journal of Environmental Quality* 50, no. 3: 547–557.
- Law, Q. D., J. M. Trappe, Y. Jiang, R. F. Turco, and A. J. Patton. 2017. "Turfgrass Selection and Grass Clippings Management Influence Soil Carbon and Nitrogen Dynamics." *Agronomy Journal* 109, no. 4: 1719–1725.
- Li, X., F. Hu, D. Bowman, and W. Shi. 2013. "Nitrous Oxide Production in Turfgrass Systems: Effects of Soil Properties and Grass Clipping Recycling." *Applied Soil Ecology* 67: 61–69.
- Macolino, S., G. Pignata, M. Giolo, and M. D. Richardson. 2014. "Species Succession and Turf Quality of Tall Fescue and Kentucky Bluegrass Mixtures as Affected by Mowing Height." *Crop Science* 54, no. 3: 1220–1226.
- Masin, R., and S. Macolino. 2014. "Ability of Some Creeping Perennial Ryegrasses to Suppress Annual Bluegrass Germination." *Turfgrass Science* 45, no. 2/14: 53.
- McLane, F. E. 1992. "Mulching Lawn Mower." United States Patent US 5,117,616.
- Miller, G. L., G. D. Pinnix, P. C. Bartley, R. K. McCauley, and B. E. Jackson. 2019. "Evaluation of Turfgrass Clippings From Mulching Versus Side Discharge Mower Operation." *Crop, Forage & Turfgrass Management* 5, no. 1: 1–5.
- Miltner, E. D., B. E. Branham, E. A. Paul, and P. E. Rieke. 1996. "Leaching and Mass Balance of 15N-Labeled Urea Applied to a Kentucky Bluegrass Turf." *Crop Science* 36, no. 6: 1427–1433.
- Morari, F. 2006. "Drainage Flux Measurement and Errors Associated With Automatic Tension-Controlled Suction Plates." *Soil Science Society of America Journal* 70, no. 6: 1860–1871.
- Murray, J. J., and F. V. Juska. 1977. "Effect of Management Practices on Thatch Accumulation, Turf Quality, and Leaf Spot Damage in Common Kentucky Bluegrass 1." *Agronomy Journal* 69, no. 3: 365–369.
- Pornaro, C., G. Henry, and S. Macolino. 2024. "Traffic Tolerance of Perennial Ryegrass (*Lolium perenne* L.) Cultivars as Affected by Nitrogen Fertilization." *HortScience* 59, no. 1: 64–72.
- Pornaro, C., A. Novello, M. Fidanza, and S. Macolino. 2022. "Grasscycling: A Key Practice for Sustainable Turfgrass Management." *Grasses* 1, no. 1: 45–52.
- Pornaro, C., V. Vincenzi, S. Furin, M. Fazzini, L. Minarelli, and S. Macolino. 2018. "Seasonal Changes in Dry Matter Yield From Karst Pastures as Influenced by Morphoclimatic Features." *PLoS One* 13, no. 9: e0204092.
- Qian, Y. L., W. Bandaranayake, W. J. Parton, B. Mecham, M. A. Harivandi, and A. R. Mosier. 2003. "Long-Term Effects of Clipping and Nitrogen Management in Turfgrass on Soil Organic Carbon and Nitrogen Dynamics: The CENTURY Model Simulation." *Journal of Environmental Quality* 32, no. 5: 1694–1700.
- R Core Team. 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing.
- Richardson, M. D., D. E. Karcher, and L. C. Purcell. 2001. "Quantifying Turfgrass Cover Using Digital Image Analysis." *Crop Science* 41, no. 6: 1884–1888.
- Schiavon, M., C. Pornaro, and S. Macolino. 2021. "Clippings Return Decreases Mineral Nitrogen Requirements for Bermudagrass (*Cynodon* spp.) Lawns in Mediterranean Europe." *Crop Science* 61, no. 5: 2916–2925.
- Sheffer, K. M., T. L. Watschke, and J. M. Duich. 1978. "Effect of Mowing Height on Leaf Angle, Leaf Number, and Tiller Density of 62 Kentucky Bluegrasses 1." *Agronomy Journal* 70, no. 4: 686–689.
- Starr, J. L., and H. C. DeRoo. 1981. "The Fate of Nitrogen Fertilizer Applied to Turfgrass 1." *Crop Science* 21, no. 4: 531–536.
- Tang, C., C. Weligama, and P. Sale. 2013. "Subsurface Soil Acidification in Farming Systems: Its Possible Causes and Management Options." In *Molecular Environmental Soil Science*, edited by J. Xu, P. M. Huang, and X. Shan, 389–412. Springer.

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