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Changes in Soil Elements and Nutritive Value of Cool-season Turfgrass during Green-up

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Abstract. **Turfgrass plays a crucial role in urban landscaping, and *Poa pratensis* L. is widely used across Asia. This study used correlation and principal component analyses to investigate soil nutrient dynamics during the green-up phase, with particular emphasis on turfgrass nutrition and soil element changes. Nutrient dynamics were critical for promoting optimal green-up. For instance, on sandy clay loam, which is rich in nutrients, the green-up date occurred approximately 7 days earlier than that on sandy loam. Differences in the principal components of soil nutrients and interactions between organic elements were observed across various soil types. Changes in soil nutrient composition in the upper soil layers were more pronounced than those in deeper layers. Notably, all six soil elements studied showed positive correlations with the principal nutrient components, particularly organic matter, available phosphorus, and urease. The most significant depletion of soil nutrients occurred when turfgrass was approximately 25% to 35% green. After this point, nutrient decreases slowed and became more gradual as the green-up phase continued.**

In recent years, the importance of green spaces in urban settings has led to a consistent increase in planted areas in China and around the world. Turfgrass plays a crucial role in the landscape design of inland regions in Eurasia, North America, and Asia, and weather conditions significantly influence the regrowth of turfgrass. Cool-season turfgrasses such as *Poa pratensis* L. have been extensively cultivated because of their high quality and low maintenance costs (Braun et al. 2022).

The term "green-up date" refers to the period after overwintering when plant foliage changes from yellow to green. Cool-season grasses in northern China, Mongolia, Russia, and some Central Asian countries also exhibit this green-up phenomenon because of the cold climate (Fan et al. 2020). The climatic conditions during the spring green-up dates are conducive to the growth and development of turfgrass (Liu et al. 2023). Specifically, as radiation, average daily temperature, and precipitation increase, the soil becomes more moist, and conditions improve compared with those in winter (Contosta et al. 2016; Vankoughnett et al. 2016; Zhang et al. 2018). The increase in temperature results in greater enzyme activity and enhanced microbial activity (Wang et al. 2023; Zhang et al. 2023). As a result, the turfgrass begins to regrow, and the lawn ecosystem thrives under undisturbed ecological conditions (Lei et al. 2013). Studies have shown that as the temperature increases, the nitrogen content in the soil increases in the spring (Hu et al. 2018). Additionally, temperature plays a vital role in the chemical transformation process within the plant (Padmore et al. 2023). Geng et al. (2014) reported that fertilization should align with the growth pattern of turfgrass in spring. This conclusion was drawn from an in-depth analysis of the correlation between the growth characteristics of spring turfgrass and the application of nitrogen fertilizer. Nutrient accumulation plays a critical role in the growth and development of turfgrass during green-up dates (Bauer et al. 2012).

Several factors influence the levels of nutrition and nutritional composition of soil. Numerous studies have investigated the correlations among nitrogen, phosphorus, and potassium in soil (Li et al. 2020a; Lin et al. 2020). Comprehensive analyses of soil nutrients have been performed. Catalase (CAT) and urease are common enzymes and organic components of soil that play a key role in nutrient cycling and nutrient uptake by turfgrass in spring (Li et al. 2023). Researchers have used correlation analyses to study temporal and spatial variations in soil nutrients (Cao et al. 2016), providing valuable insights into the dynamic nature of soil quality. Furthermore, several studies have used a principal component analysis (PCA) and other methods to identify the main factors that influence the distribution of nutrients and other beneficial elements of soil (Askari and Holden 2014; Xia et al. 2023). Such research forms a valuable basis for agricultural production and the protection of the environment. However, the interactions among various nutrients in the soil during green-up dates of turfgrass still require further investigation and research.

During green-up, the soil components underlying turfgrass interact with the surrounding environment, mirroring the growth progress of the turfgrass and its adaptability to environmental conditions (Acuña et al. 2022). Although previous research has shown that soil nutrition influences the growth of lawn grass, few studies have examined the variation in nutrient levels of soil during spring green-up. Soil nutrition is known to affect the timing of turfgrass green-up. The objective of this study was to investigate the changes in nutrient elements in both soil and turfgrass throughout the green-up stage by focusing on identifying the temporal shifts and patterns of nutrient variation. We conducted a comprehensive analysis of the changes in various soil elements and documented the patterns of changes in soil nutrients. This research lays a theoretical foundation for the early green-up of turfgrass.

Materials and Methods

Site. Two different locations in Hohhot, Inner Mongolia, China, were chosen as study sites (site 1: lat. 40°48′N, long. 111°41′E) and (site 2: lat. 40°68′N, long. 111°37′E). Hohhot is located in the mid-temperate zone and has a continental monsoon climate characterized by four distinct seasons. According to the Köppen climate classification, it is classified as a "cold semiarid climate" with significant seasonal temperature variations and a pronounced monsoon influence. It has cold and long winters and hot and rainy summers. Hohhot experiences a rainy season that lasts approximately 4 months, typically from June to September (Fig. 1). The yearly precipitation in this region ranges between 335.2 and 434.6 mm.

Turfgrass and soil species. The chosen turfgrass species was *Poa pratensis* L. cv. Daqingshan, which was developed by Chinese researchers specifically for China's cold regions. This cultivar exhibits unique traits such as rapid recovery, extended retention of green color, and a prolonged period (>200 d) before yellowing sets in. It enters a dormancy period of approximately 80 d during winter. The quality indices of turfgrass at the experimental sites are based on the average standard provided by Mengcao Company (Table 1). During the experiment, the grass coverage was obtained by digital images.

Soil 1 featured a native sandy loam soil, whereas soil 2 had a sandy clay loam with high nutrient content relative to soil 1. Each site had an area of approximately 500 m^2. The types of soil at both sites are representative

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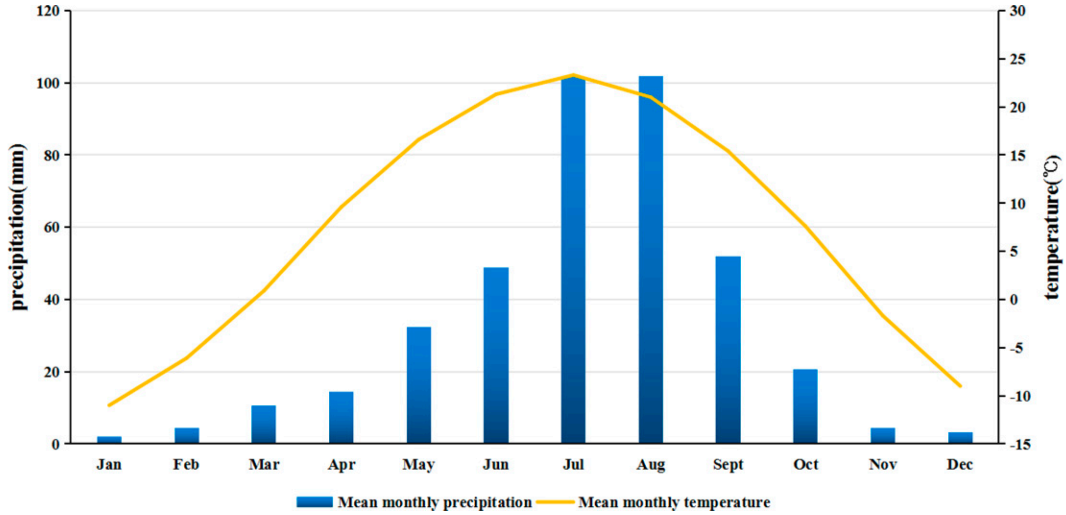

Fig. 1. Monthly average temperature and monthly average precipitation.

Table 1. Quality index of turfgrass used in experiment.

Coverage (%)	Density (branch/cm^2)	Height (cm)	Aboveground biomass (g·m^{-2})
94.00	4.07	6	268

of meso-temperate turfgrass soils. Table 2 describes their textures.

Both sites were seeded with *Poa pratensis* L. cv. starting in 2018. The turfgrass was watered twice per week, with each irrigation amounting to approximately 20 L/m^2. The height of the turfgrass was maintained at approximately 6 cm. The land was fertilized annually to maintain standard fertility levels (Table 2).

Soil and turfgrass sampling. The green-up period at Hohhot lasts from late March to mid-April. Therefore, we sampled the two sites from 12 Mar to 29 Apr during 2021 to 2023, at 4-d intervals, yielding 13 time points per year. Each soil type was divided into four parts, and each part was randomly sampled. The size of each sample quadrat was 0.1 m × 0.1 m. We sampled at the following two depths from each site: 0 to 20 cm and 20 to 40 cm. In addition, one or two turfgrass samples were randomly selected from the soil sample, and 1 g of roots and leaves was taken. Samples were collected from each site at one time point, and the sum of the four samples was averaged to obtain the data at each time point. Thirteen time points were tested yearly during the green-up dates. Soil samples were stored according to the GB/T 32722-2016 low-temperature standard and quick-frozen in liquid nitrogen at –80 °C.

Determination of soil and turfgrass elements. Soil organic matter (SOM), soil available phosphorus (SAP), soil available potassium (SAK), basic nitrogen, CAT, and urease have crucial influences on soil nutrients. We measured these six markers at the same two aforementioned soil depths. We used the cutting ring method to investigate bulk density (Bi et al. 2014). Soil moisture was measured using the drying method, whereas SOM was determined using the volumetric method of available potassium dichromate (Yang et al. 2012). The SAK was determined via flame spectrophotometry (Morais et al. 2019), and basic nitrogen levels were measured using the alkali N-proliferation method (Moraghan et al. 1983). The SAP was analyzed using the sodium hydrogen carbonate solution-Mo-Sb anti spectrophotometric method (White and Haydock 1967), and CAT was determined using the available potassium permanganate titration method (Johnson and Temple 1964). Urease levels were determined using the Nessler colorimetric method (Mihaela et al. 2018).

The measurement of water-soluble carbohydrate (WSC) was conducted using the anthrone colorimetry technique. Absorbance values were measured at 620 nm, and the sugar content was determined from calibration curves. Salt-soluble protein (SSP) was measured using the Coomassie brilliant blue method. Absorbance values were measured at 595 nm (Yu et al. 2016). The proline (PRO) content was determined using the sulfosalicylic acid method (Man et al. 2011). Soil temperature was measured using a soil temperature detector.

Data analysis. For each indicator, values recorded at 13 time points during the green-up period were averaged annually, and then a 3-year (2021–23) mean was calculated to reduce the influence of interannual variability. The standard deviation was computed as the measure of variability for each parameter. Average values were used to calculate correlation and principal component analysis statistics. All data analyses were conducted using SPSS 26 (IBM, Armonk, NY, USA) and Origin 2021 (OriginLab Corporation, Northampton, MA, USA).

A bivariate Pearson correlation procedure was used to analyze the relationships among SOM, basic nitrogen, SAP, SAK, CAT, and urease, as well as the nutrient composition of turfgrass in the different soils, using Eq. [1]. In this equation, X and Y represent two sets of data, and r denotes the correlation coefficient.

$$r = \frac{\sum_{i-1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i-1}^{n}(X_i - \bar{X})}\sqrt{\sum_{i-1}^{n}(Y_i - \bar{Y})}} \quad [1]$$

Each index was averaged for different soil depths at each time point and analyzed using a PCA. For the PCA, variables were normalized and then converted into principal components (PCs; linear combinations of original parameters) by identifying the directions in the data with high variance. The PC conversion process included computing the similarity matrix (P), making the covariance matrix

Table 2. Basic physical and chemical properties of the soils under turfgrass (0- to 40-cm depth) at two different soils.

	Clay	Sandy	Bulk density (g·cm^{-3})	Saturated water content (%)	Porosity (%)	Soil organic matter (g·kg^{-1})	Basic nitrogen (mg·kg^{-1})	Soil available phosphorus (mg·kg^{-1})	Soil available potassium (mg·kg^{-1})	pH
Soil 1	8%	86%	1.8	17	46	15.8	186.54	7.61	115.66	7.8
Soil 2	34%	61%	1.0	32.3	60	58.65	226.11	30.84	175.45	6.5

diagonal, and reordering its eigenvectors according to the corresponding eigenvalues relative size. The PC scores help visualize data in lower-dimensional space and represent projections of experimental data points onto PCs, whereas PC loadings are the coefficients used to estimate those scores.

Results

Changes in soil nutrients during green-up. The changes in six elements at different soil depths during green-up are shown in Fig. 2. The levels of all six nutrients in the sandy clay loam were greater than those in the sandy loam during green-up.

The SOM content showed depth-dependent changes, and warmer spring temperatures led to greater SOM (Fig. 2A). The levels in the 0- to 20-cm layer were considerably greater than those in the 20- to 40-cm layer in both soils. On 28 Mar, it peaked right before temperatures dropped (Table 3). On 13 Apr, temperatures dropped for a second time. Moreover, its levels reached a maximum in sandy clay loam at both depths, but in sandy loam soil its levels reached a maximum only at 0 to 20 cm during green-up. Overall, the SOM at 20 to 40 cm in sandy loam was less affected by temperature. After 13 Apr, levels gradually decreased as turfgrass greened. Overall, its levels gradually increased during green-up.

Figure 2B depicts the levels of basic nitrogen. Its levels fluctuated more in the sandy clay loam than in the sandy loam, and more at 0 to 20 cm than at 20 to 40 cm. Until 1 Apr, the levels were consistent at each depth. On 24 Mar, the levels reached their lowest point and then experienced a temporary uptick before stabilizing. Between 5 Apr and 21 Apr, levels were much higher at 20 to 40 cm than at 0 to 20 cm. After 17 Apr, its levels reached a point of convergence.

Figure 2C shows the data for the SAP content. Levels were high in sandy clay loam but fluctuated during green-up; however, they remained consistently greater in the top 20 cm of the soil than at 20 to 40 cm. On 20 Mar,

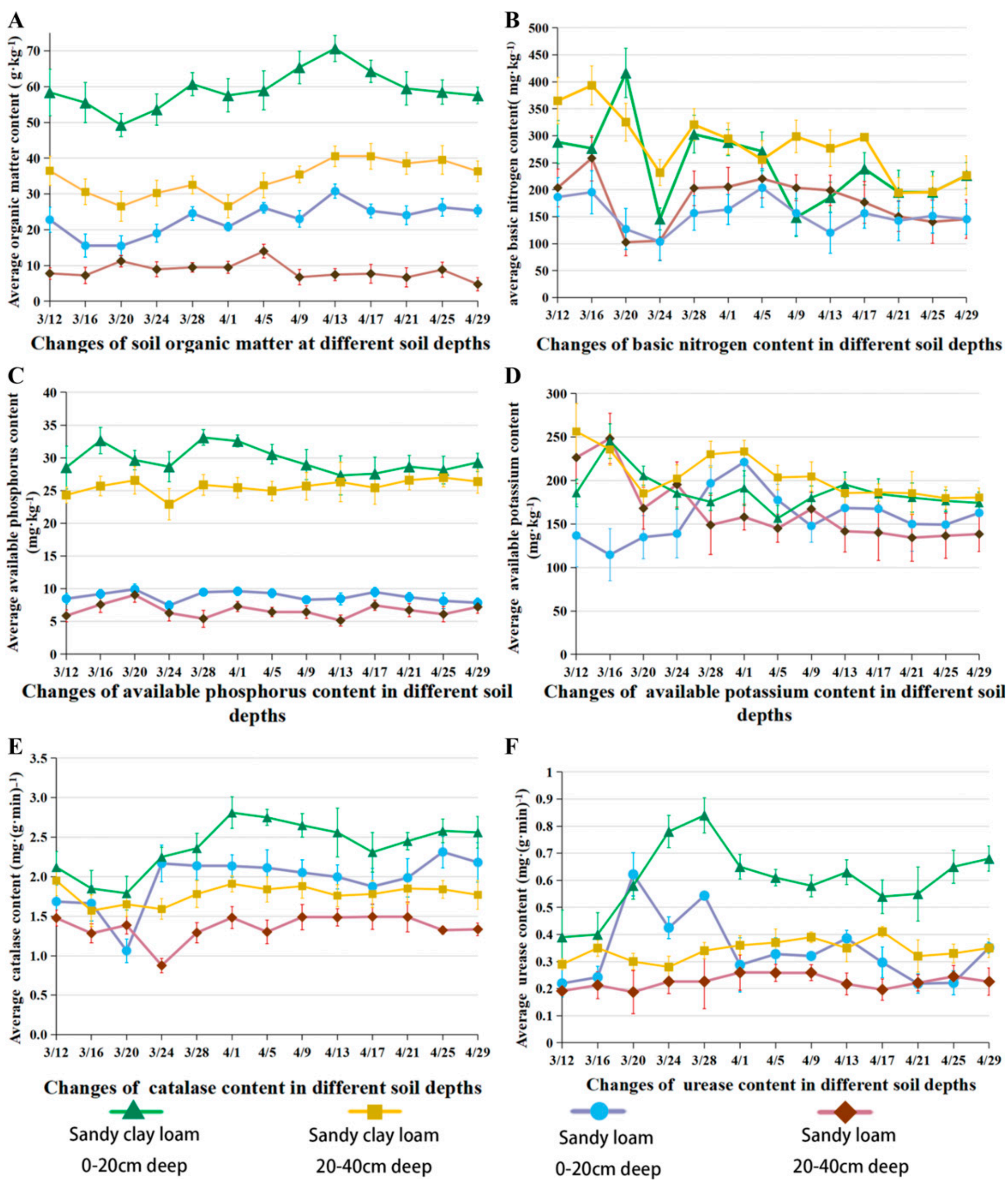

Fig. 2. Temporal changes in key soil nutrient factors (March–April). (**A**) Change in soil organic matter. (**B**) Change in basic nitrogen. (**C**) Change in soil available phosphorus. (**D**) Change in soil available potassium. (**E**) Change in catalase. (**F**) Change in urease. The green triangular line represents elemental variations in 0–20 cm sandy clay loam. The yellow square line represents the variation of each element within the 20–40 cm sandy clay loam layer. The blue circular line represents the variations of each element in the 0–20 cm sandy loam layer. The red diamond-shaped line represents the variations of each element in the 20–40 cm sandy loam.

Table 3. Mean temperature, soil moisture, and turfgrass greenness at two soils with different soils according to green-up dates.

Data	12 Mar	16 Mar[i]	20 Mar[i]	24 Mar	28 Mar	1 Apr	5 Apr	9 Apr	13 Apr	17 Apr	21 Apr[i]	25 Apr[i]	29 Apr
Soil 1 temperature (°C)	13.5 ± 2.13	15.5 ± 1.50	9.8 ± 1.26	13.5 ± 1.33	7 ± 2.32	10.3 ± 1.45	12 ± 1.63	15 ± 1.63	14 ± 1.33	13.5 ± 1.56	14 ± 1.02	15 ± 0.81	16 ± 0.85
Soil 2 temperature (°C)	14 ± 2.21	16.5 ± 1.45	10.2 ± 1.35	12.3 ± 1.21	9.6 ± 2.30	10.6 ± 1.55	12.3 ± 1.63	14.5 ± 0.81	15.6 ± 0.82	14.5 ± 1.21	15 ± 1.13	16.5 ± 0.95	17.8 ± 0.86
Soil 1 moisture (%)	35 ± 4.08	45 ± 1.24	40 ± 1.35	37 ± 2.58	28 ± 3.65	36 ± 4.08	30 ± 3.21	33 ± 2.52	32 ± 2.62	27 ± 3.50	42 ± 3.71	37 ± 2.13	40 ± 1.52
Soil 2 moisture (%)	38 ± 3.57	43 ± 2.12	37 ± 1.56	35 ± 1.35	30 ± 3.11	34 ± 2.65	35 ± 3.15	36 ± 2.23	33 ± 3.25	30 ± 3.66	43 ± 2.89	40 ± 2.55	38 ± 2.43
Soil 1 turfgrass greenness (%)	5 ± 0.68	14 ± 1.21	24 ± 2.33	25 ± 3.21	30 ± 3.69	48 ± 4.02	53 ± 3.11	56 ± 4.55	65 ± 3.85	73 ± 2.47	80 ± 3.45	88 ± 2.31	96 ± 1.24
Soil 2 turfgrass greenness (%)	7 ± 0.88	17 ± 1.65	25 ± 2.04	35 ± 3.68	46 ± 3.44	53 ± 3.95	62 ± 3.96	71 ± 3.77	84 ± 2.56	90 ± 2.49	95 ± 1.23	97 ± 1.24	97 ± 1.24

[i] Irrigation date.
Soil 1 = sandy loam soil; Soil 2 = sandy clay loam soil.

soil temperatures dropped for the first time, and SAP peaked in sandy loam soils. On 28 Mar, it peaked at 33.1 $mg \cdot kg^{-1}$ in the 0- to 20-cm layer of sandy clay loam. It exhibited a certain regularity, contrary to the temperature and soil depth changes. As the green area of turfgrass expanded, SAP content gradually decreased and then stabilized.

Figure 2D depicts the changes in SAK. During the initial period, SAK levels were greater at 20 to 40 cm than at 0 to 20 cm. However, during green-up, its levels varied more at 0 to 20 cm than at the other depth. After half of the greening stage had completed, the rate of change noticeably diminished and gradually became milder.

Figure 2E describes the changes in CAT during green-up. Its levels increased at 0 to 20 cm in both soils during the turfgrass regrowth stage. However, its activity gradually decreased with an increase in soil depth and was much higher in shallow soil. Following regrowth on 20 Mar, a sharp decrease in soil temperature resulted in a decline in enzymatic activity in the upper layer.

Finally, Fig. 2F shows the data for urease. Its activity decreased with soil depth. Plant roots usually produce urease, and leaf litter on the surface plays a role. Starting on 16 Mar, urease activity began to change at the 0- to 20-cm depth, indicating that the turfgrass's root system began to regrow. The levels in the grass gradually increased and declined after regrowth on 1 Apr. At the same time, changes in urease were stable in both soils at the 20- to 40-cm depth throughout green-up.

Changes in nutrients of turfgrass during green-up. Table 3 presents the mean measurements of turfgrass greenness, soil moisture, and temperature during the 3-year green-up dates. The dates of green-up were reasonable. Turfgrass on sandy clay loam greened-up approximately 1 week earlier than that on sandy loam soil. The grass greenness was obtained by digital images.

Turfgrass growing on sandy clay loam had more nutrients than that growing on sandy loam. As shown in Fig. 3A, WSC levels in roots and leaves generally increased as temperature increased. However, it also experienced minor fluctuations in response to the physiological activities of turfgrass. As shown in Fig. 3B, the levels of SSP and PRO in leaves consistently exceeded those in roots, but both declined during green-up, and this was correlated with variations in soil nutrients. Turfgrass assimilated soil nutrients through its roots to produce SSP, thus nourishing leaf growth. This fueled green-up, thereby leading to a rapid drop in its levels during the greening process. Turfgrass regrowth was faster in sandy clay loam; therefore, SSP dropped faster. Throughout green-up, as the temperature increased and soil nutrients improved, the growth conditions became more favorable, leading to a steady decrease in PRO content.

Correlations between soil nutrient elements and physiological indicators of turfgrass. A correlation analysis of 14 representative indicators was conducted to clarify correlations between the soil elements and physiological indicators of turfgrass in both soil types. In both soils, basic nitrogen and SAP were positively correlated with SAK, indicating that SAK was an extremely important element. The PRO levels in leaves were positively correlated with those in roots and with the levels of soluble protein in leaves. The levels of soluble protein in roots were negatively correlated with organic matter in both soils (Fig. 4).

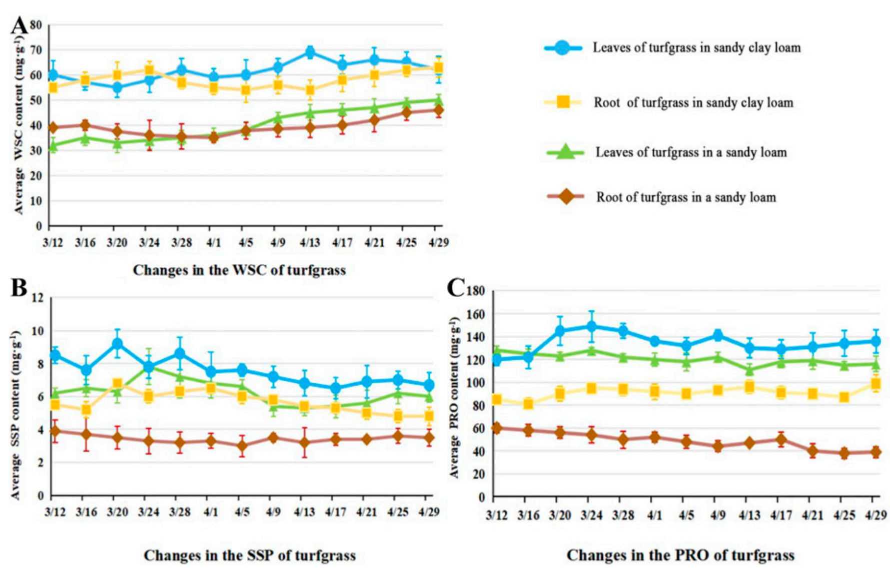

Fig. 3. Physiological changes in the leaves and roots of turfgrasses grown on different soils. (**A**) Change in the water-soluble carbohydrate (WSC) of turfgrass. (**B**) Change in the salt-soluble protein (SSP) of turfgrass. (**C**) Change in the proline (PRO) of turfgrass. The blue line represents the variation of each element of turfgrass leaves in sandy clay loam. The yellow line represents the variation of each element of turfgrass root in sandy clay loam. The green line represents the variation of each element of leaves in sandy loam. The red line represents the variation of each element of root in sandy loam.

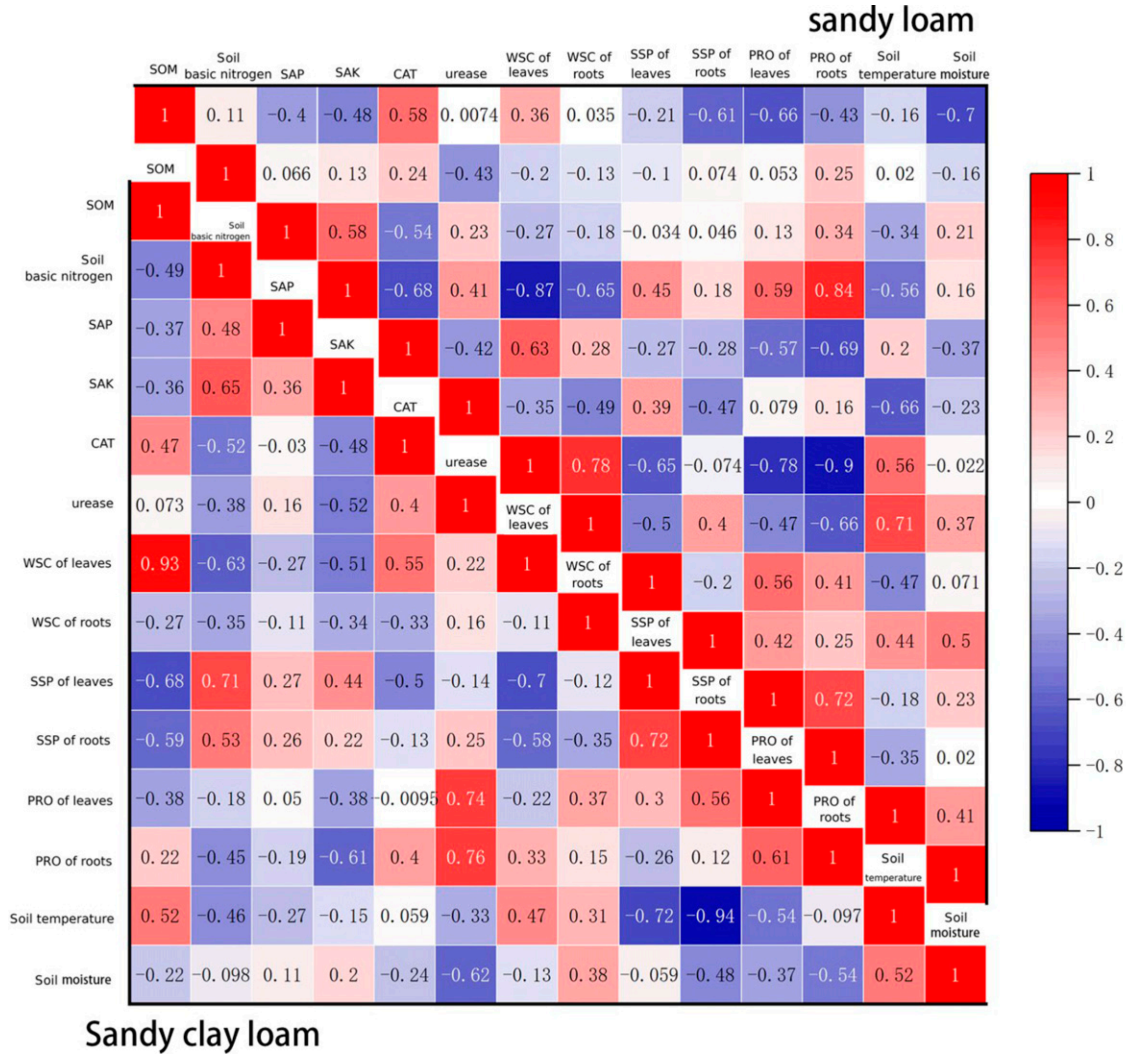

Fig. 4. Correlation matrix between soil elements and plant nutrition in sandy clay loam (lower left) and sandy loam (upper right). Blue indicates negative correlations and red indicates positive correlations. CAT = catalase; PRO = proline; SAK = soil available potassium; SAP = soil available phosphorus; SOM = soil organic matter; SSP = salt-soluble protein; WSC = water-soluble carbohydrate.

Compared to turfgrass grown on sandy clay loam, turfgrass grown on sandy loam had more elements that were significantly correlated. In turfgrass grown on sandy loam, organic matter was positively correlated with catalase and negatively correlated with leaf PRO and soil moisture. The SAK was negatively correlated with CAT, soluble sugar, and soil temperature, but it was significantly positively correlated with PRO. The CAT was positively correlated with the soluble sugar of leaves and soil temperature. In turfgrass grown on sandy clay loam, SOM was positively correlated with the levels of soluble sugar in leaves. Moreover, basic nitrogen was positively correlated with the SAK and SAP of leaves. Leaf SSP and PRO were both positively correlated with the SSP and PRO of roots, respectively.

PCA of soil nutrients. The PC results are shown in Fig. 5. The percentage of variance for the three PCs (PC1, PC2, and PC3) was 95.10%: PC1 contributed 72.40% of the variance and was positively correlated with all elements, particularly SOM, SAP, and urease; PC2 contributed 15.80% and had negative correlations with SOM, SAP, and urease but positive correlations with the other variables; and PC3 accounted for 6.90% of the total variation. In summary, there was a positive correlation between all soil nutrient elements and a single PC (PC1).

Weights for PC1, PC2, and PC3 were calculated based on the percentage of variance or cumulative variance, and then scores were assigned. To gain a better understanding of the patterns of change in nutrients during green-up, we drew a line graph. As shown in Fig. 6, there were comparable shifts in PCs in both soils. The overall nutrient level peaked on 16 Mar. However, on the same day, because of the ensuing rapid growth and greening of turfgrass as well as the impact of the higher soil temperature, nutrient levels subsequently dropped sharply. The general trend showed a gradual decline over time.

Discussion

This study demonstrated that highly nutritious soil can promote turfgrass green-up. Indeed, turfgrass regrows new shoots and roots during the green-up period following winter dormancy. The rapid increase in the growth rate of *Poa pratensis* L. cv. after spring regrowth leads to a decrease in the nutrients of the soil. This phenomenon suggests that turfgrass needs a great amount of soil nutrients in the early stages of green-up. During the green-up period, soil tends to become more productive and SOM tends to accumulate (Marcel et al. 2021). We also found that soil elements tended to fluctuate more in shallow soil layers than in deeper soil layers. Indeed, shallow soils are more sensitive to external influences (Ma et al. 2022). Furthermore, a drop in soil temperature can impede the uptake of nitrogen by plant roots (Reig et al. 2016). Our results demonstrating an inverse relationship between basic nitrogen and temperature are consistent with that notion.

Moreover, our results indicate that increased enzyme activity during the regrowth period was also important for early turfgrass green-up. Fluctuations in CAT activity were consistent with fluctuations in soil temperature. Warmer temperature conditions during green-up facilitate redox reactions catalyzed

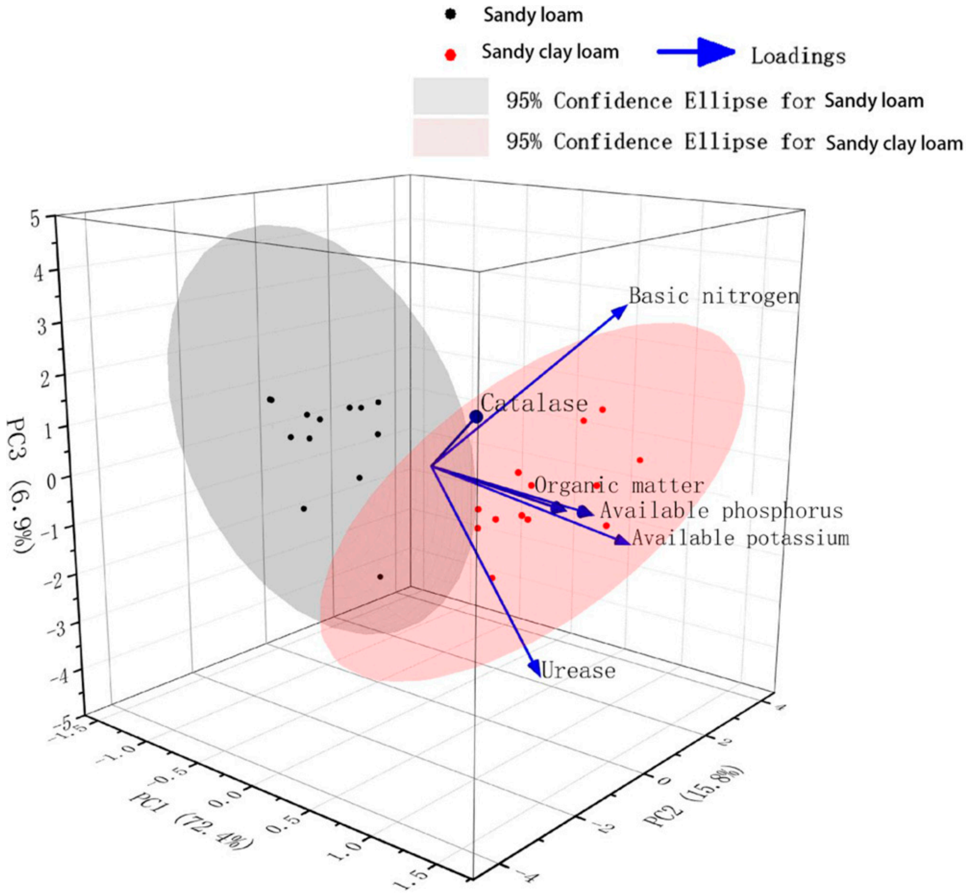

Fig. 5. Principal component analysis of soil nutrient elements (0- to 40-cm depth) during the green-up period. The arrows represent the variables.

by H_2O_2 in the soil, thereby supplying water and oxygen to the soil (Ma et al. 2019). In contrast, changes in urease activity showed an inverse relationship with soil temperature, in line with the findings of a previous study (Peryzat et al. 2022). Similarly, the fluctuation in urease activity, which initially exhibited an increase and then a drop, was correlated with the growth and development of the grass. Throughout the green-up period, the growth of turfgrass roots exhibited significant vigor and secreted urease. In spring, the activities of soil microorganisms increased. A somewhat higher soil temperature, along with secretions from roots and the activities of soil organisms, also help promote urease activity (Li et al. 2020b). Bulk density of the soil tends to increase with depth. This leads to a decrease in the variety and number of soil microorganisms, a gradual reduction in soil aeration, and a decline in enzyme activity. Consequently, enzymes deep below the soil surface reach a state of stability (Ma et al. 2022).

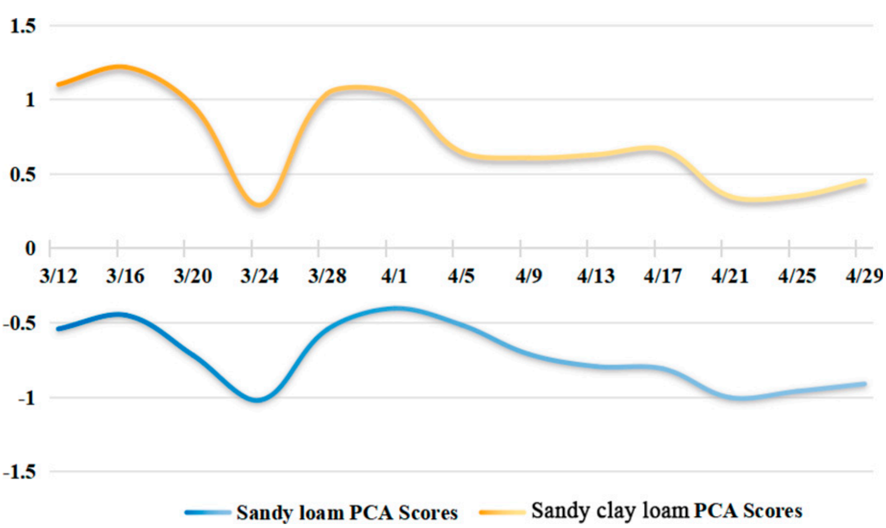

Fig. 6. Changes in the comprehensive score of the soil (0- to 40-cm depth) principal component value during the green-up period of turfgrass.

In our study, both soils showed multivariate correlation changes during the regrowth of *Poa pratensis* L. cv. Variation may arise because of changes in plant development and the surrounding ecological conditions (Cao et al. 2021). In our study, the SSP levels of leaves were negatively correlated with the soluble sugar levels of leaves in both soil types. This negative correlation indicates that the accumulation of one nutrient (e.g., soluble sugars) may reduce the availability or uptake of another nutrient (e.g., SSP), suggesting a competitive relationship within turfgrasses for the limited pool of soil nutrients. There were positive correlations among basic nitrogen, SAK, and SAP. This may be because basic nitrogen mineralization is a fundamental process that releases nitrogen, thus enhancing a plant's ability to absorb potassium and phosphorus (Qiao et al. 2021). We found that basic nitrogen and SOM were positively correlated with nutrient levels in turfgrass. This indicates that changes in one element can promote changes in the content of other elements to facilitate plant growth, with elemental nitrogen playing the most substantial role. Basic nitrogen can be absorbed by turfgrass roots and converted into SSP for the uptake of SAK and SOM (Moata et al. 2014). Tian et al. (2023) reported a negative correlation between soil temperature and SAP content and attributed it to the impact of elevated soil temperature on the microbial synthesis of acid phosphatase and its subsequent absorption by SAP in the soil.

In our study, two different soil types showed the same variation in nutrient levels during green-up. In PCA, the soil nutrients that most influenced PC1 were SOM, SAP, and urease, all of which are crucial to defining the overall nutritional value of soil (Tian et al. 2022). Thus, the overall nutritional value of soil changes regularly during green-up periods; therefore, when evaluating the nutritional value, it is essential to consider both external factors and inherent characteristics of the soil (Li et al. 2019). Some previous studies have reported that low temperatures, typically ranging from 5 to 10 °C, reduce the nutritional value of soil, while others have suggested that they can enhance it (Liu et al. 2016). Temperatures in this range can inhibit the growth of turfgrass, slowing its development. This seeming paradox may be explained by the fact that decreased soil temperatures hinder turfgrass regrowth, thereby diminishing its ability to absorb soil nutrients.

Conclusions

Turfgrass green-up largely depended on SOM, SAP, and urease in soil. Turfgrass grown on highly nutritious sandy clay loam initiated green-up 1 week earlier than that grown on sandy loam soil. Finally, soil nutrient levels declined in the early stages of green-up; thereafter, they increased and then slowly decreased. We recommend that when the greenness of turfgrass reaches 25% to 35% during the green-up phase, attention should be promptly given to changes in soil nutrition to prevent an imbalance between nutrient supply and demand caused by nutrient depletion. Changes in soil nutrients offer an opportunity to circumvent fertilizing unquestioningly and prevent the loss of soil fertility. In summary, the changes in soil nutrients that take place under turfgrass during green-up in spring are very complex. We conclude that improving soil nutrients can facilitate turfgrass green-up. Future work should explore how soil nutrients fluctuate under turfgrass at other times of the year, how turfgrass quality can be improved according to changes in soil nutrition, and how the nutritional quality of soil varies under different species of turfgrass.

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