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The influence of soil quality on the vitality of *Trifolium Pratense* L. cenopopulations in the subzone of deciduous forests of Tatarstan, Russia

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ABSTRACT

The study of plant vitality is one of the important methods in population research. *Trifolium pratense* L. is a typical representative of meadow herbs that have medicinal value. It is one of the most ubiquitous species of natural flora in the subzone of deciduous forests in Tatarstan, Russia. Various morphometric indicators reflecting the level of plant development, such as dry biomass of aerial parts, the height of plants, and the number of generative sprouts, were used in this study, ensuring sufficiently informative analysis of the vitality of the studied cenopopulations. The quality of soil on which the plants grow has a significant impact on their development. Therefore, the agrochemical analysis of soils which are the habitats of the studied cenopopulations was carried out. Cenopopulation vitality index (CVI) and soil quality index (SQI) were proposed and used with the aim to determine the dependence of the vitality of *T. pratense* cenopopulations on the soil quality in their habitats. It was found that for the calculation of SQI, it was necessary to consider the contribution of each of the soil quality indicators: total humus content, pH of salt extract, and the content of mineral elements. The proposed algorithm for the determination of weighting coefficients is based on the analysis of the distribution of linear correlation coefficients between SQI and CVI samples. The revealed interrelations between the indicators of soil quality and the vitality of populations allow their use for the targeted selection of the most favorable soils and large-scale cultivation of *T. pratense* on agricultural lands.

Keywords: *Trifolium pratense* L., Cenopopulation, Vitality, Soil, Quality, Index.

INTRODUCTION

Modern population research considers various biological characteristics of development of particular plant species. An individual of seed origin is used as a counting unit in such studies. As a biological system, cenopopulation has certain properties: abundance, density, age distribution and spatial structure, etc. (Zaugolnova *et al*. 1988; Ehsanpour *et al.* 2015). Analyzing the obtained material, we took into account that each cenotic population goes through several stages during succession development, such as formation, flourishing and extinction. Three types of populations correspond to these stages: invasive (invading), normal, and regressive (aging). An additional type that is called invasive-regressive is also known. It is represented by oppressed young plants dying at the first stages of their development and not leaving progeny (Rysin & Kazantseva 1975). The study of these aspects of plant populations' existence is the theoretical basis for solving scientific and applied questions, such as the identification, conservation and rational use of plant resources of particular species, the preservation of the gene pool of natural populations, allowing their use for breeding purposes, and the restoration of natural populations in disturbed habitats. The Republic of Tatarstan is located in the Russian Federation, on the East European Plain, at the confluence of two rivers, the Volga and the Kama. The territory of Tatarstan is represented by forest and forest-steppe zones. The climate is moderate continental. The average temperature of the coldest month (January) is -14

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°C; the average temperature of the warmest month (July) is +19 °C. The average precipitation ranges from 460 to 520 mm. The vegetation period is about 170 days. This territory is characterized by a wide variety of soils: from the gray forest and podzolic soils in the north and the west to chernozems in the south of Tatarstan. One of the most ubiquitous species of natural flora in the subzone of deciduous forests in Tatarstan is *Trifolium pratense* L., which is also of medicinal value. Meadow clover, *T. pratense* is among long-day plants. According to Posypanov *et al.* (2006), a slight extension of daylight period accelerates its development, while shortening of the day slows it down. A critical period in the development of plants is associated with insufficient daylight during the formation of pollen. This may be the reason for the death of ovules and the formation of unfertile ovaries of *T. pratense*, which is associated with a slowdown in the movement of organic substances from leaves to forming inflorescences. The effect of land-use change on boundaries of the dirt was assessed in soil tests from arable land, plantation land, and meadow in West Azerbaijan, Iran, contrasted and their neighboring regular forestland, utilizing some natural records (Rasouli-Sadaghiani *et al.* 2018). Since the dependability of soil totals is influenced by numerous variables, totals shaped in backwoods and agrarian soils in various soil types (Cambisols, Luvisols, Chernozems) was considered. The distinctions in water-stable totals as identified with soil type and land the board and furthermore the connections among quantitative and subjective boundaries of soil natural issue, molecule size dissemination and individual size classes of WSA were assessed (Polláková *et al.* 2018).

It is concluded that restricted admittance and procurement of supplements and water because of the more limited length of primary root probably assumed a vital job for development and physiological reactions to soil compaction in Q. robur seedlings (Cambi *et al*. 2017). It is proposed that drawn-out timberland progression improves plant variety, yet additionally improves soil science and quality, despite the fact that it does not altogether build soil microbial variety (Liu *et al.* 2020). Meadow clover prefers soils with a high content of organic substances. It grows well on meadow alluvial, clay and loamy, non-acidic and slightly acidic soils, on the sod-podzolic, gray forest, chernozem soils. *T. pratense* grows badly on acidic and highly saline soils.

When assessing the suitability of land for plants development, a measure of similarity between the values of indicators characterizing the soil of the habitat of the population and the values of the same indicators reflecting the requirements of plants can be used (Rozhkov 2014; Sharifi *et al*. 2016). Water availability, the thickness of soil, pH of salt extract, concentrations of available nitrogen, phosphorus, potassium, etc. are used as such indicators. The main disadvantage of this approach is the difficulty of identifying a particular set of population requirements for the numerical values of specific indicators of soil quality. The vital state is an important diagnostic characteristic of a plant population. This indicator is complex, as when it is formed, the complete bio-morphological characteristics of individuals in the population are being assessed (Ishbirdin *et al.* 2005). Currently, there is no single approach to the formation of integral indicators. There are indicators which are developed and successfully applied for specific tasks, depending on the objectives of the research and the type of data being processed (Wienhold *et al*. 2004; Bastida *et al.* 2008; Kozlov *et al*. 2009; Rodríguez *et al*. 2016; Magomedova & Adjieva 2017; Kovalenko *et al*. 2019). Overall, the chief purpose of this survey is to identifying and investigating The Influence of Soil Quality on the Vitality of *T. Pratense* cenopopulations in the Subzone of Deciduous Forests of Tatarstan, Russia, and eventually observe its environmental consequences.

MATERIALS AND METHODS

The final results of any study are significantly affected by choice of baseline indicators. Therefore, the preliminary assessment of the significance of particular indicators for cenopopulations and soils was made, taking into account the possibility of their measurement in certain scales and ranges of variation. In addition, the requirements of estimability, representativeness, and non-redundancy were considered when forming the list of indicators. The collection of plant material was carried out during the growing season of 2018-2019 in four administrative regions of Tatarstan which are in the subzone of deciduous forests: Laishevsky district (cenopopulations 1 and 2), Tetyushsky district (cenopopulations 3, 4, and 5), Kamsko-Ustyinsky district (cenopopulation 6) and Apastovsky district (cenopopulation 7). At each sampling site, one × 1 m in size, all plants of *T. pratense* were collected for herborization and further morphometric analysis, which was carried out in the laboratory. In addition, in accordance with the methodological recommendations, geobotanical descriptions of plant communities on an area of 200-500 m^2 were carried out (Golub *et al*. 2012).

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In the process of morphological analysis, the following parameters were determined on herbarized plants: dry biomass of plant (p_1), plant height (p_2) and the number of generative sprouts (p_3). The agrochemical analysis of soils of the studied cenopopulations habitats was carried out. The following indicators were determined according to the common methods (Chekmarev et al., 2015): pH of salt extract (g_1), total humus content (g_2), concentrations of nitrate and ammonia nitrogen (g_3 and g_4), mobile phosphorus (g_5), exchange potassium (g_6), calcium (g_7) and magnesium (g_8).

RESULTS AND DISCUSSION

One of the most important concepts in biology in general and botany, in particular, is the concept of norm, i.e., the optimum in functioning and development of biological systems. The norm is often expressed as a range of values of some indicator. For example, in the assessment of soil quality, a small or large deviation of an indicator from the boundary values in one direction or another is a criterion showing the reduction of soil quality. Table 1 presents the variation ranges of the main indicators of soil quality in general for all studied habitats of cenopopulations.

Table 1. Variation ranges of the soil quality indicators.

Parameter	g_1, unit pH	g_2, %	g_3, mg kg^{-1}	g_4, mg kg^{-1}	g_5, mg kg^{-1}	g_6, mg kg^{-1}	g_7 mmol/ 100 g	g_8 mmol/ 100 g
Parameter range	4.4-7.2	1.6-2.7	2.8-19.5	9.1-14.5	35-264	58-444	5.5-29.5	1.75-7.25

The analysis of the indicators given in table 1 allows us to conclude that all indicators correspond to their norms and do not exceed the boundaries of the optimum ranges. Table 2 presents the variation ranges of the indicators of plant development level for each cenopopulation.

Table 2. Variation ranges of the indicators of plant development level.

Parameter*	Parameter variation range for cenopopulation *j*						
	j=1	*j*=2	*j*=3	*j*=4	*j*=5	*j*=6	*j*=7
p_{1j}, g	0.6-9.3	0.32-8.1	0.7-14.18	0.46-7.12	4.18-9.84	0.6-30.88	0.66-32.6
p_{2j}, cm	8-56	4-69	16-42	16-54	11-50	15-64	15-70
p_{3j}, pcs	1-9	1-7	1-15	1-7	3-20	1-15	1-21

*p_1, dry biomass of plant; p_2, plant height; p_3, the number of generative sprouts.

The methods of mathematical statistics were used to process the results of measurements of plant characteristics. The mean values, standard deviations, standard errors of the mean, the coefficients of variation of each indicator for all studied cenopopulations were determined. Figs. 1, 2 and 3 show these results for the indicators of plant development level.

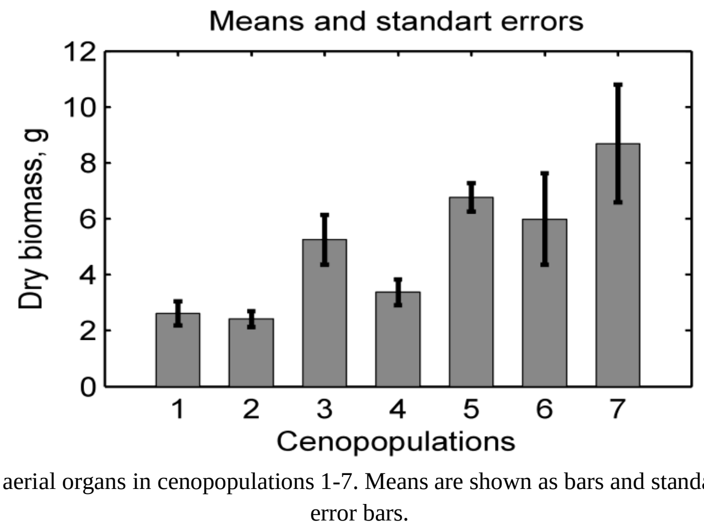

Fig. 1. Dry biomass of aerial organs in cenopopulations 1-7. Means are shown as bars and standard errors of the mean as error bars.

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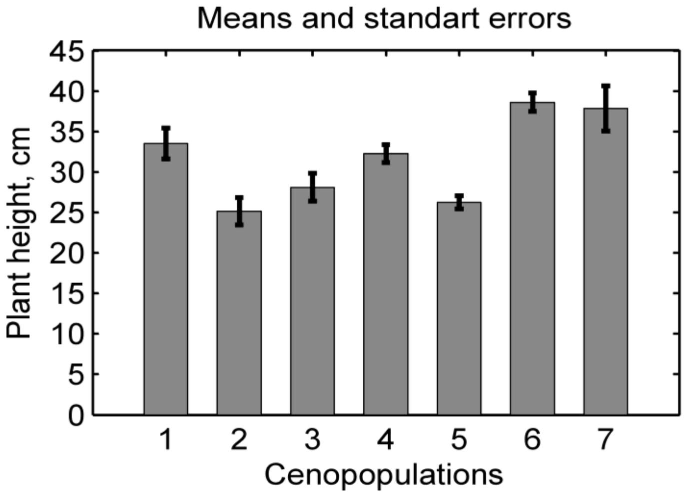

Fig. 2. Plant height in cenopopulations 1-7. Means are shown as bars and standard errors of the mean as error bars.

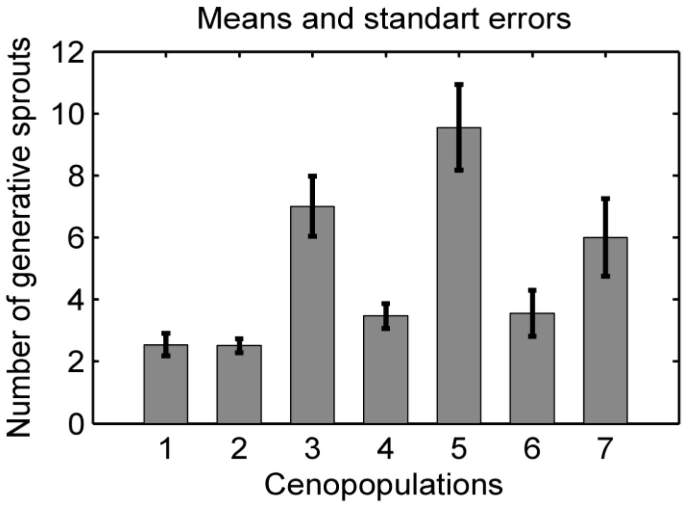

Fig. 3. The number of generative sprouts in cenopopulations 1-7. Means are shown as bars and standard errors of the mean as error bars.

An increased informativeness in the processing of results was achieved by the formation and use of the integrated characteristics of cenopopulations, on the one hand, and the integrated characteristics of soil habitat of cenopopulations, on the other hand. Integral characteristics were applied in the calculation of the Pearson linear correlation coefficients, which, in turn, were used with the aim to identify the presence and strength of the relationship between the integral indicators of soil quality and the integral indicators characterizing the development of plants. When forming integral characteristics for soil and cenopopulations, the positive influence of soil quality indicators on the indicators of cenopopulations development level was taken into account. The proposed integral indicators are, in essence, a mathematical convolution of the initial indicators with different levels of hierarchy. Before combining into the integral indicator, the initial indicators were additionally processed: they were converted into a dimensionless form in a variation range from 0 to 1. The differences in the hierarchy levels of particular indicators were taken into account using the corresponding weighting factors. Cenopopulation vitality index (CVI = [y_1, ..., y_7]) was used to assess the development level of each of the studied cenopopulations. This index was calculated for each cenopopulation according to the formula:

$$y_j = \sum_{i=1}^{n} r_i \cdot p_{ij} / \max(p_{ij}), \quad \textbf{(1)}$$

Where r_i is the weighting coefficient of the indicator i, $r_i = 1/n$;

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p_{ij} is the average value of the indicator i for the cenopopulation j;
n is the number of indicators i, $n = 3$.

Soil quality index ($SQI = [x_1,\dots,x_7]$) was used in the habitats of each of the studied populations to define the soil characteristics which determine the viability of plants. Its values for each habitat of cenopopulations were calculated according to the formula:

$$x_j = \sum_{i=1}^{N} w_i \cdot g_{ij} / \max(g_{ij}), \qquad (2)$$

where w_i is the weighting coefficient of the indicator i;
g_{ij} is the value of the indicator i of habitat j;
N is the number of indicators i, $N = 6$.

Fig. 4 shows the integrated indicators of soil quality and the vitality of cenopopulations, ranked by increasing x_j values. The values of x_j are calculated according to the formula 2 with the same values of weighting coefficients $w_i = 1/N$. The figure shows the distribution of cenopopulations relative to the increase of SQI with the same impact of each soil quality indicator. Cenopopulation 2 has the smallest SQI value, while cenopopulation 1 has the largest. The value of the Pearson linear correlation coefficient r_{xy} for this option is 0.398. The low value of this parameter is primarily due to the low CVI for cenopopulation 1 ($y_1 = 0.4783$). If the SQI and CVI values are excluded for cenopopulation 1, $r_{xy} = 0.803$ is obtained. The most likely reason for the abnormally low CVI value of cenopopulation 1 is low water availability of the soil. At this habitat, the local elevation of the studied area was observed and, as a result, relatively high drainage of the soil.

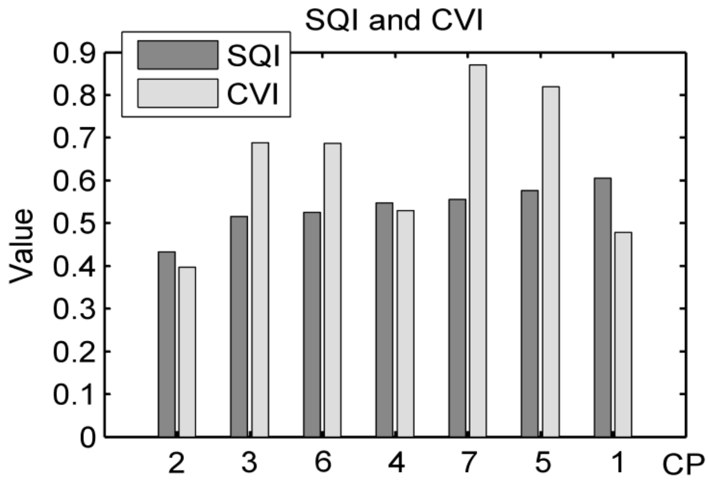

Fig. 4. Integral indicators of soil quality and vitality of cenopopulations (CP) with the same weighting coefficients of soil quality indicators.

It is known that sufficiently strong positive correlation should exist between the indicators of soil quality and vitality of cenopopulations. The reasonable choice of weighting coefficients of SQI is important for the determining of this relationship. When using the expert methods, the probability of an error is high due to the subjectivity of expert estimates. Therefore, the following algorithm, consisting of three stages, was proposed for the definition of weighting coefficients w_i.

At the first stage, the values of SQI and coefficient r_{xy} were calculated with successive sequential exclusion from the calculation of each of the indicators g_i. All remaining weighting coefficients were identical and equal to 1/5. Data for cenopopulation one was not taken into account in r_{xy} calculations.

At the second stage, the values of weighting coefficients w_i were calculated according to the following principle: the larger is the value of r_{xy}, the less is the influence of the excluded indicator. The next formula was used for calculations:

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$$w_{1k} = (1 - r_{xy}(k) + \min(R_{xy})) / \sum_{i=1}^{N=6} (1 - r_{xy}(i) + \min(R_{xy})), \quad (3)$$

Where k is the number of the excluded indicator of soil quality; $R_{xy}=[r_{xy}(1),\ldots,r_{xy}(6)]$.
At the third stage, the method (Zent & Maffi 2009) was used. In order to increase r_{xy} coefficients for each indicator, the corresponding numbers n_k were established from 1 to $n = 6$. The adjusted weighting coefficients were calculated by the formula:

$$w_{2k} = (n + 1 - n_k) / (n \cdot (n+1)/2). \quad (4)$$

Table 3 shows the results obtained using the proposed algorithm for determining the weighting coefficients for soil quality indicators.

Table 3. Weighting coefficients w_{1k} and w_{2k} for soil quality indicators.

k	1	2	3	4	5	6
$r_{xy}(k)$	0.476	0.435	0.971	0.767	0.704	0.970
w_{1k}	0.22367	0.23335	0.10822	0.15573	0.17059	0.10844
n_k	2	1	6	4	3	5
w_{2k}	0.23810	0.28571	0.04762	0.14286	0.19048	0.09524

Fig. 5 shows the integrated indicators of soil quality and vitality of cenopopulations ranked by increasing x_j values and obtained using the weighting coefficients w_{2k}.

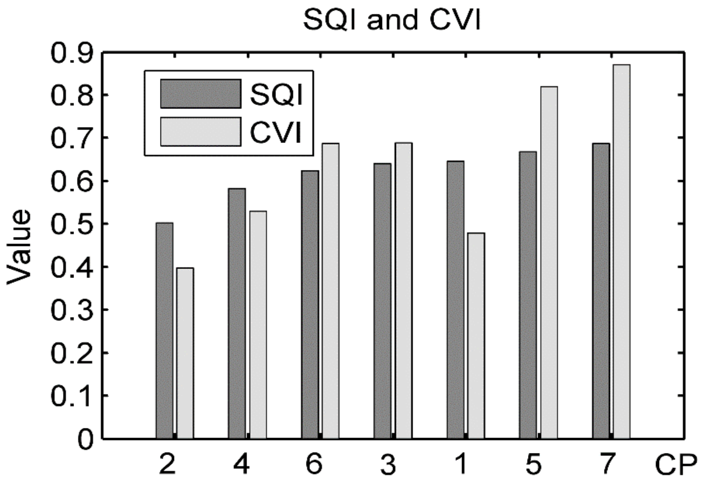

Fig. 5. Integral indicators of soil quality and vitality of cenopopulations (CP) at weighting coefficients w_{2k}.

Using weighting coefficients w_{1k} and taking into account the indicators of soil quality for all cenopopulations, the correlation coefficient r_{xy} = 0.693 was obtained while excluding the indicators of cenopopulation 1, the correlation coefficient was r_{xy}=0.938. Using weighting coefficients w_{2k}, higher r_{xy} values were obtained: 0.817 and 0.982, respectively. The most favorable soil conditions for the growth of *T. pratense* were identified in the Apastovsky district.

SUMMARY

The obtained results allow ranking soil quality indicators by decreasing significance for the calculation of SQI as follows: total humus content, pH of salt extract, concentration of mobile phosphorus, ammonia nitrogen, exchange potassium, and nitrate nitrogen. The established hierarchy of indicators is characteristic precisely for the studied cenopopulations and their habitats. The strong correlation between the quality of soils and viability of *T. pratense* populations was confirmed.

CONCLUSIONS

The results of the research are important for the definition of the vitality of *T. pratense* cenopopulations as a valuable medicinal plant, growing on the territory of Tatarstan, Russia. Cenopopulation vitality index (CVI) and

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soil quality index (SQI) were proposed and used with the aim to determine the dependence of the vitality of *T. pratense* cenopopulations on the soil quality of their habitats. The dimensionless values of these indicators were in the range from 0 to 1. Such indicators of plant development as dry biomass and height of plants, the number of generative sprouts were used in the study for the calculation of CVI. The results of agrochemical analysis (humus content, pH of salt extract, etc.) were used for the calculation of SQI. The proposed SQI can be used along with other comprehensive indicators for the assessment of lands and soils suitability for agricultural purposes, for example, based on the calculated LUI index (land unit index).
It was defined that for the adequate calculation of SQI values, the qualified determination of weighting coefficients for each soil quality indicator is necessary. The algorithm for the determination of such weighting coefficients was proposed in work. It was based on the analysis of the distribution of linear correlation coefficients between SQI and CVI samples. Such distribution of the coefficients was obtained due to successive exclusion from the calculation of SQI of each of the soil quality indicators. Those indicators that allow obtaining small values of the linear correlation coefficients when these indicators are excluded from the calculation of SQI have the largest values of weighting coefficients. The final values of weighting coefficients were established by the ranking of correlation coefficients, similarly to the expert method. The revealed interrelations between the indicators of soil quality and the vitality of populations make it possible to use them for the targeted selection of the most favorable soils and large-scale cultivation of meadow clover on agricultural lands.

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تأثیر کیفیت خاک بر بنیه‌ی شبدر قرمز در زیرمنطقه جنگل‌های برگ ریز تاتارستان روسیه

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چکیده

مطالعه‌ی بنیه‌ی گیاه یکی از روش‌های مهم در تحقیقات جمعیتی است. شبدر قرمز، از گونه‌های پهن‌برگ با ارزش دارویی است. این‌گونه، فراوان‌ترین گونه طبیعی در زیر منطقه جنگل‌های برگ ریز تاتارستان روسیه است. در این مطالعه شاخص‌های ریخت سنجی مختلف نشان‌دهنده‌ی سطح رشد گیاه، مانند زی توده خشک اندام‌های هوایی، ارتفاع گیاهان و تعداد جوانه‌های زایشی، به‌منظور تجزیه تحلیل دقیق بنیه‌ی جمعیت‌های مطالعه شده استفاده شدند. کیفیت خاکی که گیاه روی آن رشد می‌کند، اثر مهمی روی نمو گیاه دارد. بنابراین، تحلیل شیمیایی و زراعی خاک که زیستگاه جمعیت‌های مورد مطالعه هستند، انجام شد. شاخص بنیه‌ی جمعیت (CVI) و شاخص کیفیت خاک (SQI) پیشنهاد شد و باهدف تعیین وابستگی بنیه‌ی جمعیت‌های شبدر قرمز به کیفیت خاک در رویشگاه‌ها، استفاده شد. نتایج نشان داد که برای محاسبه‌ی SQI، در نظر گرفتن سهم هر یک از شاخص‌های کیفیت خاک، لازم و ضروری است که شامل مقدار هوموس کل، pH عصاره‌ی املاح، و مقدار عناصر معدنی است. الگوریتم پیشنهاد شده برای تعیین ضرایب وزنی بر مبنای تحلیل توزیع ضرایب همبستگی خطی بین نمونه‌های SQI و CVI است. همبستگی بین شاخص‌های کیفیت خاک و بنیه‌ی جمعیت‌ها، امکان استفاده از آن‌ها را برای انتخاب مطلوب‌ترین خاک‌ها و کشت بزرگ مقیاس شبدر قرمز در اراضی کشاورزی می‌دهد.

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