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A DECISION-SUPPORT FRAMEWORK FOR SUSTAINABLE MANAGEMENT OF NATURAL SPORTS TURF UNDER TEMPERATE-CONTINENTAL CONDITIONS - A REVIEW AND CASE STUDY

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Abstract

Managing natural sports turf under a temperate-continental climate requires maintenance operations to be sequenced within short climatic windows and triggered by measured site conditions rather than by a fixed calendar. This review synthesizes the scientific and technical literature on aeration, scarification, topdressing, fertilization, evapotranspiration-based irrigation, integrated pest and disease management and monitoring technologies, and organizes it into a circular decision-support framework with five components: diagnosis, planning, intervention, monitoring and adjustment. The framework is made operational through a seasonal calendar and a set of alert thresholds, and is applied in a case study of a 9,600 m² natural-turf rugby field with loamy sand soil, no subsurface drainage and a history of low-input maintenance. For this field, the case study derives the annual maintenance programme and the expected 12-month changes in five turf-quality indicators. The operating parameters of the framework fall within the ranges recommended in the literature, and the expected changes agree in direction with published empirical results. Because these changes are estimates rather than measured outcomes, monitoring of the field over several seasons is needed to validate the framework.

Key words*: decision-support framework, sports turf management, turf maintenance operations, alert thresholds, temperate-continental climate, case study.*

INTRODUCTION

Natural turf sports fields remain, for football and rugby, the technical and functional benchmark against which every alternative surface is judged: they offer a combination of impact absorption, controlled traction, evaporative cooling and ecological reversibility that synthetic surfaces reproduce only partially (Cumberbatch et al., 2025). Unlike a construction material, sports turf is a living system, permanently subject to the combined action of climatic factors, the mechanical stress generated by matches and training, and the maintenance resources available.

The temperate-continental climate of much of Central and Eastern Europe, including Romania, adds a further layer of complexity. Large annual temperature ranges, winters with freeze–thaw episodes and summers with drought and heatwaves, together with increasingly variable precipitation driven by climate change (Hatfield, 2017), require intervention windows that differ from those recommended in manuals developed for oceanic or Mediterranean climates. The updated Köppen-Geiger classification of Beck et al. (2018) places most of Romania within the humid continental climate classes, with warm summers in the hilly and plateau regions and hot summers in the southern lowlands. For the cool-season species used on sports fields, this pattern restricts active growth mainly to spring and autumn, with summer heat and drought stress and winter dormancy in between (Fan et al., 2020; Braun et al., 2022). Observations on a football pitch in south-western Romania illustrate this seasonal pressure: frequent spring rainfall disrupted mowing, weed control and fungicide applications, and the disease resistance of the sward declined during spring (Corlan et al., 2019).

There is a recognized gap, both in the scientific literature and in the practice of sports field management, between technical knowledge of effective maintenance operations and their

systematic application on the ground: correct operations, applied at the wrong time or without justification based on measurements, produce poorer results than a coherent programme based on diagnosis and explicit decision thresholds. International standards for natural turf, such as the FIFA Quality Programme for Natural Playing Surfaces (FIFA, 2021), the FIFA Natural Turf Guidelines (FIFA, 2023) and the Sport England guidance on natural turf (Sport England, 2011), set targets for surface hardness, stability, evenness and agronomic condition, but only partially prescribe the temporal and decisional logic through which these targets can be achieved and maintained under specific climatic conditions.

This study pursues two complementary objectives. The first is to synthesize critically the scientific and technical literature on the maintenance methods applied to sports turf, organized around the five components of a decision cycle: diagnosis, planning, intervention, monitoring and adjustment. The second is to apply the resulting framework in a case study of a natural-turf rugby field, deriving its maintenance programme and expected effects, and to compare these with the ranges reported in the literature.

MATERIALS AND METHODS

This article combines a narrative review of the scientific and technical literature with a case study. Sources were identified through searches in academic databases and publisher platforms (Wiley Online Library, ScienceDirect, SpringerLink, MDPI, Taylor & Francis Online, Emerald, PubMed and Google Scholar) and through direct consultation of technical documents issued by FIFA, World Rugby, Sport England, FAO and the European Commission. Search terms included: turfgrass management, sports turf, soil compaction sports field, turfgrass wear tolerance, turfgrass irrigation evapotranspiration, turfgrass integrated pest management, decision support system turfgrass, remote sensing turfgrass monitoring and turfgrass biodiversity pollinators, alone and in combination. The search covered publications from 2000 to 2026, together with a small number of standard reference texts on turf science. Sources were included if they were peer-reviewed articles, scientific monographs or technical documents of sports governing bodies and public authorities; dealt with cool-season turfgrass or with soil, water and pest processes transferable to sports turf; and reported quantitative results or operational recommendations. Studies on warm-season species were excluded.

The case study applies the framework to a natural-turf rugby field of 9,600 m² (120 × 80 m, including in-goal areas and run-off zones), with loamy sand soil, no subsurface drainage and a history of low-input maintenance. For this field, the authors established the starting condition, the annual maintenance programme, and the expected changes in five turf-quality indicators after 12 months. The expected changes are estimates made by the authors, not field measurements, and are reported as such in the **Results and discussions** section. The case study concerns a natural-turf rugby field located in Oltenia Plain. The starting values were obtained from field measurements carried out in March - April, penetration resistance with a cone penetrometer (0-10 cm), infiltration rate with a ring infiltrometer, and thatch thickness on soil cores, at 15 points distributed over the playing area. The expected changes after 12 months were estimated by applying to these starting values the effect ranges reported in the literature for the same operations (Table 3).

The literature was synthesized thematically, around the main groups of maintenance operations and the five components of the decision-support framework. For each theme, the relevant contributions were identified and, where possible, compared with the corresponding operating parameters of the framework, in order to show both where they agree and the limits of the comparison.

Within the framework, each intervention (aeration, scarification, topdressing, fertilization, irrigation, deep decompaction and drainage, overseeding, integrated pest and disease management) uses operating parameters taken from the specialized literature (Table 1). The authors' contribution lies in integrating these parameters into a seasonal calendar adapted to the temperate-continental climate and into a set of decision rules based on

alert thresholds that are measured periodically and recorded in a field register (Table 2). An operation is scheduled only when the diagnosis or a threshold exceedance calls for it, which avoids both under- and over-maintenance and makes management decisions transparent, justifiable and adjustable from one season to the next.

RESULTS AND DISCUSSIONS

1. Soil physical properties: compaction, aeration, topdressing and drainage

Soil compaction, generated by repeated traffic from players and maintenance equipment, is consistently identified as one of the main causes of sports turf degradation, through reduced porosity, gas exchange and water infiltration (Adams & Gibbs, 1994; Christians et al., 2016). The review by Hamza and Anderson (2005) on soil compaction in cropping systems confirms, at a more general scale, the same physical mechanisms: reduced macroporosity, restricted root growth and decreased infiltration.

Mechanical aeration is the reference operation for counteracting compaction. Recent research refines the effectiveness of different aeration technologies: Dalsgaard et al. (2020) compared Shockwave-type aeration with conventional core aeration on athletic fields and found relevant differences in surface disruption and infiltration recovery, while Isom and Thompson (2026) analysed, on putting greens, the effect of aerator-pass frequency on sand incorporation and organic-matter accumulation. Sand topdressing complements aeration: Chen et al. (2025) showed, on creeping bentgrass, that the fineness of the topdressing sand significantly influences turf quality and surface characteristics, while the monograph edited by Stier et al. (2013) synthesizes the mechanisms of thatch formation and the options for its control. Surface and subsurface drainage are treated as structural components of performance sports fields, since the capacity for rapid water removal directly determines the number of available playing hours (Adams & Gibbs, 1994; Puhalla et al., 2020).

The framework translates these principles into explicit operating parameters (Table 1): two to four aeration passes per year within the April-May and September-October windows, scarification at a depth matched to the thatch layer, and topdressing with fine quartz sand at 1-3 mm per application. Within each window, the actual date is set by field conditions rather than by the calendar: operations are carried out while the turf is actively growing and the soil is neither frozen nor saturated. This level of operational detail, rarely made explicit in review articles, shows how general recommendations from the literature can be turned into an applicable annual programme.

Table 1. Operating parameters used in the framework for the main maintenance operations applied to sports turf (values set by the authors on the basis of the cited literature)

Operation	Operating parameters	Optimal window (temperate-continental climate)	References
Mechanical aeration	Solid tines 5-10 cm, core aeration 8-12 cm, or pneumatic 10-20 cm; 2-4 passes/year	April-May; September-October	Beard, 2002; Christians et al., 2016; Dalsgaard et al., 2020
Scarification / verticutting	Working depth 5-15 mm, matched to the depth of the thatch layer; 1-2 passes/year	April; September	Christians et al., 2016; Stier et al., 2013
Topdressing	Quartz sand 0.2-0.8 mm (70-90%) + organic matter (10-30%); 1-3 mm/application, 2–3 applications/year	After aeration, spring and autumn	Chen et al., 2025; Stier et al., 2013
Fertilization	N 15-25 g/m²/year, P_2O_5 5-8 g/m²/year, K_2O 15*20 g/m²/year, in 4-6 applications; rates adjusted to annual soil analysis	Seasonal programme (spring-summer-autumn)	Carrow et al., 2001; Carey et al., 2012
Irrigation	ETc = Kc × ETo, with Kc 0.90–0.95 for cool-season turf; irrigation when depletion reaches 40% of available soil water (p = 0.40)	April-September, during active growth	Allen et al., 1998; Braun et al., 2022; Leinauer et al., 2025
Deep decompaction and drainage	Deep decompaction 40-60 cm (every 5-10 years); drains 80-110 mm at 30-60 cm depth	Outside the competition period, on soil neither frozen nor saturated (late summer-early autumn)	Adams & Gibbs, 1994; Puhalla et al., 2020
Overseeding	10-20 g/m² (general), 20-40 g/m² (worn areas), mainly *Lolium perenne*	April-May; September	Christians et al., 2016; Corlan et al., 2019
Integrated pest management (IPM)	Intervention thresholds: 2-5% affected area (diseases); about 30-120 larvae/m², depending on species (soil-dwelling larvae)	Continuous monitoring; targeted treatment	Potter, 1998; Sapkota et al., 2022; Batistič & Trdan, 2025

2. Species selection, nutrient management and water management

Turfgrass species and cultivar selection is a structural decision with long-term effects on a field's capacity to withstand intense traffic. Wear tolerance is determined by anatomical and morphological factors, analysed in detail by Głąb et al. (2015). Under actual tennis match play, Ebdon et al. (2021) found that Kentucky bluegrass and perennial ryegrass had the highest wear tolerance and carrying capacity among the cool-season species tested, well above fine fescues. Fan et al. (2020) synthesize, at a more general level, the physiological mechanisms of environmental-stress tolerance in turfgrass.

Balanced fertilization supports turf density, colour and recovery capacity, but excess nitrogen is associated with losses through leaching and runoff, with implications for water quality (Carey et al., 2012). Fertilizer rates are best adjusted to the nutrient status measured by soil analysis rather than applied as a fixed routine (Carrow et al., 2001). Scheduling irrigation from reference evapotranspiration is a documented alternative to fixed-calendar irrigation. FAO-56 gives crop coefficients of 0.90-0.95 and an allowable depletion fraction of 0.40 for cool-season turf (Allen et al., 1998); Leinauer et al. (2025) developed and tested variable crop coefficients, and Meza et al. (2025) showed, using high-resolution imagery, the spatial relationship between turf quality and actual evapotranspiration. The review by Braun et al. (2022) on water requirements and drought-stress responses provides a directly applicable reference for the cool-season species used in the temperate-continental climate.

The fertilization programme of the framework follows the same seasonal logic: balanced NPK in spring, reduced nitrogen and increased potassium in summer (for tolerance to heat and drought stress), and potassium and phosphorus in autumn, with annual nitrogen rates of 15-25 g/m² split into four to six applications. Splitting moderate rates into several applications is one of the practices that Carey et al. (2012) associate with a lower risk of nitrogen losses.

3. Integrated pest and disease management

Integrated Pest Management (IPM) is established as the best-practice standard for sports turf protection: cultural and preventive measures come first, the field is monitored regularly, and chemical treatments are used only when intervention thresholds are exceeded. The recent review by Batistič and Trdan (2025) highlights both the effectiveness of combining cultural and biological methods and the growing influence of climatic variability on disease dynamics. Microdochium patch and pink snow mould (*Microdochium nivale*), favoured by cool, wet weather and prolonged snow cover, whose virulence was recently investigated at genome scale by Tsers et al. (2023), and dollar spot (*Clarireedia jacksonii*), favoured by warm, humid weather, long periods of leaf wetness and low nitrogen fertility (Sapkota et al., 2022), illustrate the phytosanitary challenges of the temperate-continental climate. The framework uses intervention thresholds of 2-5% of the affected area for diseases and about 30-120 larvae/m² for soil-dwelling larvae, the latter corresponding to the species-dependent thresholds of roughly 3-12 larvae per square foot used in turfgrass entomology (Potter, 1998). The exact thresholds remain dependent on species, cultivar, irrigation and regional context.

4. Quality standards, safety and monitoring technologies

International sports organizations have developed technical standards for the quality and safety of playing surfaces. For natural turf, the FIFA Quality Programme for Natural Playing Surfaces (FIFA, 2021) assesses surface hardness, stability and evenness, ball–surface interaction and agronomic condition, while the FIFA Natural Turf Guidelines (FIFA, 2023) describe construction and maintenance practices adapted to local climate and soil. In rugby, impact-attenuation requirements are defined mainly for artificial surfaces through World Rugby Test Method 01, whose head injury criteria were recently re-examined by Colino et al. (2026); these values are a useful benchmark for natural turf, although they were not developed for it. The link between surface quality and injury risk is supported by a worldwide survey in which elite football players associated specific surface characteristics with injury (Mears et al., 2018),

although perception data cannot by themselves establish causality.

For monitoring technologies, the framework proposed by Helps et al. (2024) for evaluating pest management decision support systems offers criteria that can be transferred to sports turf management, while the review by Benos et al. (2021) on machine learning in agriculture shows a rapid expansion of predictive models. Alahmad et al. (2023) document how Internet of Things (IoT) sensors and big-data analysis support precision crop production, a direction with potential for large sports facilities. The review by Parra et al. (2024) on drones for turfgrass monitoring highlights the usefulness of multispectral imaging for early detection of drought stress, while Huang et al. (2021) draw attention to the interpretive limits of the NDVI index. The framework, in turn, uses a field register (date, indicator, value, operation applied), which applies the principles of a decision support system on a smaller scale.

5. Sustainability, circular economy and biodiversity

The EU Soil Strategy for 2030 (European Commission, 2021) sets explicit objectives on soil health and the reduction of compaction, which also apply to sports infrastructure. Strandberg et al. (2012) identify environmental regulation, pressure on water, energy and land, ecosystem services and biodiversity, integrated pest management and adaptation to climate change as priorities for sustainable turfgrass management, and argue that managers who minimize labour, energy and agronomic inputs are best placed to respond. Lower inputs are consistent with circular-economy principles, as illustrated by the recovery of organic matter through composting (Manea et al., 2024). The comparison between natural and synthetic turf by Cumberbatch et al. (2025) shows that natural turf offers relevant ecological advantages, provided that it is actively and continuously managed. For biodiversity, Lerman et al. (2018) showed that mowing less often increased bee abundance and diversity in suburban lawns, a result that may be transferable to the non-playing margins of sports facilities, while Lindsey et al. (2025) synthesize the broader ecological benefits of turfgrass in urban landscapes.

6. An integrated decision-support framework

The literature reviewed in sections 1-5 converges on a common principle: effective sports turf management is not mainly a matter of access to individual technologies, but of sequencing and triggering operations on the basis of up-to-date diagnostic information. This is consistent with the criteria for effective decision support systems identified by Helps et al. (2024). The framework proposed here puts this principle into practice in five stages (Figure 1).

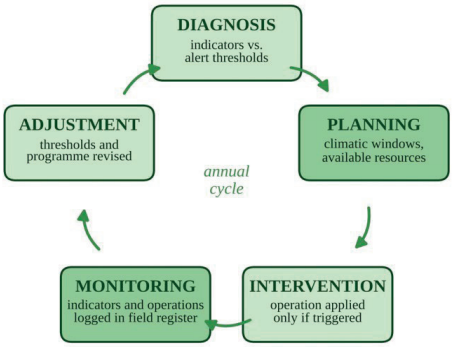


Figure 1. The five-stage decision-support cycle for natural sports turf management

Diagnosis establishes the condition of the field through indicators measured at set intervals (Table 2). Planning places the required operations within the climatic windows of the temperate-continental climate (Table 1) and within the resources available. Intervention applies an operation only when an alert threshold is exceeded. Monitoring records indicator values and the operations applied in the field register, and adjustment uses these records to revise the thresholds and the programme for the next cycle.

The five stages form a loop rather than a sequence: monitoring results feed into adjustment, and adjustment redefines the diagnosis and planning of the following cycle. This adaptive design is needed under a climate with marked year-to-year variability (Hatfield, 2017), where the same calendar cannot be applied unchanged from one season to the next. The thresholds in Table 2 are operational values set by the authors on the basis of the literature cited in sections 1-3; they are starting points to be recalibrated with the data accumulated in the field register.

Table 2. Indicators, alert thresholds and triggered operations in the decision-support framework (operational thresholds set by the authors)

Indicator (method)	Monitoring frequency	Alert threshold	Triggered operation
Penetration resistance, 0–10 cm (cone penetrometer)	Spring and autumn, before the aeration windows	> 2.0 MPa	Core or solid-tine aeration; if compaction persists after two aeration cycles, deep decompaction is recommended
Infiltration rate (ring infiltrometer)	Spring and autumn	< 10 mm/h	Aeration + sand topdressing; drainage works if < 5 mm/h after two cycles
Thatch thickness (soil cores)	Spring and autumn	> 10 mm	Scarification; > 15 mm: scarification + topdressing in both windows
Soil water balance (ETo, rainfall)	Weekly, April–September	Depletion ≥ 40% of available water	Irrigation replacing ETc
Turf cover (visual or image-based, % of area)	Monthly and after matches	< 90% cover, or bare patches in high-wear areas	Overseeding and spot repair
Disease incidence (% of area affected)	Weekly in high-risk periods	2-5%	Targeted fungicide treatment
Soil-dwelling larvae (soil sampling)	Late summer	About 30-120 larvae/m², depending on species	Targeted insecticide or biological control
Soil nutrient status and pH (soil analysis)	Annually, late winter	Below sufficiency range	Adjustment of the fertilization programme

7. Application of the framework: case study of a natural-turf rugby field

The case study applies the framework to a 9,600 m² natural-turf rugby field in Oltenia Plain (120 × 80 m, including in-goal areas and run-off zones) with loamy sand soil, no subsurface drainage and a history of low-input maintenance (see Materials and methods). The starting conditions for the field were: penetration resistance of 3.2 MPa, infiltration rate of 7.8 mm/h and a thatch layer of 18 mm. All three values exceed the alert thresholds in Table 2, so the diagnosis called for aeration, scarification and topdressing in both growing-season windows.

The programme can be scaled to three levels of intensity (minimum, standard and premium) according to the resources available, in line with the emphasis placed by Strandberg et al. (2012) on minimizing labour, energy and agronomic inputs; heavy works (drainage, deep decompaction) are planned separately. The case study presents the standard level.

At the standard level, the annual programme combines core and solid-tine aeration, scarification, topdressing, fertilization in five applications, general overseeding and spot repairs, and two phytosanitary treatments planned for the case in which thresholds are exceeded. After 12 months, the authors expect the infiltration rate to increase from 7.8 to 17.2 mm/h (+121%), penetration resistance to fall from 3.2 to 1.8 MPa (−44%), thatch thickness to fall from 18 to 8 mm (−56%), turf density to increase by 39% and weed cover to fall by 76% (Figure 2), while the recovery time after heavy rain is expected to drop from about 48 hours to under 24 hours. These values are estimates, not field measurements, and serve as the targets against which the monitoring stage will assess the programme. The expected reductions in penetration resistance and recovery time are at the upper end of what can be achieved without subsurface drainage and depend on the deep decompaction work carried out separately.

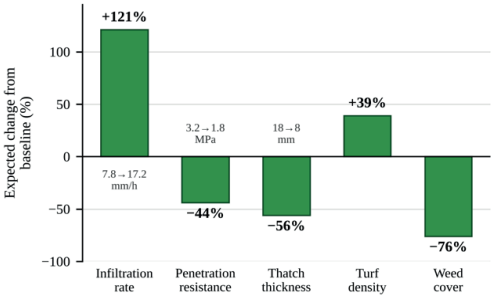


Figure 2. Expected changes in turf-quality indicators after 12 months of the standard programme on the case-study field (authors' estimates)

The direction of these changes is consistent with the effects reported in the empirical literature reviewed above: the improvement in infiltration through combined aeration and topdressing agrees with the comparative results of Dalsgaard et al. (2020) and Craft et al. (2017), and the reduction in weed cover through a denser sward agrees with the general principle that a dense, wear-tolerant sward is the most effective barrier to weed

establishment (Christians et al., 2016; Ebdon et al., 2021). The magnitude of the expected changes cannot, however, be generalized: it refers to a single combination of soil, climate and intensity of use, and for most of these indicators the literature does not offer reference ranges narrow enough for a strict quantitative comparison (Table 3). The agreement is therefore one of direction and plausible order of magnitude; it does not amount to an empirical validation of the framework, which requires repeated measurements on the field.

Table 3. Trends reported in the international literature compared with the parameters and expected results of the case study

Parameter	Trend / range reported in the literature	Value in the case study	References
Aeration frequency	Recommended within active-growth windows, typically a few times per year	2–4 passes/year (April–May, September–October)	Beard, 2002; Christians et al., 2016
Nitrogen application (annual)	Moderate rates, split applications; controlled-release sources as best practice	15–25 g N/m²/year, in 4–6 applications	Carey et al., 2012
Infiltration rate (response to aeration + topdressing)	Consistent improvement, magnitude study-dependent	+121% expected (7.8 → 17.2 mm/h)	Craft et al., 2017; Dalsgaard et al., 2020
Penetration resistance (response to aeration)	Reduced compaction, magnitude variable with soil and technique	−44% expected (3.2 → 1.8 MPa)	Hamza & Anderson, 2005; Craft et al., 2017
Thatch thickness (target)	Below 10 mm considered non-limiting; above 10–15 mm requires intervention	18 → 8 mm expected, through scarification + topdressing	Stier et al., 2013

CONCLUSIONS

This review shows that the management of natural sports turf under a temperate-continental climate depends on sequencing maintenance operations within short climatic windows and on triggering them by measured field conditions. The literature supports the following conclusions:

(i) aeration, scarification and topdressing are the main operations for controlling compaction and thatch accumulation, and are best carried out in the April–May and September–October windows, while the turf is actively growing;

(ii) fertilization and irrigation should be treated as decision variables conditioned by soil analyses and reference evapotranspiration, not as calendar routine;

(iii) integrated pest and disease management, with explicit intervention thresholds, is the recommended approach for reducing reliance on chemical treatments;

(iv) international quality standards and remote-sensing tools provide reference values and data for the monitoring stage, although standards developed for artificial turf can serve only as benchmarks for natural turf;

(v) the case study shows how the five-stage framework (diagnosis, planning, intervention, monitoring and adjustment) translates into an annual programme and measurable targets for a specific field, and the expected effects agree in direction with published empirical results.

The main limitations of this study are that the case-study effects are estimates rather than measured outcomes, and that the reviewed literature comes largely from other climatic and institutional contexts, with few studies from Central and Eastern Europe. Monitoring the case-study field over several seasons and testing the framework on other soil types in the temperate-continental zone are the next steps, together with the integration of remote-sensing data into the diagnostic stage and an assessment of the cost–benefit ratio of precision monitoring on small and medium-sized fields.

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