A multifunctional alternative lawn where warm-season grass and cold-season flowers coexist

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Abstract

Lawns provide green infrastructures and ecosystem services for anthropized areas. They have a strong impact on the environment in terms of inputs (water and fertilisers) and maintenance. The use of warm-season grasses, such as *Cynodon dactylon* (L.) Pers., provides a cost effective and sustainable lawn in the dry summers of the Mediterranean. In winter, Bermudagrass is dormant and brown, which instead of being a problem could be an opportunity for biodiversity through the coexistence of flowering species. This study assesses the possibility of growing autumn-to-spring-flowering bulbs and forbs with Bermudagrass, in order to provide ecosystem services in urban areas. Eight geophytes and 18 forbs were incorporated into a mature turf of hybrid Bermudagrass, *Cynodon dactylon* x *C. transvaalensis* cv. “Tifway”. At the same time, a commercial flowering mix was sown in the same conditions. Two different soil preparations, scalping and turf flaming, and two different nitrogen doses, 50 and 150 kg ha^{-1}, were carried out before sowing and transplanting. The flowering plants were counted. All the bulbs and six of the 18 forbs were able to grow and flower in the first and second years. The commercial mix was in full bloom from April until the cutting time for the hybrid Bermudagrass, at the end of May. Adding the flowering species did not affect the healthy growth of the warm season grass. The fertilization dose had no effect, while turf flaming led to a wider spread of *Bellis perennis* L and *Crocus spp*. Several flower-visiting insects were observed in the spring.

Keywords: *Cynodon dactylon* (L.) Pers.; *Cynodon transvaalensis*; geophytes; forbs; flaming; nature-based solutions.

Highlights:

- Warm season grass lawns are effective in dry climates
- Turf flaming before seeding affected the establishment of some forbs
- Forbs and geophytes develop and flower in turfs, thus providing ecosystem services
- *Muscari armeniacum* L. showed a great adaptation to the naturalisation in Bermudagrass
- Bermudagrass dormancy can be considered as an opportunity for biodiversity

1. Introduction

The continuous increase in land areas devoted to urban development has an impact on the wildlife species normally found in such areas. The appropriate planning of landscapes around homes, businesses, industrial complexes, and public buildings can help support a representative wildlife community that residents can enjoy (Beard and Green 1994), as well as contributing to managing the range of habitats in and around where people live, work, and play (Nilon 2011).

Lawns can provide beauty and appeal that help to improve the quality of life for citizens, recreational activities on turf are vital to contemporary society, especially in densely populated urban areas (Ignatieva *et al*. 2015) Their aesthetic benefits are enhanced when combined within an integrated landscape of trees, shrubs, and flowers and where urban pollinators can find a suitable habitat (Ahrné et al. 2009; Ockinger *et al*. 2009; Matteson and Langellotto 2010).

Bolund and Hunhamma (1999) proposed six major groups of important urban ecosystem services for lawns: air filtering, micro-climate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational/cultural factors.

In studies carried out in Texas (USA) by Beard and Johns (1985), in August the overall temperature of urban areas may be as much as 5 to 7 °C warmer than that of nearby rural areas. Through the cooling process of transpiration, turfgrasses dissipate high levels of radiant heat. Maximum daily canopy temperatures of a growing Cynodon turf were found to be 21°C cooler than a brown dormant turf and 39°C cooler than a synthetic surface (Beard and Johns 1985; Beard and Green 1994).

One of the most important ecosystem services provided by green urban infrastructures is rainwater drainage: in cities lacking vegetation, up to 60% of the rainwater is lost with the surface runoff. On the other hand in permeable surfaces, such as lawns, the rainwater infiltrates the soil, supplying moisture for the plants and fauna, ending up in the water table: so the runoff is only reduced to 5–15% (Ignatieva *et al*. 2015).

Lawns can also have positive effects on the environment, through carbon sequestration in the soil (Qian *et al*. 2010; Zirkle *et al*. 2011), however the positive effect on the environment may be negated by the frequent use of lawnmowers powered by fossil fuels that cause pollution (Law *et al*. 2016; Ignatieva 2017). In fact, the environmental impact of lawns very much depends on the intensity of the management: when chemical fertilizers, pesticides and herbicides are used, the surrounding surface water and ground-water may be contaminated (Cameron *et al*. 2012). Lawn grasses are also the largest irrigated non-food crops (Ignatieva and Hedblom 2018).

So-called “conventional” lawns are intensively managed and frequently cut short, whereas “meadow-like lawns” are cut less frequently. The latter lawns are closer to natural grassland as they are rarely mown and have a higher number of species (Ignatieva 2017). The level of management interferes negatively with the degree of biodiversity (Bertoncini *et al*. 2012).

Warm season grasses, in physiological terms C4 photosynthetic pathway grasses, are commonly used for turfs in tropical to temperate climates, as they have a good wear resistance and high tolerance to summer drought and heat stress. This is unlike the cool season grasses, in physiological terms C3 photosynthetic pathway grasses, which are more sensitive to these environmental factors (Beard 1973). However, in Mediterranean climate areas in Europe, there is a distinctly seasonal pattern: winter low temperatures prevent growth, and the warm season turfgrass species enter winter dormancy and turn brown (Croce *et al*. 2004; Volterrani and Magni 2004). To overcome this problem, high maintenance lawns, such as sports turfs, are generally overseeded with a cool season grass, to obtain a green cover throughout the year. This practice requires agronomic knowledge and is not always economically feasible for home lawns or amenity ornamental lawns (Mirabile *et al.* 2016).

Cynodon dactylon (L.) Pers. (Bermudagrass) is one of the warm season grasses that best tolerates drought stress (Beard 1989). It is widely used in Italy due to its adaptability to the Mediterranean climate both as *Cynodon* spp and as interspecific hybrid with *Cynodon transvaalensis* Burtt Davy (Volterrani and Magni 2004). When temperatures fall below 10°C in autumn or early winter, *C. dactylon* stops growing, and when temperatures drop below 0°C, plants enter dormancy and the leaf blades turn brown. Low temperature tolerance varies significantly among cultivars, but on average, all bermudagrasses lose their green colour when the temperatures fall below 0°C. In spring, dormancy terminates when the soil temperature has an average above 10°C for several days (Double 1996; Mirabile *et al*. 2016).
Bermudagrass survives the dormancy period using the reserves of non-structural carbohydrates and nitrogen compounds accumulated in storage organs (Macolino *et al*. 2010; Volterrani *et al*. 2012; Giolo *et al*. 2013; Pompeiano *et al*. 2013; Magni *et al*. 2014).
Traditional turfs in parks or in private areas are dominated by a grass monoculture, preventing the growth of other species. They are kept constantly mown and weeded in order to have a short and tidy sward: the perfect green lawn (Jenkins 1994).
Ignatieva (2017) reviewed the early landscape gardeners at the beginning of the 20th century, who proposed the use of alternative lawns enriched with wild flowers. In his wild garden in the UK, William Robinson experimented with hardy native and exotic bulbs and various

herbaceous perennials in the grass. Deriving inspiration from nature, Willy Lange in Germany proposed the use of natural flowering seed mixtures in lawns. Recent research into natural landscape gardening has focused on urban forestry, sown-on-purpose meadows, and extensive green roofs (Dunnet and Hitchmough 2004; Bretzel *et al*. 2016).
In Arkansas (USA) a trial was carried out to examine the flowering capacity and persistence of several early spring bulbs in a zoysia grass lawn (*Zoysia japonica* Steud.) (Richardson *et al*. 2015). In Italy intercropping was carried out between some forbs and bulbous species with hybrid Bermudagrass, “to provide an aesthetically pleasing groundcover during its winter dormancy” (Mirabile *et al*. 2016). “The presence of flowering species in the dormant turf provided an attractive green groundcover and created a more sustainable lawn with a higher biodiversity” (Mirabile *et al*. 2016 p. 196). Lawns can provide a habitat for pollinators if incorporating flowering species (Robinson and Lundholm 2012). Biodiversity conservation needs to be considered when planning new urban green areas (Bretzel *et al*. 2016; Gavrilidis *et al*. 2019), while multi-coloured flowering habitats can attract people and insects (Hoyle *et al*. 2017; Hoyle *et al*. 2018).

In the warm-temperate Mediterranean area of central Italy, our aim was to improve, the visual attractiveness and biodiversity of a warm-season turf of hybrid Bermudagrass, by incorporating autumn-to-spring flowering bulbs and forbs together with a commercial annual mix. In addition, we assessed the effects of management: turf flaming and scalping as weed control, and two different doses of organic fertiliser, on plant establishment and development, thus enabling us to evaluate the cost efficiency. To assess the overall value of the lawn, we also observed the presence of pollinators.

2. Materials and Methods

2.1 Experimental set up

The trial started in October 2016 and ended in May 2018 at the Experimental Research Station of the Department of Agriculture, Food and Environment (DAFE), University of Pisa, (Italy) (43◦40_N,10◦18_E, 6 m asl.).
Table 1 shows temperatures and rainfall during the experimental period. The trial site is open and sunny. The soil presents the following properties: silty loamy texture, pH 7.7, nitrogen 1.0 g kg^{-1}, phosphorus 12 mg kg^{-1}, potassium 126 mg kg^{-1}, organic matter 21 g kg^{-1} (ASA-SSSA 1996). The experiment was carried out on a hybrid Bermudagrass lawn composed of *Cynodon dactylon* x *Cynodon transvaalensis* cv. “Tifway” (hereafter Cdxt), as in a

previous trial (Mirabile *et al*. 2016). Native forbs (18 species of annuals and perennials) were seeded, and eight species of geophytes were planted (Table 2). The ecological model that inspired the choice of species was the spontaneous vegetation (spontaneously appearing biotopes dominated by grass and forbs) of local urban and rural areas, mown periodically in summer. Our key criteria were the flowering period (autumn-spring) and the capacity to thrive with grasses and mowing frequencies typical of ornamental lawns.
At the same time, on different plots of the same hybrid Bermudagrass sward, the commercial mix "*Poesie printaniere*" (Euroflor) was sown. The mix was composed of the selling company of variable quantities, not specified, of the following species: *Centaurea cyanus* L.*, Chrysanthemum carinatum* Schousb., *Clarkia elegans* Lindl., *Coreopsis tinctorial* Nutt.*, Echium vulgare* L.*, Layia platyglossa* (Fisch.&C.A.Mey.)A.Gray, *Linum grandiflorum* Desf.*, Linum usitatissimum* L.*, Nigella damascene* L.*,* and *Papaver rhoeas* L..

The experimental design was a split plot with four replications. The first order plots were 4.8 m^2 (4.0 m x 1.20 m), and the second order plots were 2.40 m^2 (2.0 m x 1.20 m). Plots were separated by a pathway of 0.5 m. Before sowing and transplanting, two different soil preparations, turf flaming (hereafter, flaming) and scalping were carried out in the first order plots, and two different fertilizer doses of 50 and 150 kg ha^{-1} N (Grena Ultra micro fertilizer, total N 6%) were applied in the second order plots. Turf scalping was carried out with a flail lawn mower (Amazone) at a 1.0 cm cutting height. Weed flaming was carried out with a self-propelled experimental machine built at the University of Pisa (Raffaelli *et al*. 2013) and used previously for weed control in urban contexts, the machine was equipped with five 25-cm-wide rod burners and fuelled by liquefied petroleum gas (LPG).

The aim of the soil preparations was to eliminate any excessive thatch, thus improving the contact seed/soil and creating free space to allow for the growth of bulbs and forbs. Flaming is becoming more common as an alternative to chemical weed control, and scalping is widely used to prepare the soil before turf overseeding and to reduce the thatch (Aldous et al. 2014). Fertilization was applied only during the first year. Seeding and the manual transplanting of bulbous species took place on 22 November 2016, and for a more uniform distribution, the seeds were mixed with silica sand. The broadcast seeding was carried out when there was no wind, and close to the soil surface to prevent seeds drifting into adjacent plots.

2.2 Germination treatments

After monitoring the first results, germination trials were set up to examine the possible reasons for the failure of field germination. Different seed treatments were administered to some of the forb seeds (Table 3): chilling, gibberellic acid (GA3), sodium hypochlorite (NaClO) and washing (Benvenuti and Macchia 2006). Seeds that had the chilling treatment were placed in Petri dishes equipped with moistened filter paper, and maintained at a low temperature (4 °C) in darkness. Seeds treated with gibberellic acid, were soaked in a solution containing 200 ppm of GA3 for 30 minutes. Throughout the treatment, seeds were constantly stirred in order to achieve uniform seed contact with the solution. Seeds treated with sodium hypochlorite solution, diluted to 50% with distilled water for 10 minutes, were washed under running water to eliminate the residual solution at the end of the treatment. Seeds were washed under running water for five minutes.

The mean germination time (MGT) was calculated as follows: $\sum_{i=1}^{k} n_i t_i / \sum_{i=1}^{k} n_i$. t_i refers to the days from the start of the germination test to the i^{th} observation, n_i is the number of germinated seeds in the i^{th} time and k is the last day of germination (Benvenuti et al. 2001; Ranal et al. 2009). To determine the percentage of germination and MGT, treated and non-treated seeds were incubated in a climatic chamber at 20°C for four weeks and a photoperiod of 12 hours.

2.3 Turf management

From the end of May, corresponding to the complete spring green-up of the Cdxt, to November, corresponding to the start of dormancy of the turf, plots were mown once a week at a mowing height of 4 cm, for the two years of the trial. Turfs were irrigated once a week from June to September during both years of the trial.

2.4 Data collection

Every two weeks from autumn to spring, the number of bulb and forb flowers produced were counted. The counting of the commercial mix was carried out just during the first year as all the species were annual.

Cdxt spring green-up, expressed as the percentage of green cover was estimated every week from April 2017 to May 2017, and from April 2018 to May 2018. Data reported refer to 31 May when some of the plots first exceeded the 60% threshold (NTEP 2012).

The pollinators were observed in April, while they were visiting flowers, at the warmest time of the day (about h 12.00 a.m.) and in the absence of wind. They were identified from the photos at the possible taxon level (genus or species) (Benvenuti and Bretzel 2017).

2.5 Statistical analysis

All data collected were subjected to two-way ANOVA to examine the effects of the type of treatment (flaming and scalping) and the year of the trial, on the density of flowers in bulbs and forbs. The homogeneity of the variance within the classes was verified with Bartlett's test. The two-way ANOVA showed statistically significant differences in the variance depending on the year (P-value <0.05), but not on the treatment administered, because the individual species have very different behaviours compared to the administration of the trial. For this reason, we did not perform multiple comparisons on the entire data set, but instead investigated the behaviour of the individual species, with respect to the year and to the trial, by carrying out the paired-sample T-test (U-test in the non-parametric case). All statistical analyses were conducted using R Studio (Version 3.5.3).

For germination, average germination time and flower density standard errors (SEs) were also calculated.

The analysis showed that there was no statistical difference in the flower density in bulbs and forbs attributable to the different doses of nitrogen administered, and therefore we did not group the data on the basis of this variable.

3. Results

3.1 Bulbous species

In terms of flower density, the results showed that for *Galantus nivalis* L., *Iris reticulata* M. Bieb., *Allium triquetrum* L. and *Anemone blanda* L. an average flower density lower than 3 (number of flowers m^{-2}) was recorded, while for *Crochus pulchellus* Herb 6.3 flowers m^{-2} and *Allium roseum* L. and *Muscari armeniacum* Leich 9 and 8.8 flowers m^{-2}, respectively (Table 4). Considering the propensity of the species to emit multiple inflorescences, *M. armeniacum* showed the best propensity, producing 2.2 inflorescences per plant. The lowest production was observed for *I. reticulata, G. nivalis*, *Crochus tommasianus* Herb. and *A. blanda* with values lower than 1 (0.4, 0.6, 0.7 and 0.8 inflorescences per plant, respectively).

In the second year, *M. armeniacum* greatly increased the number of inflorescences per plant (4.4), as shown in the boxplot (Fig. 1a), while other species remained constant or decreased (*A. roseum*).

3.2 Forb species

Sowing after flaming generally produced the greatest density. In the first year (P<0.01) and the second year (P<0.01), flaming significantly affected the flower density in *Bellis perennis* L. (Fig. 1b). During the second year, the number of flowers in *B. perennis* significantly increased (P<0.01) (Fig. 1c).

The flower density of *Calendula arvensis* L. was highest with flaming (P<0.01) (Fig. 1d). *Erodium cicutarium* L.*, Geranium mole* L., and *Lobularia maritima* L. did not seem to be influenced by the effect of soil preparation in the first year. By the early May monitoring (10^{th}) the annual species had produced seeds.

During the second year, the flower density in the plots of *C. arvensis* and *G. molle* increased (Fig. 1e); *E. cicutarium* reduced its density, and *L. maritima* disappeared from the plots. *Tordilium apulum* L. appeared with an average constant density in the plots, regardless of the soil preparation and the N dose (Table 5).

3.3 Flowering period

Table 6 shows the complementarity of flowering between bulbs and forbs during the two years of the trial.

Most of the forbs species flowered from early to late spring, while the bulbs had an earlier flowering at the end of winter. In the second year, the flowering was generally earlier than the first year, although the forbs and some bulbs carried on flowering at the beginning of the Cdxt green-up. *Crocus pulchellus* flowered in the winter, which in the second year was one month earlier. In fact it produced flowers from November to December in 2016, while in 2017 the flowering lasted throughout November. *M. armeniacum* flowered from March to April for both years of the trial, producing 1-7 inflorescences per plant, and at the end of flowering, this species produced seeds. *Bellis perennis* and *C. arvensis* were the earliest flowering species in the second year after seeding. Alliums showed late flowering (April-May), when hybrid Bermudagrass spring green up had almost finished. No flowering was detected for *T. apulum* in 2016, which flowered throughout April 2017, displaying a massive quantity of flowers and attracting many insects.

3.4 Commercial mix

Some of the species in the mix began flowering in April (*Laija platyglossa* and *Linum grandiflorum*), and *Papaver rhoeas* flowered at the beginning of May, while all the others flowered from May 10 onwards. They all kept flowering until the cutting time at the end of May. The total flower density of the species was similar in all the experimental conditions (Table 7). As regards the individual species, *L. platyglossa* (Fig. S1) and *Clarkia elegans* had the largest production of flowers.

3.5 Hybrid Bermudagrass green-up

The Bermudagrass turf green cover at the end of the spring green-up (May), was not significantly influenced by soil preparation or by the nitrogen doses applied (Table 8). The green cover mean value of Cdxt was 66% the first year, and 61% the second year. These values were not significantly different from the non-treated turf (not sown with forbs and not transplanted with bulbs). The remaining area on the plots (34% the first year, and 39% the second year) was represented in equal measure by bare soil and weeds.

3.6 Forb germinability

To investigate the reasons why many forb species failed to germinate in the field trial, we carried out a germinability test *a posteriori*. The results are reported in Table 3. *Erodium cicutarium* and *G. molle*, which had failed to germinate in the laboratory trial, succeeded in the field trial; *B. perennis* and *C. arvensis* succeeded in both; *Hypochoeris radicata* L.:*, Leontodon autumnalis* L.*, Linaria vulgaris* Mill.*, L. maritima, Primula veris* L., *Prunella vulgaris* L.*, T. apulum, Veronica chamaedris* L. benefited from the germination treatments and succeeded in the germination trials.

3.7 Insect observation

The observations were at the beginning of the warm season (March-April). The flowers that attracted insects the most were: *M. armeniacum* which attracted Hymenoptera Apoidea (*Apis mellifera* L., honey bee, (Fig. S2), *Xylocopa violacea* L., violet carpenter bee, Lepidoptera *Vanessa cardui* L. (painted lady); *T. apulum* attracted Diptera Syrphidae (*Episyrphus* spp. and *Eristalis* spp.), hover fly and Tipuloidea, crane fly (Fig. S3). We also observed active Coleoptera (*Coccinella septempunctata* L. (ladybird) on the green parts of the plants and *Oxythyrea funesta* P., chafer beetle, on *B. perennis* inflorescences.

3.8. Cost-efficiency

The installation cost of the hybrid Bermudagrass turf, by sod, is about €15/m^2 including materials, transport and installation, while the approximate cost of the sowing is 4 €/m^2, including all the operations. Overseeding with winter grass can cost 0.40 €/m^2, however it has to be repeated every year. On the basis of the results of our study the most successful bulb and forb mix is shown in Figure 2 and Figure S4, we thus considered the costs of this mix: 6.4 €/m^2 (5.7 €/m^2 bulbs and 0.72 €/m^2 forbs). The seeding of the commercial mix "*Poesie printaniere*" (Euroflor), costs about 1 €/m^2, seeding 4 g/m^2.

4. Discussion

Our results showed that it is possible to incorporate bulbs and forbs in a mature turfgrass, composed of *C. dactylon x transvaalensis*. The results also showed that flaming prior to seeding is beneficial for forb establishment, especially *B. perennis* and *C. arvensis* and for some flowering bulbs. Different doses of nitrogen fertilization had no effect on the flowering, although during the second year without fertilization, the bulb flower production declined, except for *M. armeniacum*. While the forb germination benefited from flaming, this treatment did not negatively affect the turf vigour nor the presence of forbs and bulbs. The annual commercial mix produced considerable blooming in April - May, just before the green up of the hybrid Bermudagrass.

Early flowering bulbs provide colour and decoration in gardens, when the need for turf mowing is not urgent, because of the warm-season grass dormancy. Richardson *et al*. (2015) found that after three years, only Ruby giant crocus performed effectively in Zoysiagrass. On the other hand, our findings showed that *M. armeniacus* is a promising species for naturalization in hybrid Bermudagrass, as well as *I. reticulata*, *G. nivalis*, and *A. blanda*. The latter three species are appropriate for adding colour and biodiversity to the warm season grass, in spite of the reduction in the number of flowers in the second year. *Crocus pulchellus* proved very interesting for the early flowering, and was the only species in our trial that flowered in November-December (Mirabile *et al*. 2016).

In terms of forbs, in the second year, *B. perennis and G. molle* showed a good tendency to spread and naturalise in the turf. In addition, *C. arvensis* was able to seed disperse and grow, unlike findings in a previous study (Mirabile *et al*. 2016). *Bellis perennis* has a great phenotypic plasticity (i.e. an adaptive strategy), and tends to vegetate and flower in early spring, while it dies back in summer (Warwick and Briggs 1979). *Erodium cicutarium* generally colonises mowed lawns abundantly in spring, thanks to the particular features of its seeds: a ballistic dispersal and capability of penetrating the soil when the crevices are small and frequent (Stamp 1984). The reason for the lack of colonization in our trials could be the impossibility of penetrating the compact soil.

The starting time of the summer mowing at the beginning of May affected whether *L. maritima* was able to reach seed maturity (Bertoncini *et al.* 2012), which may be one of the reason why this species disappeared. *Tordilium apulum*, on the other hand, tends to germinate in the summer. Consequently, due to the autumn sowing time, in our experiment it germinated in summer and developed the next year with an abundant flowering (Benvenuti and Macchia 2006). The second year, the abundant flowering of *T. apulum* attracted many different insect species, especially Diptera Syrphides. Syrphides are beneficial insects as pollinators and in the larval phase as predators of aphids, which are noxious phytophagous, so they greatly contribute to the complexity of the food web (González-Chang *et al*. 2019). During the field observations, we also found the presence of Chafer beetle (*Amphimallon* sp.), the habitat opportunist, whose presence is related to the density of the flowering plants, causing significant damage to the floral organs (Horák 2016).

The germinability test carried out to investigate the possible causes of failures highlighted the efficacy of the treatments, on some of the species that had failed to germinate in the field trial. The species with the highest percentage of germination apart from *B. perennis,* which received no treatment, were *H. radicata*, *L. maritima*, *V. chamaedris*, which only received chilling. Chilling is carried out by bringing the seeding time forward to the end of summer, so the seeds can be exposed to cycles of chill. In fact, *H. radicata* and *V. chamaedris* did not germinate in the field, while the germination rate was high in the laboratory. Probably after being buried, not by tilling but by the rain and the seed movement, the seeds of these species undergo secondary dormancy induced by poor gas diffusivity in the soil and thus low oxygen content (Benvenuti and Mazzoncini 2019). These species may need longer in the field to germinate and undergo more cycles of wet chill in order to be able to break secondary dormancy. Some of the thin seed species that failed in the germinability test, but succeeded in the field trial, such as *G. molle*, may have been affected by the excess moisture of the Petri dishes (Benvenuti 2018).

The commercial mix produced a colourful and abundant flowering. Although the period of 40 days was short, it took place at the point in the year when people start to enjoy open air activities, thus the shape and colours of the flowers are at their best appearance (Lindemann-Matthies and Brieger 2016). Plantings with a high percentage of colours (about 30%)

tend to be preferred by the general public even if just for a short period, but outside the flowering period, green is very much appreciated (Hoyle *et al*. 2017)

In terms of lawn management, *Cynodon dactylon* x *C. transvaalensis*, bulbs and forbs can be intercropped, as mowing during the summer does not hinder the flowering of bulbs and forbs in the autumn-spring period. On the other hand, the presence of bulbs and flowers enables the hybrid Bermudagrass to maintain an acceptable coverage in the summer, and it can be managed with minimal inputs. This type of intercropping may become a stable association over time by slightly increasing the amount of fertilization, as *Cynodon* needs nitrogen during the active growth period (Christians 2004).

4. Conclusions

Our study highlights the feasibility of a combination of hybrid Bermudagrass, bulbs and forbs in order to create a multifunctional, sustainable lawn, exploiting the phenological complementarity of the different life forms. In particular, the *B. perennis*, *C. arvensis*, and *G. molle* forbs and the *M. armeniacum* bulbs showed a great adaptability to coexistence, leading to a flowering and biodiverse lawn mixed with hybrid bermudagrass. The spring blooming of the commercial mix composed of flowering annuals may be an appealing ornamental solution for providing colours and shapes at the beginning of the fine weather season. The presence of some flower-visiting entomofauna is a sign of the ecological potential of the system as a habitat, which could be explored further in future studies, also in relation to the colonisation by spontaneous species of the gaps in the turf left open by the other species. Hybrid Bermudagrass dormancy from October to May represents an opportunity for increasing biodiversity during that period.

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References

Ahrné K, Bengtsson J, Elmqvist T (2009) Bumblebees (*Bombus spp*.) along a gradient of increasing urbanization. PLoSONE. http://dx.doi.org/10.1371/ journal.pone.0005574

Aldous DE, Hunter A, Martin PM, Nektarios PA, McAuliffe KW (2014) Management of sports turf and amenity grasslands. In: Dixon GR, Aldous DE (ed) Horticulture: Plants for People and Places. Springer, Dordrecht, Volume 2, pp 731-761

ASA-SSSA (1996) Methods of Soil Analysis, Part 1 and 3. Physical and Chemical Methods, 2nd edn. Madison, Wisconsin, USA

Beard JB, Johns D (1985) The comparative heat dissipation from three typical urban surfaces: asphalt, concrete and bermudagrass turf. In: Texas turfgrass Res.-1985. Texas Agricultural Experiment Station. PR-4329. College Station, pp 125-133

Beard JB, Green RL (1994) The role of turfgrasses in environmental protection and their benefits to humans. J Environ Qual 23(3):452-460.

Beard JB (1973) Turfgrass: Science and Culture. Prentice Hall, Englewood Cliffs, NJ.

Benvenuti S (2018) Propagazione della specie orticole. In: Pardossi A, Prosdocimi Gianquinto G, Santamaria P, Incrocci L (ed) Orticoltura, principi e pratica. Edagricole, Bologna, pp 74-79

Benvenuti S, Bretzel F (2017) Agro-biodiversity restoration using wildflowers: What is the appropriate weed management for their long-term sustainability? Ecol Eng 102: 519-526.

Benvenuti S, Macchia M, Miele S (2001) Light, temperature and burial depth effects on *Rumex obtusifolius* seed germination and emergence. Weed Res 41(2): 177-186.

Benvenuti S, Macchia M (2006) Germination ecology of wildflower species native to the Mediterranean environment selected for landscape restoration. Agr Med 136:167-180.

Benvenuti S, Mazzoncini M (2019) Soil physics involvement in the germination ecology of buried weed seeds. Plants 8 (1) 7.

Bertoncini AP, Machon N, Pavoine S, Muratet A (2012). Local gardening practices shape urban lawn floristic communities. Landscape Urban Plan 105(1-2): 53-61

Bolund P, Hunhamma S (1999) Ecosystem services in urban areas. Ecol Econ 29:293–301.

Bretzel F, Vannucchi F, Romano D, Malorgio F, Benvenuti S, Pezzarossa B (2016) Wildflowers: From conserving biodiversity to urban greening—A review. Urban For Urban Green 20: 428-436.

Cameron RWF, Blanusa T, Taylor JE, Salisbury A, Halstead AJ, Henricot B (2012) The domestic garden – its contribution to urban green infrastructure. Urban For Urban Green 11:129–137.

Christians N. 2004. Fundamentals of turfgrass management. Wiley, Hoboken, New Jersey. p. 359

Cornelissen JHC, Lavorel S, Garnier E, Diaz S, Buchmann N, Gurvich DE, Reich PB, ter Steege H, Morgan HD, van der Heijden MGA, Pausas JG (2003) A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. Aust J Bot 51(4):335-380.

Croce P, De Luca A, Mocioni M, Volterrani M, Beard JB (2004) Adaptability of warm season turfgrass species and cultivars in a Mediterranean climate. Acta Hortic 61:365–368.

Double R (1996) Turfgrasses, Their Management and Use in the Southern Zone. Texas A&M University Press.

Dunnett N, Hitchmough J (2004) The dynamic landscape: design, ecology and management of naturalistic urban planting. Taylor & Francis, London

Gavrilidis A A, Niță MR, Onose DA, Badiu DL, Năstase II (2019) Methodological framework for urban sprawl control through sustainable planning of urban green infrastructure. Ecol Indic 96:67-78.

Giolo S, Macolino M, Barolo E, Rimi F (2013) Stolons reserves and spring green-up of seeded bermudagrass cultivars in a transition zone environment. HortScience 48(6): 780-784.

González-Chang M, Tiwari S, Sharma S, Wratten SD (2019) Habitat management for pest management: Limitations and prospects. Ann Entomol Soc Am 112(4): 302-317.

Horák J (2016) Threatened or harmful? Opportunism across spatial scales apparently leads to success during extralimital colonisation. Insect Conserv Diver 9(4): 351-357.

Hoyle H, Norton B, Dunnett N, Richards JP, Russell JM, Warren P (2018) Plant species or flower colour diversity? Identifying the drivers of public and invertebrate response to designed annual meadows. Landscape Urban Plan 180:103-113.

Hoyle H, Hitchmough J, Jorgensen A (2017) All about the 'wow factor'? The relationships between aesthetics, restorative effect and perceived biodiversity in designed urban planting. Landscape Urban Plan 164: 109-123.

Ignatieva M, Ahrné K, Wissman J, Eriksson T, Tidåker P, Hedblom M, Kätterer T, Marstorp H, Berg P, Eriksson T, Bengtsson J (2015) Lawn as a cultural and ecological phenomenon: a conceptual framework for transdisciplinary research. Urban For Urban Green 14(2):383-387.

Ignatieva M, Hedblom M (2018) An alternative urban green carpet. Science 362(6411):148-149.

Ignatieva M (2017) Lawn alternatives in Sweden - from theory to practice. Swedish University of Agricultural Sciences Department of Urban and Rural Development. Division of Landscape Architecture. ISBN (Printed version) 978-91-85735-39-6 ISBN (Electronic version) 978-91-85735-40-2.

Jenkins S. (1994) The Lawn: a history of American obsession. Washington DC: Smithsonian Institution Press.

Law QD, Bigelow CA, Patton A J (2016) Selecting turfgrasses and mowing practices that reduce mowing requirements. Crop Sci 56(6):3318-3327.

Lindemann-Matthies P, Brieger H (2016) Does urban gardening increase aesthetic quality of urban areas? A case study from Germany. Urban For Urban Green 17:33-41.

Macolino S, Serena M, Leinauer B, Ziliotto U (2010) Preliminary finding on the correlation between water-soluble carbohydrate content in stolons and first year green-up of seeded bermudagrass cultivars. HortTechnology 20:758-763.

Magni S, Gaetani M, Grossi N, Caturegli L, La Bella S, Leto C, Virga G, Tuttolomondo T, Lulli F, Volterrani M (2014) Bermudagrass adaptation in the Mediterranean climate: phenotypic traits of 44 accessions. Adv Hort Sci 28(1):29-34.

Matteson KC, Langellotto GA (2010) Determinates of inner city butterfly and bee species richness. Urban Ecosyst 13:333–347.

Mirabile M, Bretzel F, Gaetani M, Lulli F, Volterrani M (2016) Improving aesthetic and diversity of bermudagrass lawn in its dormancy period. Urban For Urban Green 18:190-197.

NTEP, National Turfgrass Evaluation Program (2012) National turfgrass evaluation program, Beltsville, MD. http://www.ntep.org. Accessed 20 July 2018.

Nilon CH (2011) Urban biodiversity and the importance of management and conservation. Landscape Ecol Eng 7(1):45-52.

Ockinger E, Dannestam A, Smith HG (2009) The importance of fragmentation and habitat quality of urban grasslands for butterfly diversity. Landscape Urban Plan 93(1):31–37.

Pignatti S, Guarino R, La Rosa M (2017) Flora d'Italia. Edagricole, Bologna

Pompeiano A, Volpi I, Volterrani M, Guglielminetti L (2013) N source affects freeze tolerance in bermudagrass and zoysiagrass. Acta Agric Scand B-S P 63:341-351.

Qian Y, Follett RF, Kimble JM (2010) Soil organic carbon input from urban turf-grasses. Soil Sci Soc Am J 74:366–371.

Raffaelli M, Martelloni L, Frasconi C, Fontanelli M, Peruzzi A (2013) Development of machines for flaming weed control on hard surfaces. Appl Eng Agr 29:663–673.

Ranal MA, Santana DGD, Ferreira WR, Mendes-Rodrigues C (2009) Calculating germination measurements and organizing spreadsheets. Braz J of Bot 32(4): 849-855.

Rashed A, Sherratt TN (2006) Mimicry in hoverflies (Diptera: Syrphidae): a field test of the competitive mimicry hypothesis. Behav Ecol 18(2):337-344.

Robinson SL, Lundholm JT (2012) Ecosystem services provided by urban spontaneous vegetation. Urban Ecosyst 15(3):545-557.

Richardson MD, McCalla J, Buxton T, Lulli F (2015) Incorporating early spring bulbs into dormant warm-season turf grasses. HortTechnology 25 (2):228–232.

Stamp NE (1984) Self-burial behaviour of *Erodium cicutarium* seeds. J Ecol 611-620.

Volterrani M, Magni S (2004) Species and growing media for sports turfs in Mediterranean area. Acta Hortic 661:359–364.

Volterrani M, Pompeiano A, Magni S, Guglielminetti L (2012) Carbohydrate content, characterization and localization in bermudagrass stolons during establishment. Acta Agric Scand B-S P 62:62–69.

Warwick SI, Briggs D (1979) The genecology of lawn weeds. III. Cultivation experiments with *Achillea millefolium* L., *Bellis perennis* L., *Plantago lanceolata* L., *Plantago major* L. and *Prunella vulgaris* L. collected from lawns and contrasting grassland habitats. New Phytol 83:509–536.

Zirkle G, Rattan L, Augustin B (2011) Modelling carbon sequestration in home lawns. Hortic Sci 46: 808–814.

Table 1. Mean air temperatures and rainfall during the trial period (Oct 2016- May 2018).

	Mean air temperature (°C)						**Rainfall** (mm)		
	2016		2017		2018		2016	2017	2018
	Min	Max	Min	Max	Min	Max			
Jan.			1.8	9.9	6.1	13.6		41	49
Feb.			6.1	14.0	2.9	9.4		89	82
Mar.			6.9	17.0	5.5	13.2		48	185
Apr.			8.3	19.3	9.8	20.1		20	64
May			12.6	23.3	13.1	21.9		32	91
Jun.			17.2	28.2				29	
Jul.			18.1	29.5				1	
Aug.			19.0	31.5				3	
Sep.			14.9	24.2				194	
Oct.	11.9	20.4	9.8	21.1			106	7	
Nov.	8.4	16.1	5.8	14.2			123	124	
Dec.	3.6	13.6	3.0	11.2			5	135	

Table 2. Forb and bulb species added to the warm season grass (life form: A= annual; P=perennial; G=geophyte; commercial= purchased; wild=harvested in nature) (Pignatti et al. (2017); Cornelissen et al. (2003))

Species	**Family**	**Life form**	**1000 seeds weight (g)**	**Grams/ bulbs m^{-2}**	**Origin of seeds**
Alyssum alyssoides (L) L.	Brassicaceae	A	2	0.2	commercial
Calendula arvensis L.	Asteraceae	A	9	1.0	commercial
Erodium cicutarium L.	Geraniaceae	A	2	0.2	commercial
Euphorbia cyparissias L.	Euphorbiaceae	A	2.2	0.2	commercial
Geranium molle L.	Geraniaceae	A	1.1	0.08	wild
Tordilium apulum L.	Apiaceae	A	3.8	0.6	wild
Veronica chamaedrys L.	Scrophulariaceae	A	0.2	0.2	commercial
Allium roseum L.	Amaryllidaceae	G	-	6	commercial
Allium triquetrum L.	Amaryllidaceae	G	-	2	commercial
Anemone blanda L. Mix	Ranunculaceae	G	-	4	commercial
Crocus pulchellus Herb	Iridaceae	G	-	4	commercial
Crocus tommasianus Herb	Iridaceae	G	-	5	commercial
Galanthus nivalis L.	Amaryllidaceae	G	-	3	commercial
Iris reticulata M. Bieb. Mix	Iridaceae	G	-	5	commercial
Muscari armeniacum Leich. ex B.	Liliaceae	G	-	4	commercial
Bellis perennis L.	Asteraceae	P	0.1	0.2	commercial
Galium verum L.	Rubiaceae	P	0.5	0.08	commercial
Hypochoeris radicata L.	Asteraceae	P	0.7	0.08	wild

Leontodon autumnalis L.	Asteraceae	P	0.7	0.2	commercial
Leontodon tuberosus L.	Asteraceae	P	1	0.04	wild
Linaria vulgaris Mill.	Plantaginaceae	P	0.1	0.3	commercial
Lobularia maritima L.	Brassicaceae	P	0.4	0.1	wild
Primula veris L.	Primulaceae	P	1.2	0.3	commercial
Prunella vulgaris L.	Lamiaceae	P	0.7	0.2	commercial
Ranunculus acris L.	Ranunculaceae	P	1.6	0.3	wild

Table 3. Trials on forbs' germination (%) (MGT = mean germination time). Means are followed by the relative standard error. 1w= one week; 3w= three weeks; 4w=four weeks; NaClO=Sodium Hypochlorite; HCl= Hydrochloric acid; nt= not treated; GA3=Gibberellic Acid. Species that germinated in the field trial are shown with an X in the last column, ng=not germinated.

Species	Treatment	Germination (%)	MGT (days)	Field
Alyssum alyssoides	nt	ng	-	ng
Bellis perennis	nt	98±2	7±1	x
Calendula arvensis	1w-chilling	12±3	7±2	x
Erodium cicutarium	1w-chilling	ng	-	x
Euphorbia cyparissias	1w-chilling	ng	-	ng
Galium verum	HCl	ng	-	ng
Geranium molle	nt	ng	-	x
Hypochoeris radicata	washing	91±4	7±1	ng
Leontodon autumnalis	washing	5±1	26±3	ng
Leontodon tuberosus	washing	ng	-	ng
Linaria vulgaris	3w-chilling	8±2	7±1	ng
Lobularia maritima	nt	67±3	8±2	x
Primula veris	GA3	10±2	28±3	ng
Prunella vulgaris	1w-chilling	6±1	22±2	ng

Ranunculus acris	4w-chilling	ng	-	ng
Tordilium apulum	NaClO	5±1	19±3	x
Veronica chamaedris	1w-chilling	45±3	13±1	ng

Table 4. Bulbous species: flower density (number of flowers m^{-2}) recorded during the apex of blooming period of each species (November 2016-May 2017 First year, October 2017-April 2018 second year). Data are means of 4 replicates ±SD.

Species	**Year 1**		**Year 2**	
	Flaming	Scalping	Flaming	Scalping
Allium roseum	9.5±1.1	8.5±0.7	0.6±0.5	0.4±0.6
Allium triquetrum	2.0±0.4	2.0±0.4	2.0±1.1	1.5±0.5
Anemone blanda Mix	1.5±0.7	5.0±1.5	3.5±3	4.0±1.8
Crochus pulchellus	6.5±0.4	6.0±0.6	4.0±1.4	4.0±1.6
Crochus tommasianus	4.0±0.7	3.0±0.5	2.5±0.7	2.0±1.0
Galantus nivalis	2.0±0.5	1.5±0.3	1.5±0.2	1.0±0.5
Iris reticulata Mix	2.5±0.5	1.5±0.8	2.0±1.0	1.2±1.0
Muscari armeniacum	8.5±1.2	9.0±0.7	18.0±4.5	17.0±3.6

Table 5. Forb species: flower density (number of flowers m^{-2}) in relation to the effect of soil preparation and N doses, recorded during the apex of the blooming period of each species (from March 2017 to April 2017 First Year, from November 2017 to April 2018 Second year). Data are means of four replicates ±SD.

Species	**Year 1**		**Year 2**	
	Flaming	Scalping	Flaming	Scalping
Bellis perennis	3.3±0.5	1.0±0.1	57.0±7.2	23.5±3.4
Calendula arvensis	4.2±1.2	1.6±0.3	6.6±1.2	5.7±1.1
Erodium cicutarium	4.2±1.1	3.2±0.4	2.0±0.3	2.4±0.2
Geranium molle	1.0±0.2	1.0±0.1	5.4±0.6	4.0±0.3
Lobularia maritima	1.0±0.4	1.1±0.2	nd	
Tordilium apulum	nd		43.0±5.0	46.0±5.6

Table 6. Phenological complementarity of the tested species (November 2016- April 2018). The number of points (1-3) indicate the flowering period in the 10-day period of the relative months.

Forbs	**2016**		**2017**												**2018**			
	Nov	Dec	Ja	Fe	Ma	Ap	Ma	Jun	Jul	Au	Sep	Oc	No	Dec	Ja	Fe	Mar	Apr
B. perennis						●●	●●									●●	●●	●●●
C. arvensis					●	●●	●●									●●	●●	●●
E. cicutarium					●	●●	●●										●	●●
G. molle						●●	●●											●●●
L. maritima					●	●●	●●											
T. apulum																		●●●
Bulbs																		
A. roseum						●●	●●											●
A. triquetrum						●●	●●											●●
A. blanda Mix					●●	●											●●	●●
C. pulchellus	●●	●										●	●●					
C. tommasianus					●●											●●	●	
G. nivalis				●	●●											●●	●	
I. reticulata Mix				●	●											●●	●	
M. armeniacum					●●	●											●●	●●

Table 7. Commercial mix species: flower density (number of flowers m^{-2}) recorded during the apex of the blooming period (April-May 2017). Data are means of 4 replicates ±SD.

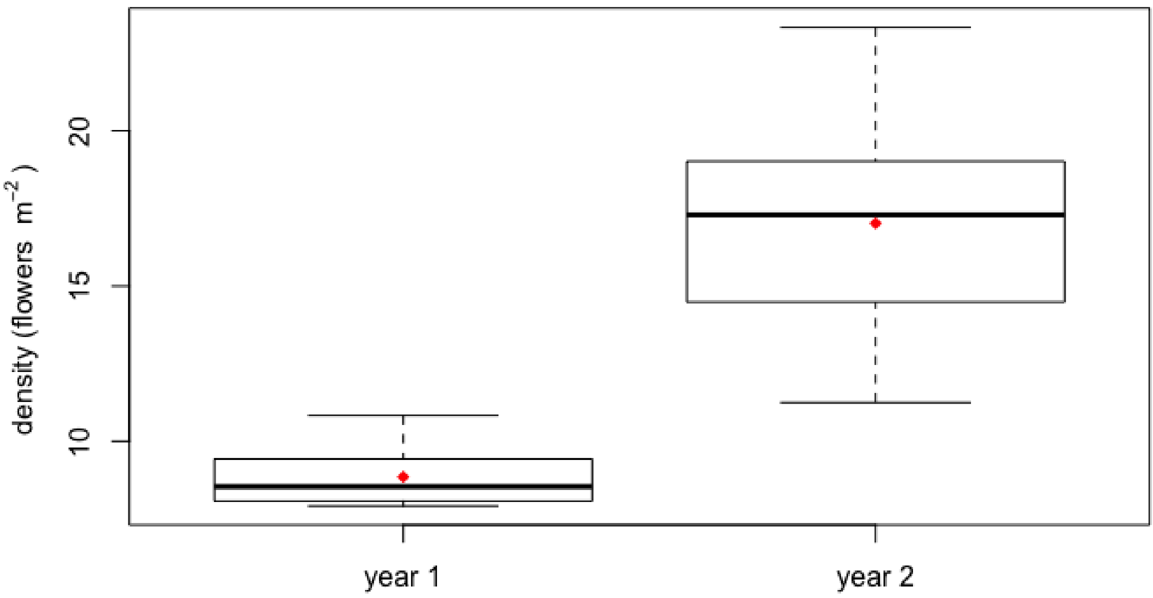
Species	**flower density (number m^{-2})**	
	Flaming	**Scalping**
Centaurea cyanus	0.2±0.06	0.06±0.01
Clarkia elegans	11.4±3.9	11.8±6.6
Echium vulgare	0.5±0.2	0.9±0.5
Laija platyglossa	6.8±2.2	8.4±1.9
Linum grandiflorum	3.7±0.3	1.7±0.7
Linum usitatissimum	1.5±0.6	2.3±0.5
Nigella damascena	0.1±0.01	0.1±0.01
Papaver rhoeas	2.8±1.3	2.4±1.4

Table 8. *Cynodon dactylon* x *C. transvaalensis* green cover (%) at the end of spring green-up period (31 May).

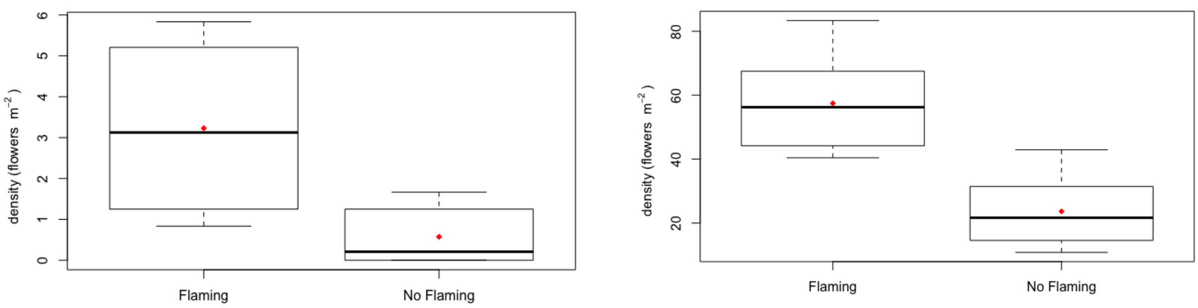
Year	**Flaming**		**Scalping**	
	N 50	N 150	N 50	N 150
2017	60	70	65	70
2018	60	60	65	60

Figure 1. Boxplots of single species flower density in relation to year and treatment. Statistical significance was determined by a paired-sample T-test (U-test in the non-parametric case).

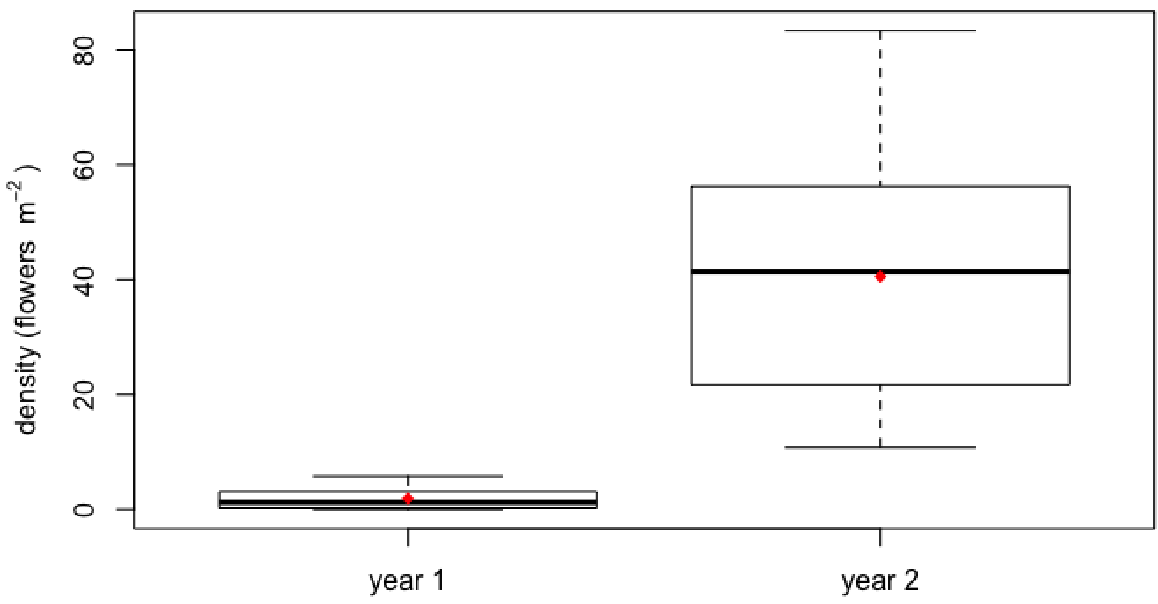
a) Effect of time on flower density in *Muscari armeniacum* ($P<0.01$).



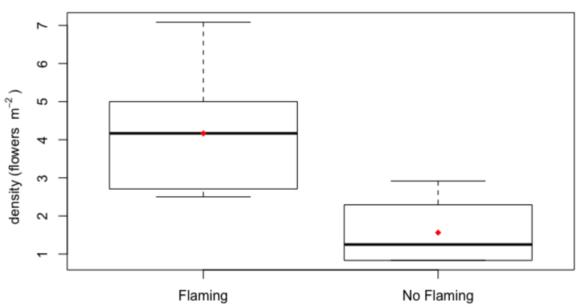
b) Effect of flaming and scalping on *Bellis perennis* flower density: on the left in the first year ($P<0.01$) and on the right in the second year ($P<0.01$).



c) Effect of time on *B. perennis* flower density (*P*<0.01)



d) Effect of flaming and scalping on *Calendula arvensis* flower density (*P*<0.01).



e) Effect of time on *Geranium molle* flower density (*P*<0.01).

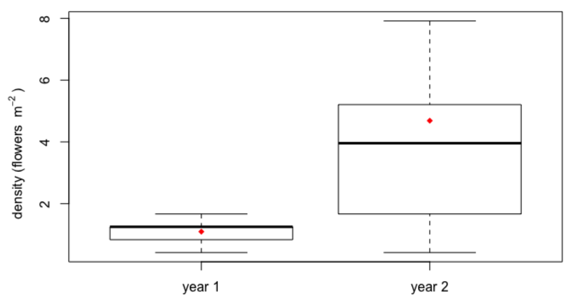


Figure 2. Color and seasonality of the lawn composed of successful bulbs, forbs and hybrid Bermudagrass (*C. dactylon* x *C. transvaalensis*).