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Yarrow (*Achillea millefolium*) for low-input lawns in the Mediterranean environment

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A R T I C L E I N F O

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A B S T R A C T

In recent years, environmental concerns have created a desire for the sustainable care of grass swards, with a specific goal of reducing resources needed for turfgrass maintenance by utilising low-input species best adapted to specific local environmental conditions. A two-year field experiment was conducted to compare the aesthetic or ornamental quality, and function potential, of different swards. The treatments consisted of four monostands of white clover (*Trifolium repens* L.), yarrow (*Achillea millefolium* L.), strong creeping red fescue (*Festuca rubra* L. ssp. *rubra* Gaudin), and tall fescue (*Festuca arundinacea* Schreb. = *Schedonorus arundinaceus* Schreb. Dumort.*),* three two-species mixtures of white clover + yarrow, white clover + strong creeping red fescue, and yarrow + strong creeping red fescue, and one three-species mixture of white clover + yarrow + strong creeping red fescue. Within each plot, a botanical survey was performed each spring to estimate species relative abundance by determining the proportions of different species present. All plots were evaluated every two weeks during the growing period for visual quality and normalised difference vegetative index. Vegetation canopy height in each plot was measured before each biweekly mowing event, and clippings were collected to measure vegetative dry matter. Relative abundance of yarrow, strong creeping red fescue, and tall fescue was stable throughout the entire study period. The mixtures including yarrow displayed sufficient or higher quality ratings (≥6) in all seasons with the exception of winter, however, yarrow + strong creeping red fescue compensated each other's defects by maintaining their relative abundance (≥ 80%) over time as well suppressing or prevent significant weed invasion (relative abundance <15%). Moreover, yarrow or strong creeping red fescue monostands, or yarrow + strong creeping red fescue could be maintained with lower number of mowing events, due to their lower vertical growth. In conclusion, alternative plant species to turf-type grasses produced a visual quality equal to or better than tall fescue maintained under low fertilisation and mowing frequency. All swards that included yarrow produced better visual quality, exhibited better weed control, had lower vertical growth rate, and provided an aesthetically pleasant, persistent, and sustainable vegetative ground cover than other swards, and can be utilised as a low-input species.

1. Introduction

In recent years, environmental concerns and increased awareness for safety to human health have created a desire for the sustainable care of sports turf and athletic pitches, public greenspace areas, amenity grasslands, and residential gardens (Matheny, 2009). In Europe, as well as in the United States, concerns over utilisation and depletion of natural resources and potential contamination of waterways have led to an increased focus on sustainable or best management practices (Cisar, 2004). This tendency to place restrictions on herbicide and fertiliser applications to the landscapes requires alternative intervention where possible (Gelernter et al., 2016). Ornamental or recreational turfgrass and sports turf are not considered as semi-natural or planted grassland subject to minimal or non-intensive management (Handley, 2015). Intensively managed turfgrass swards, however, often require frequent cultural management inputs of fertilisation, irrigation, and mowing (Ignatieva and Hedblom, 2018).

Among the vast number of the grass genera, the most utilised species as a managed turfgrass are bermudagrass (*Cynodon dactylon* L. Pers.), zoysiagrass (*Zoysia japonica* Steud), and *Paspalum* spp. within warm-

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season grasses, and tall fescue (*Festuca arundinacea* Schreb. = *Schedonorus arundinaceus* Schreb. Dumort.), Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), and red fescue (*Festuca rubra* L.) within cool-season grasses (Ignatieva and Hedblom, 2018). The most important strategy employed to reduce inputs in maintaining a turfgrass sward is to select the appropriate species and cultivar (Christians et al., 2016). Low-input sustainable turfgass species should be tolerant to both abiotic and biotic stresses, have low-nutrient and water requirements, and grow competitively to minimise weed invasion (Diesburg et al., 1997; Hugie et al., 2012).

A common approach for reducing resources needed for turfgrass maintenance is to encourage the use of low-input turfgrass species best adapted to the regional climatic and also the local environmental conditions (Hann et al., 2020). For example, warm-season turfgrasses typically are better adapted to higher air and soil temperatures and are more tolerant to low nitrogen fertility (Brown, 1985) and low soil or root zone moisture compared to cool-season turfgrasses (Biran et al., 1981; Gibeault et al., 1989). Among cool-season turfgrasses, tall fescue typically exhibits better tolerance to environmental stresses compared to Kentucky bluegrass and perennial ryegrass (Pornaro et al., 2016). Tall fescue is a rustic plant that is adaptable to many soil and climate conditions, and is the most used species for low-maintenance turfgrasses within the transition zone environment (Pornaro et al., 2016; Schiavon et al., 2021a, 2021b). Since traditional high input-required turfgrasses grow aggressively and therefore require more frequent mowing, fine fescues (e.g. strong creeping red fescue) have also been indicated as a potential low input turfgrass that requires less maintenance while producing both acceptable visual quality and ecological function (Barnes et al., 2020; Dernoeden et al., 1998; Hugie et al., 2012; Kowalewski et al., 2014; Miller et al., 2013; Ruemmele et al., 2003; Reiter et al., 2017; Watkins et al., 2014).

Golf course superintendents and greenkeepers, municipal water conservationists, school grounds managers, and landscape professionals are interested in alternative groundcovers and low-input native or ornamental plants as potential replacements for turfgrass (Burayu and Umeda, 2021). Lawns are perceived as uniform and aesthetically desired short-cut grass swards (Ignatieva and Hedblom, 2018). However, the idea of installing urban meadows as a "natural landscape" has received favourable consideration in recent years (Florgård, 2009; Ignatieva and Hedblom, 2018; Smith and Fellowes, 2014). Alternative plant species that can tolerate abiotic and biotic stresses are desirable if they can satisfy the need for sward uniformity and function that is typically achieved with a closely mowed or lower height-of-cut turfgrass lawn (Ignatieva and Hedblom, 2018).

Few references are available on studies involving native or no-grass species for lawns. The ornamental ground cover plant kurapia (*Lippia nodiflora* L.) has been evaluated to replace turfgrasses in golf course out-of-play areas and showed promise as a low-input species based on uniformity, coverage, and greenness (Burayu and Umeda, 2021). Yarrow (*Achillea millefolium* L.) was used in lawns and playing areas in the last centuries displaying good tolerance to heavy traffic and drought conditions (Bourdôt, 1980). This species is tolerant to close mowing, however, and can be an aggressive weed in a turfgrass stand and in pastures (Bourdôt et al., 1984; Hann et al., 2020). Yarrow is of European origin and is widely distributed from the Mediterranean region to the Arctic Circle (Clausen et al., 1958), thus thriving in diverse altitude and climate conditions (Bourdôt, 1980; Pignatti, 1982). White clover (*Trifolium repens* L.) also has been evaluated for inclusion in managed turfgrass swards, and in test plots has been shown to increase overall turfgrass colour ratings and vegetative cover (Bigelow et al., 2021; Braun et al., 2022; Dudeck and Peacock, 1983; McCurdy, 2013; Sincik and Acikgoz, 2007).

Mixing two, three, or more plant species potentially could be an alternative method to reduce maintenance inputs and requirements for turfgrasses, especially in the transition zone and Mediterranean climate (Dunn and Diesburg, 2004; Turner and Carroll, 2015). Mixtures of different turfgrass species has been shown to reduce environmental and pest stresses compared with monostands (Salehi and Khosh-Khui, 2004). However, the botanical dynamics of different species affect uniformity and composition of the turfgrass sward, and are influenced by several factors such as seeding rates (Brede and Duich, 1984a), mowing height and frequency (Brede and Duich, 1984b), and fertilisation (Gough et al., 2000).

Therefore, the overall goal of this study was to evaluate monostands and mixtures of widely used turfgrass species and a non-grass species, maintained under low input practices, for use as an amenity lawn for golf course roughs, roadsides, school grounds and landscapes, parks, large-scale commercial sites, and residential gardens. A two-year field experiment was conducted to compare the aesthetic or ornamental quality, and function potential, of yarrow established alone or within a mixture of white clover or strong creeping red fescue. Our hypothesis is that yarrow could provide a lawn with similar or better quality than turfgrass species under low-input maintenance, with tall fescue monostand for comparison.

2. Materials and methods

A field experiment was established during September 2018 at the Experimental Agricultural Farm of Padova University (Legnaro, Italy; 45°20′ N, 11°57′ E; 8 m asl). The soil at the site was a coarse-silty, mixed, mesic, Oxyaquic Eutrudept, of a loam soil texture (13.4% clay, 44.4% silt, and 42.2% sand), with a pH of 8.6, 2.73% organic matter (loss on ignition method), C:N ratio of 11:1, 1.4 mg total nitrogen (N) g^{-1} (combustion method), 2.3 mg phosphorus (P) kg^{-1} (Olsen method), and 135.4 mg potassium (K) kg^{-1} (buffered $BaCl_2$ method). The region is described as a humid subtropical climate (Köppen classification). The long-term (36 years data) annual mean air temperature is 12.6 °C (8.0 = minimum, 17.4 = maximum) and annual rainfall is 831 mm $year^{-1}$ (ARPAV, 2022). Monthly air temperatures and precipitation during the study period are listed in Figs. 1 and 2, respectively.

Individual plots (1.5 × 1.5 m) were arranged in a randomised complete block design with three replications. The treatments consisted of four monostands of a forage-type white clover (*Trifolium repens* L.), yarrow (*Achillea millefolium* L.), strong creeping red fescue (Festuca rubra L. ssp. *rubra* Gaudin), and tall fescue (*Schedonorus arundinaceus* Schreb. Dumort.), three two-species mixtures of white clover + yarrow, white clover + strong creeping red fescue, and yarrow + strong creeping red fescue, and one three-species mixture of white clover + yarrow + strong creeping red fescue. Seeding rates for each monostand and mixtures are listed in Table 1, and those seeding rates were based upon seed company recommendations.

The study site was seeded on 13 Sep 2018 after the area was ploughed, harrowed, and received 50 kg N ha^{-1}, 150 kg P_2O_5 ha^{-1}, and 150 kg K_2O_5 ha^{-1} from a granular fertiliser. During establishment in September through October 2018, plots were irrigated every other day to an amount of water of 5 mm using a conventional overhead sprinkler system. All plots were fertilised at 75 kg N ha^{-1} yr^{-1} with an organo-mineral fertiliser (14 N-5 P_2O_5-8 K_2O), with the application rate split equally in two applications (March and September) in 2019, 2020, and 2021. All plots were mowed biweekly from March until November in 2019, 2020, and 2021, at 47 mm height-of cut using a rotary mower (HRD536, Honda Europe Power Equipment, Bracknell, United Kingdom) with clippings removed, and irrigation was occasionally applied only to prevent severe drought stress.

Within each plot, a botanical survey was performed using the vertical point-quadrat method (Daget and Poissonet, 1971) along three, 1 m linear transects, recording plant species touching a steel needle for each point quadrat at every 10 cm interval. For each survey, species relative abundance was calculated and utilised to detect the proportions of different species according to the equation of Daget and Poissonet (1971) [1].

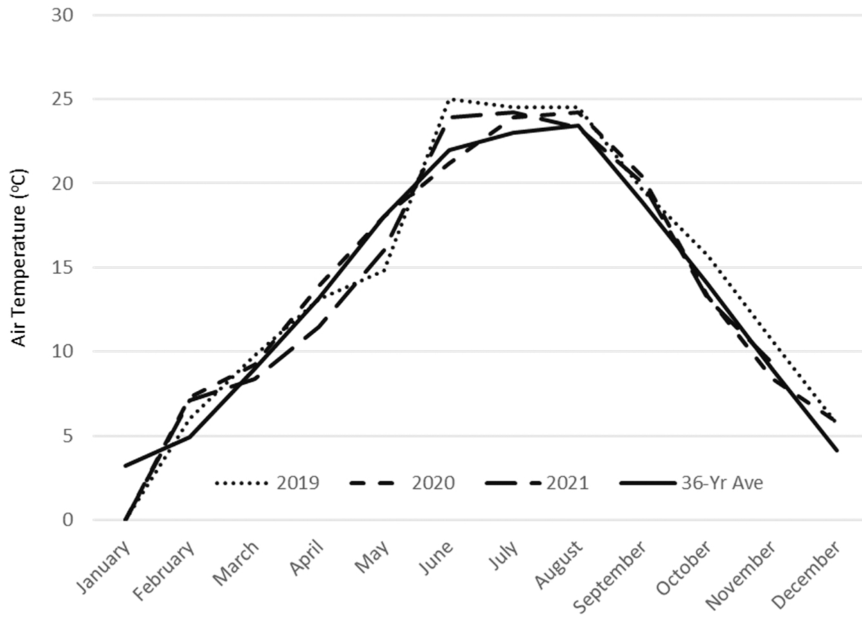

Fig. 1. Monthly mean air temperature during the study period, and 36-year long-term average (1964–2018), at the agricultural experimental farm of Padova University (Legnaro, Italy; 45°20′ N, 11°57′ E).

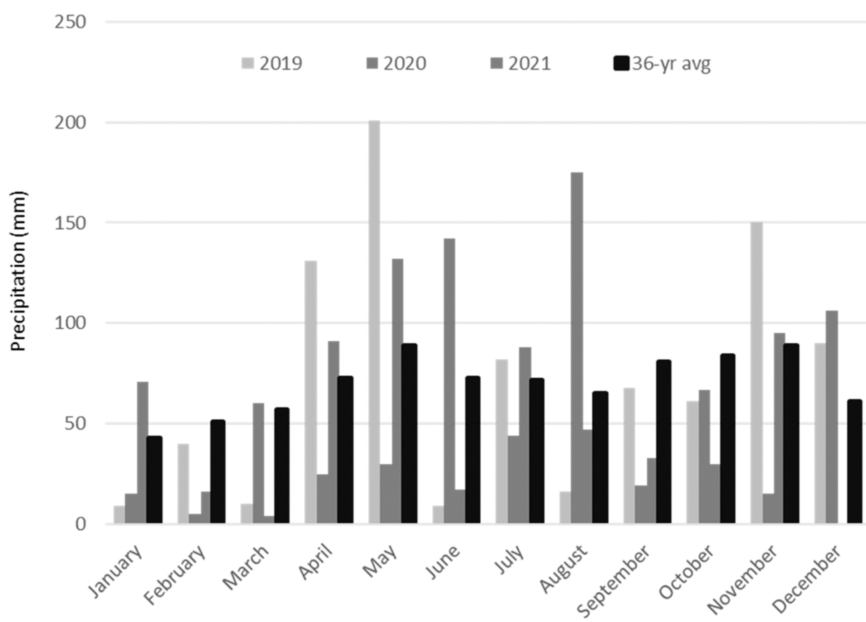

Fig. 2. Monthly total precipitation during the study period, and 36-year long-term average (1964–2018), at the agricultural experimental farm of Padova University (Legnaro, Italy; 45°20′ N, 11°57′ E). Total precipitation per year recorded as 867 mm, 702 mm, 660 mm, and 837 mm, for 2019, 2020, 2021, and 36-year average, respectively.

Table 1
Seeding rates of species established in monostands and mixtures.

Species	Species common name	Monostand	A+T	A+Fr	T + Fr	A+T + Fr
		g m^{-2}				
Achillea millefolium (A) local ecotype	Yarrow	8	4	4	–	3
Trifolium repens (T) cv Rivendel	White clover	15	7.5	–	7.5	5
Festuca rubra (Fr) cv Maxima	Strong creeping red fescue	32	–	16	16	11
Schedonorus arundinaceous cv Lexington	Tall fescue	40	–	–	–	–

[1] Species relative abundance $= \frac{f_i}{\sum_{i-1}^{n} f_i} * 100$,

with f_i=number of occurrences/30 points.

The botanical surveys were performed in May 2019, 2020, and 2021. From March 2019 through April 2021, all plots were evaluated every two weeks for visual quality on a 1–9 scale, where 1 = worst, 6 = minimally acceptable, and 9 = best quality according to the commonly accepted method described in Krans and Morris (2007). From March 2019 through April 2021, normalised difference vegetation index (NDVI; GreenSeeker; Trimble Navigation Unlimited, Sunnyvale, CA) was measured in all plots every two weeks. All biweekly data were subsequently averaged for each month.

During the growing periods of March to October in 2019 and 2020, vegetation canopy height in each plot was measured before each mowing event using a rising grass plate metre (Pornaro et al., 2017). Five randomly selected measurements were taken within each plot. Furthermore, at each mowing event from March through October in 2019 and 2020, clippings were collected in a 0.8 m^2 area within each plot and oven-dried at 105 °C for 48 h to measure vegetative dry matter (Pornaro et al., 2017). Therefore, vertical growth and dry matter for all plots were determined for the growing seasons of 2019 and 2020 as the cumulative sum of vertical growth and the dry matter from data measured and calculated every two weeks.

The relative abundance of species was subjected to analysis of variance using a linear mixed effect model to test the effects of year, sward type, species, and their interactions. Visual quality, NDVI, cumulative vertical growth of growing seasons 2019 and 2020, and cumulative dry matter of 2019 and 2020 were subjected to analysis of variance using a linear mixed effect model to test the effects of sampling date, sward type, and their interactions. Normality and homoscedasticity of residuals were checked by using graphical analyses. A least significant difference test with Bonferroni correction at a $P \leq 0.05$ was used to identify statistically significant differences among means. All statistical analyses were performed in R version 4.0.2 (R Core Team, 2020) and additionally the "nlme" package for fitting mixed models, and "multcomp" for post-hoc comparisons were used.

3. Results

3.1. Botanical composition

Among seeded species, yarrow, fine fescue, and tall fescue were well established in spring 2019 following seeding in September 2018, with relative abundance higher than 95% in both monostand and mix plots (Fig. 3, Table 2). This relative abundance was maintained throughout the entire study period. White clover displayed an abundance of 87% in 2019 when seeded as monostand while a lower percentage occurred when mixed with yarrow or fine fescue, and when mixed with both yarrow and fine fescue (Fig. 3, Table 2). White clover maintained its relative abundance by 2020, but declined in 2021. The percentage of species other than seeded was low and stable over time in plots with yarrow (i.e., alone or in combination with strong creeping red fescue and/or white clover), but in plots where yarrow and white clover were mixed an increase of other species was observed in 2021 (Fig. 3). This increase was due to the greater presence of strong creeping red fescue (Table 2) probably as a consequence of seed dispersion from other plots. Whereas strong creeping red fescue was seeded as a monostand, the percentage of species other than seeded increased each year due to the increase of dandelion (*Taraxacum officinale* (L.) Weber ex F.H. Wigg) and yarrow. All plots seeded with white clover as a monostand displayed a rapid increase of other species, with yarrow, tall fescue, and strong creeping red fescue being the most abundant followed by bermudagrass (*Cynodon dactylon* (L.) Pers.) and dandelion.

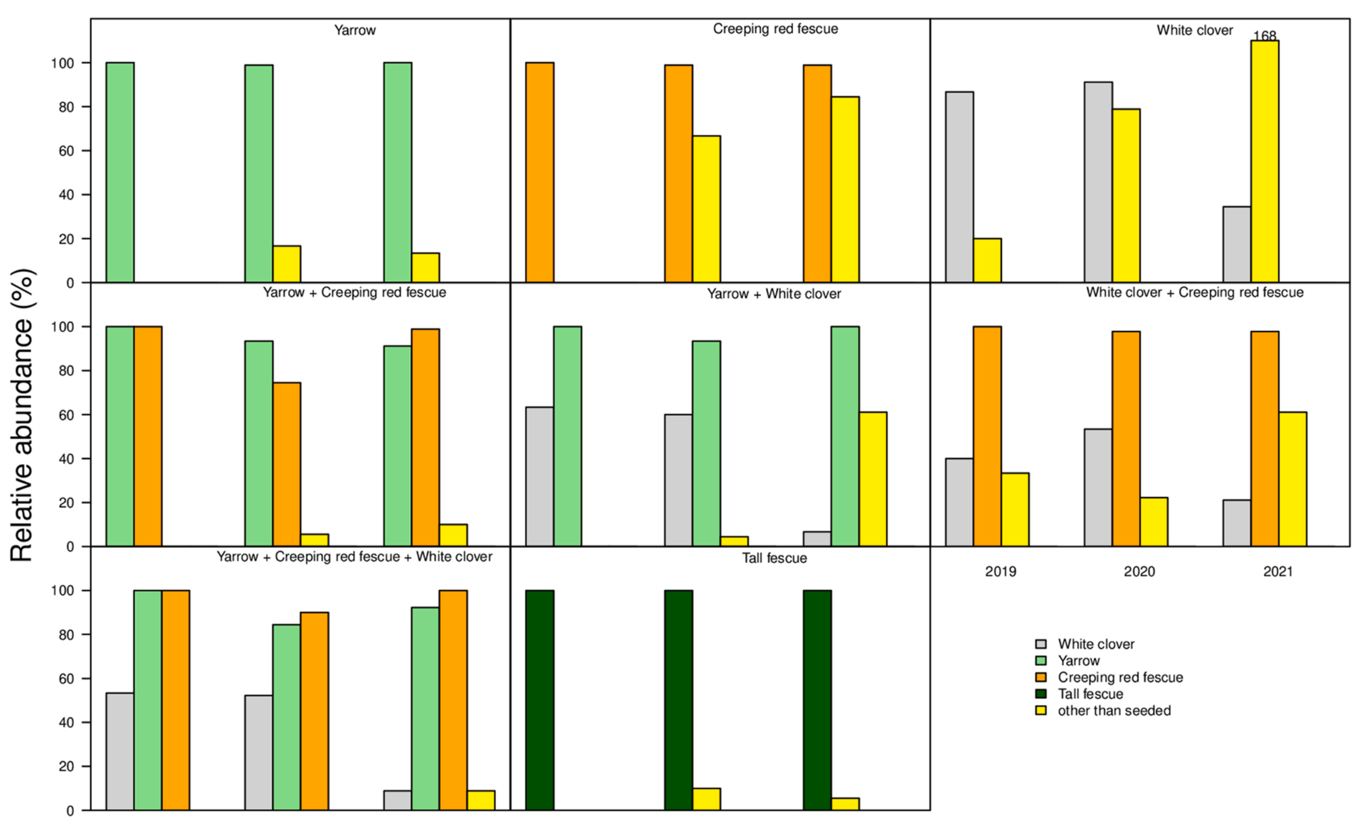

Fig. 3. Relative abundance (%) of seeded species for monostands and mixtures measured in May 2019, 2020, and 2021.

Table 2
Percent relative abundance (min-max) of seeded and invaded species detected in monostands and mixtures plots in May 2019, 2020, and 2021.

Seeded species	Year	*Trifolium repens*	*Achillea millefolium*	*Festuca rubra*	*Festuca arundinacea*	*Medicago lupulina*	*Cynodon dactylon*	*Poa pratensis*	*Poa annua*	*Tarassaco officinale*	*Potentilla reptans*
Yarrow	2019	0	100	0	0	0	0	0	0	0	0
	2020	16(3–33)	99(97–100)	1(0–3)	0	0	0	0	0	0	0
	2021	2(0–7)	100	2(0–7)	1(0–3)	0	8(0–17)	0	0	0	0
Strong creeping red fescue	2019	0	0	100	0	0	0	0	0	0	0
	2020	37(17–50)	26(0–43)	99 (97–100)	0	0	4(0–10)	0	0	0	0
	2021	4(3–7)	58(10–93)	99 (97–100)	3	0	10(3–16)	0	0	7(3–10)	2(0–7)
White clover	2019	87(80–90)	0	0	0	0	0	6(0–17)	13 (10–20)	1(0–3)	0
	2020	91 (83–100)	13(0–23)	29(0–57)	16(0–30)	0	0	7(0–20)	11 (7–17)	1(0–3)	0
	2021	34(30–40)	28(0–50)	48(0–50)	31(0–40)	0	24(17–30)	8(0–24)	0	24(17–29)	4(0–13)
Yarrow + Strong creeping red fescue	2019	0	100	100	0	0	0	0	0	0	0
	2020	1(0–3)	93(90–97)	74 (67–80)	0	4(3–7)	0	0	0	0	0
	2021	0	91(83–97)	99 (97–100)	2(0–7)	0	6(0–17)	0	0	2(0–3)	0
Yarrow + White clover	2019	63(60–70)	100	0	0	0	0	0	0	0	0
	2020	60(47–77)	93(87–97)	3(0–10)	0	0	0	0	0	1(0–3)	0
	2021	7(3–10)	100	44(7–73)	9(0–23)	0	7(3–10)	0	0	1(0–3)	0
Strong creeping red fescue + White clover	2019	40(0–60)	11(0–33)	100	0	0	0	0	0	0	0
	2020	53(30–70)	13(0–23)	98 (93–100)	6(3–10)	1(0–3)	0	0	0	0	2(0–7)
	2021	21(0–47)	32(3–67)	98 (97–100)	6(7–10)	0	11(0–17)	0	0	12(7–17)	0
Yarrow + C. r. fescue + W. clover	2019	53(50–60)	100	100	0	0	0	0	0	0	0
	2020	52(47–57)	84(80–90)	90 (87–93)	0	0	0	0	0	0	0
	2021	9(0–13)	92(80–100)	100	2(0–7)	0	3(0–10)	0	0	3(0–7)	0
Tall fescue	2019	0	0	0	100	0	0	0	0	0	0
	2020	8(0–23)	1(0–3)	0	100	0	0	0	0	1(0–3)	0
	2021	0	0	0	100	0	0	0	0	5(3–7)	0

All data subjected to analysis of variance and means within each column compared at $P \leq 0.05$ resulting in a least significant difference value = 13.8.

Table 3
Results of the analysis of variance testing the effects of species, sampling date, and their interaction on visual quality, normalised difference vegetation index (NDVI), and cumulative vertical growth during growing season of 2019, cumulative dry matter production during growing season of 2019, cumulative vertical growth during growing season of 2020, and cumulative dry matter production during growing season of 2020 of seven sward types established at the experimental agricultural farm of the University of Padova in Legnaro, northeastern Italy (45°20’ N, 11°57’ E; elevation 8 m).

	Cultivar	Sampling date	Cultivar × Sampling date
Visual quality	***†	***	***
NDVI	***	***	***
Cumulative vertical growth 2019	***	***	***
Cumulative dry matter 2019	***	***	***
Cumulative vertical growth 2020	***	***	***
Cumulative dry matter 2020	***	***	***

*** Significant F test at $P \leq 0.001$. †ns, not statistically significant at $P \leq 0.05$.

3.2. Visual quality and NDVI

A significant interaction was found between sampling date and sward type for visual quality and NDVI (Table 3). The visual quality of all monostands and mixtures was rated as ≤ 5 in March 2019, which represented a spring evaluation after seeding in September 2018 (Fig. 4), although no differences were found with NDVI in March 2019 with the exception of the white clover monostand. Until May 2019, the NDVI values were stable for all monostand and mixtures, but higher for white clover monostand. The monostand with yarrow showed sufficient quality ratings (i.e., ≥ 6) until November 2019 (Fig. 4), with visual quality ratings approaching 7 except for July (visual quality = 5.7), even if the high air temperatures during August 2019 (Fig. 1) reflected a decline in NDVI (Fig. 4). In 2019, the strong creeping red fescue monostand never reached a sufficient quality rating, which reflected abiotic stress due to high air temperatures in June 2019 (Fig. 1). This low tolerance to high summer air temperatures was most likely caused by the presence of species other than seeded as recorded in the botanical survey in May 2020 (Fig. 3). During June and July 2019, the white clover monostand produced visual quality and NDVI similar to the yarrow monostand (Fig. 4), however, in December 2019 white clover monostand’s visual quality was lower than yarrow monostand and similar to strong creeping red fescue monostand.

In January 2020, visual quality and NDVI were similar for the three monostands of white clover, yarrow, and strong creeping red fescue (Fig. 4). During March 2020, all plots showed a quick response to favourable environmental conditions with the exception of tall fescue, however, yarrow was the only monostand displaying sufficient or better visual quality (Fig. 4). Furthermore, in 2020, the yarrow monostand showed a trend similar to 2019 with higher NDVI values in fall 2020 compared to fall 2019. In 2020, the strong creeping red fescue monostand plots were more tolerant to summer temperature conditions most likely due to the existence of other species present other than seeded, even though during August and September its visual quality was ≤ 3 (Fig. 4).

The yarrow + strong creeping red fescue mixture had visual quality and NDVI trends similar to the yarrow monostand (Fig. 4), although the abundance of the two species was similar over three years (Fig. 3). The yarrow + white clover mixture revealed quality and NDVI trends similar to the yarrow monostand, but with higher NDVI values and quality ratings from December 2019 to March 2020 (Fig. 4). The white clover + strong creeping red fescue mixture produced a sward with NDVI values similar to those of a white clover monostand, and a visual quality

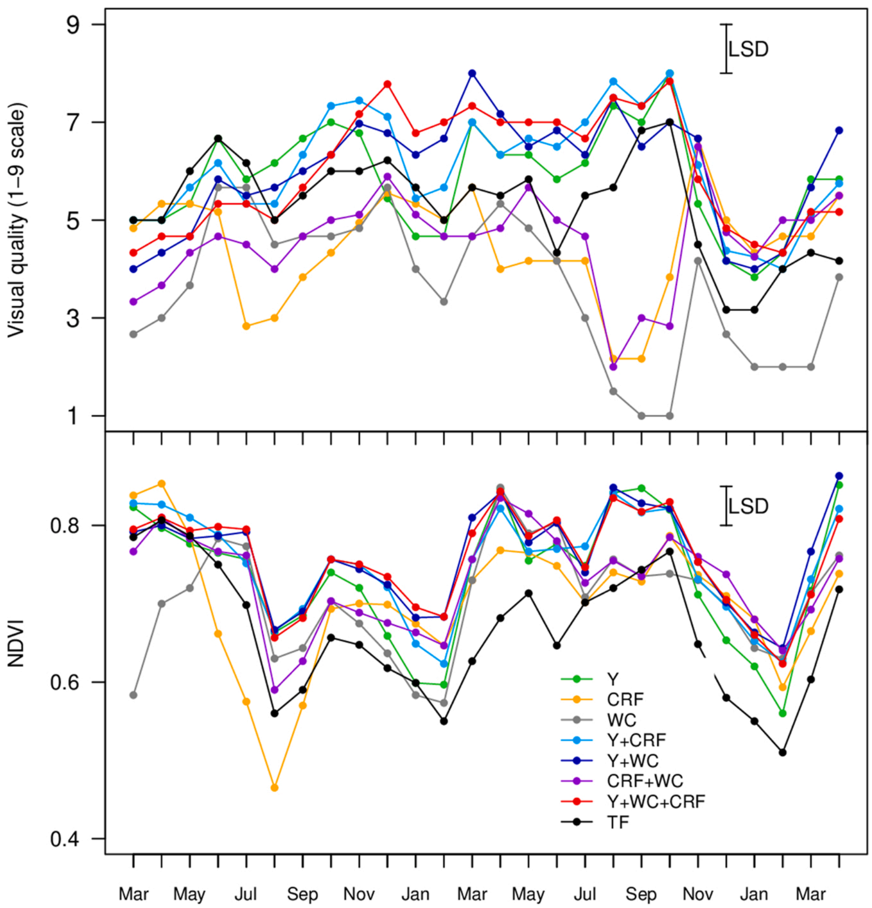

Fig. 4. Visual quality and normalised difference vegetative index (NDVI) of plots during the study period (March 2019-March 2021). Y = plot seeded with yarrow; CRF = plot seeded with strong creeping red fescue; WC = plot seeded with white clover; Y+CRF = plot seeded with yarrow and strong creeping red fescue; Y+WC = plot seeded with yarrow and white clover; CRF+WC = plot seeded with strong creeping red fescue and white clover; Y+WC+CRF = plot seeded with yarrow, white clover, and strong creeping red fescue; Fa = plot seeded with tall fescue. Error bars represent the least significant difference determined at $P \leq 0.05$.

behaviour halfway between the monostand of the two species (Fig. 4). However, the white clover + strong creeping red fescue mixture provided its best quality rating of ≥ 5 only in December 2019 and again in November 2020. The mixture of yarrow + strong creeping red fescue + white clover had visual quality similar to the mixture of yarrow + white clover (Fig. 4) as a consequence of the low presence of white clover in this mixture (Fig. 3).

The tall fescue monostand displayed visual quality between 5 and 6 until the end of 2020, with a decrease to 3 and 4 in the last months of the field study (Fig. 4). In the tall fescue monostand plots, NDVI values were low throughout the entire study period, with some slight increases corresponding to fertilisations in March and September.

3.3. *Vertical growth and dry matter production*

A significant interaction between sampling date and sward type was detected for cumulative vertical growth and for cumulative dry matter in both growing seasons (Fig. 5). In 2019, the vertical growth and the dry matter production were higher than in 2020, especially from mid-May (Fig. 5), probably due to the lower air temperatures of the season. In 2019, the vertical growth and the dry matter production displayed increasing differences among sward types starting in July (Fig. 5). At the end of the growing season, cumulative vertical growth was higher for the white clover monostand and the white clover + strong creeping red fescue mixture, followed by the yarrow + white clover mixture, and between the yarrow + strong creeping red fescue + white clover mixture which were different from yarrow monostand, the mixture between yarrow + strong creeping red fescue, and the strong creeping red fescue monostand (Fig. 5). The yarrow monostand was the sward type with the lowest vertical growth (Fig. 5). Conversely, the sward type with higher dry matter production at the end of the growing season were the white clover monostand, the strong creeping red fescue + white clover mixture, the yarrow + white clover mixture, and the yarrow + strong creeping red fescue + white clover mixture (Fig. 5). The yarrow monostand and the yarrow + strong creeping red fescue mixture displayed higher dry matter production than the tall fescue monostand (Fig. 5). Within the tall fescue monostand from the end of June until mid-August in 2020, the lower turf growth was most likely attributed to low precipitation (Fig. 2). At the end of the field study in 2020, sward types with higher vertical growth were the white clover monostand, the white clover + strong creeping red fescue, the yarrow + white clover, and the yarrow + strong creeping red fescue + white clover mixtures (Fig. 5), confirming the results observed in 2019.

4. Discussion

4.1. *Sward stability and performance*

The competition among species affects uniformity and visual or aesthetic quality of a turfgrass sward, and for this reason several studies investigated the dynamics of botanical composition in turfgrasses (Dernoeden et al., 1998; Hall and Taylor, 1989; Hunt and Dunn, 1993; Macolino et al., 2014; Pornaro et al., 2021). In this study, we observed that among seeded species, yarrow, strong creeping red fescue, and tall fescue were well established in the spring following the late summer/-early fall seeding and their relative abundance was stable through the entire study period. This confirms the aggressive behaviour in terms of competition for space and nutrients of these species (Bourdôt, 1980; Elliott and Baenziger, 1977) forming a dense and uniform canopy and ground cover. It is interesting to observe that yarrow and strong creeping red fescue are able to cohabit, thus resulting in a canopy with a

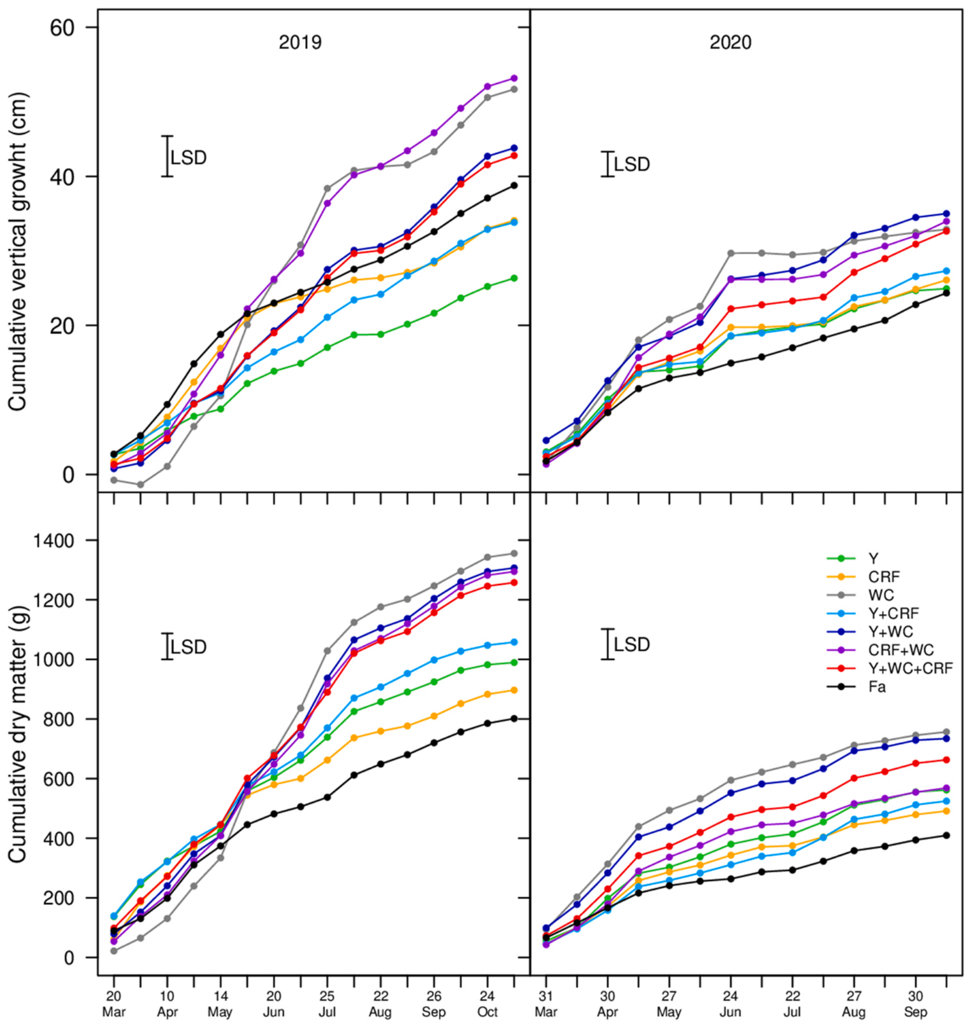

Fig. 5. Cumulative vertical growth and dry matter of plots during the growing period (March-October) of 2019 (on the left) and 2020 (on the right). Y = plot seeded with yarrow; CRF = plot seeded with strong creeping red fescue; WC = plot seeded with white clover; Y+CRF = plot seeded with yarrow and strong creeping red fescue; Y+WC = plot seeded with yarrow and white clover; CRF+WC = plot seeded with strong creeping red fescue and white clover; Y+WC+CRF = plot seeded with yarrow, white clover, and strong creeping red fescue; Fa = plot seeded with tall fescue. Error bars represent the least significant difference at a probability level of 0.05.

stable botanical composition over time (Fig. 3). The botanical surveys made in May 2019 revealed the presence of species other than seeded only in the white clover monostand and in the mixture containing white clover + strong creeping red fescue (Fig. 3). The low NDVI value observed in the white clover monostand in March 2019, and most likely due to low vegetative plot coverage, suggests that a slow growth during the early establishment phase of white clover favours weed invasion. The percentage of species other than seeded was also low and stable over time in plots with yarrow either in monostand or mixture (yarrow + strong creeping red fescue, or yarrow + white clover +strong creeping red fescue), demonstrating that a dense sward formed by yarrow can reduce or suppress weed invasion (Hann et al., 2020). Moreover, forage-type white clover, with its sparse habitus (Smith and Fellowes, 2014) was unable to compete with other species (i.e., seeded or weeds) even at a mature stage of growth. This result agrees with a study comparing different seeded grass-free swards reporting that white clover was not suitable in a sward because its' stolon growth decreased with increasing stolon density (Smith and Fellowes, 2014). Furthermore, Smith and Fellowes (2014) observed that older parts of white clover die after two to three years from establishment. In the strong creeping red fescue monostand, the percentage of species other than seeded increased over time due to low tolerance of this species to higher summer air temperature (Elliott and Baenziger, 1977).

Our results demonstrated that until fall 2020, plots seeded with a mixture including yarrow displayed sufficient or higher quality ratings in all seasons. Yarrow alone was not able to maintain such quality in winter, but when mixed with strong creeping red fescue the two species seemed to compensate each other's defects respectively, maintaining their relative abundance over time as well as suppress or prevent significant weed invasion. Hiesey (1953), reported that a temperature below 5 °C induced a winter dormancy in yarrow while high summer temperature did not influence plant vigour, but only flowering stem production. This suggest that a sward composed by yarrow and red fescue takes advantages by yarrow high temperature tolerance in summer, when strong creeping red fescue suffers (Elliott and Baenziger, 1977). On the other hand, in winter, strong creeping red fescue performs well as it easily withstands the cold temperature of the study site (Braun et al., 2020; Ruemmele et al., 2003). Of note, the mixtures of yarrow + white clover, or white clover + yarrow + strong creeping red fescue produced a better sward performance during winter than yarrow monostand and yarrow + strong creeping red fescue, probably due to N fixation process of white clover. Sincik and Acikgoz (2007) found that inclusion of white clover in turf mixtures with grasses showed better turf colour ratings than the pure grasses at all sampling dates, especially in unfertilised low-fertilised plots, but the botanical composition was not stable over time.

Generally, during spring the yarrow monostand, tall fescue monostand, and yarrow + strong creeping red fescue mixture reached sufficient or high quality ratings, and that quality increased during late summer and fall. The performance of the strong creeping red fescue monostand and the strong creeping red fescue + white clover mixture was poor in summer and fall, again due to low tolerance of this species to higher summer air temperature (Elliott and Baenziger, 1977). Even if white clover growth well in soils with high moisture content (Sheaffer and Evers, 2007), it maintained a quality rate of 5 during the summer of the first year suggesting that water availability was not a limiting factor.

Schiavon et al. (2021a) compared tall fescue cultivars under two N fertilisation regimes (75 and 150 kg N ha^{-1} $year^{-1}$) including the cultivar 'Lexington', and reported visual quality trends similar to those found in this study. However, the results reported in Schiavon et al. (2021a) were derived from the average of the two fertilisation rates, while in this experiment the N rate was 75 kg N ha^{-1} $year^{-1}$. Compared to tall fescue, which is considered an excellent low maintenance species able to maintain sufficient visual quality and high NDVI values with low N inputs (Schiavon et al., 2021a, 2021b), the major plots in this study that included yarrow consistently produced higher visual quality. The low rate reached by tall fescue throughout the study period could be due to the low-mowing frequency that resulted in a scalping during the growing season (Beard, 1973), while it suffered the low temperature during winter (Fig. 1; Schiavon et al., 2021).

4.2. Sward type effect on management

The vertical growth and dry matter production displayed increasing differences among sward type starting from July. These differences in vertical growth were due to the different plant habitus of the species rather than plant vigour. In fact, the sward type with higher NDVI values were not necessarily the sward with the higher growth rate. In particular, the leaves of white clover tend to growth vertically with a long petiole compared with yarrow leaves that tend to be more prostrate (Fig. 5; Smith and Fellowes, 2014). However, summer annual C4 grasses such as *Digitaria sanguinalis* (L.) Scop. or *Setaria italica* (L.) P. Beauvois, not recorded during the spring surveys but which may reasonably have emerged in plots where competition of seeded species was low, could also have affected canopy vertical growth rate. Seasonal variations in air temperature and precipitation strongly affected vertical growth and dry matter production. In 2020, from the end of June until the mid-August, most plots produced no or slight growth due to low precipitation and high temperatures (Figs. 1 and 2). In fact, the tall fescue monostand was the only one with a slight increase in vertical growth, confirming the high drought tolerance of this species (Pornaro et al., 2016; Schiavon et al., 2014). In autumn 2020 and 2021, the sward types with higher vertical growth were the white clover monostand, the two-species mixtures white clover + strong creeping red fescue and yarrow + white clover, and the three-species mixture yarrow + strong creeping red fescue + white clover (Fig. 5). However, among the swards compared, the yarrow monostand, the strong creeping red fescue monostand, and the yarrow + strong creeping red fescue mixture could be maintained with lower number of mowing events.

5. Conclusion

This field study demonstrated that alternative plant species to turf-type grasses produced a visual quality equal to or better than tall fescue maintained under low fertilisation and mowing frequency. Among the alternative species evaluated, yarrow was associated with better overall sward quality. All swards that included yarrow produced better visual quality ratings, exhibited better weed control, had lower vertical growth rate, and provided an aesthetically pleasant, persistent, and sustainable vegetative ground cover. Thus, yarrow can be successfully utilised as an alternative to traditionally grown turf species in the environment and climate of northern Italy, the Mediterranean region, with the potential to be used as a low-input species. Although yarrow has been speculated to be wear resistant, which is a useful characteristic for vegetative swards, further experiments are needed to test its wear resistance when managed as an amenity turf.

CRediT authorship contribution statement

Cristina Pornaro: Data curation, Formal analysis, Investigation, Software, Visualization, Roles/Writing – original draft. **Michael Fidanza**: Supervision, Validation, Visualization, Writing – review & editing. **Stefano Macolino**: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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