DOI: 10.37555/2707-3114.18.2022.270615
УДК: 581.5: [581.522.4 + 581.95]

Ефект сумарної дії екологічних чинників на життєвий стан інтродукованих рослин та його енергетична оцінка

Микола І. Шумик, Петро Є. Булах, Надія І. Попіль✉
Національний ботанічний сад імені М. М. Гришка НАН України, м. Київ,
e-mail: green@nbg.kiev.ua; pbulakh2017@ukr.net; nadiapopil76@gmail.com
ORCID ID 0000-0003-1415-7482; ORCID ID 0000-0002-7774-1654

✉ nadiapopil76@gmail.com

Реферат.

Мета. Необхідність узагальнення результатів комплексного впливу зовнішніх чинників різної природи на інтродуковані рослини та аналіз трьох основних типи ефектів, які при цьому відбуваються: адитивність, синергізм і антагонізм, зумовили проведення досліджень. ***Матеріали і методи***. Стійкість рослин вивчали з позицій системного аналізу, згідно з яким будь-який тип стійкості формується під впливом не одного, а системи лімітувальних чинників, які взаємодіють між собою згідно з відповідними закономірностями. Лінію песимуму як межу між зонами адаптації та дискомфорту визначали за Генадієм Зайцевим (Zaytsev, 1983) та Петром Булахом (Bulakh, 2010). Енергоємність надземної частини рослин визначали у фазі цвітіння (середня вибірка). Життєві показники для видів роду *Allium* L. на індивідуальному рівні визначали візуально за показником потужності розвитку вегетативних і генеративних органів, а на популяційному рівні — за співвідношенням особин різного віку. Життєздатність видів роду *Lonicera* L. визначали за розростанням пагонів рослин під час їхнього активного росту. ***Результати та обговорення***. Показано, що ефект комплексного впливу будь-яких чинників на рослинні організми проявляється у зміні показників їх життєвого стану (життєвості), а поняття “життєвість” розглядається як відображення стійкості та енергетичного стану рослин. Обговорюються різні тлумачення понять «стійкість» та «надійність» і окреслюються шляхи до пошуку методів оцінки життєвості організмів. ***Висновки.*** Показано, що для комплексної оцінки стійкості інтродукованих рослин за умов комбінованої дії чинників навколишнього

середовища можна використовувати показники їхнього енергетичного балансу, а оптимальним у певних умовах потребам життєдіяльності рослин відповідає мінімальне значення їхніх енергетичних показників. Сформульоване положення підтверджене експериментально за результатами визначення теплотворної здатності рослин колориметричним методом.

Ключові слова: синергізм, антагонізм, адитивність, життєздатність, стійкість, надійність функціонування рослин, енергозалежна природа стійкості, мінімалізація енергетичних витрат, теплотворна здатність.

The effect of the combined impact of environmental factors on the vitality of introduced plants and their energy assessment

Mykola I. Shumyk, Petro E. Bulakh, Nadia I. Popil✉
M. M. Gryshko National Botanic Garden NAS of Ukraine, Kyiv, Ukraine,
e-mail: green@nbg.kiev.ua; pbulakh2017@ukr.net; nadiapopil76@gmail.com
ORCID ID 0000-0003-1415-7482; ORCID ID 0000-0002-7774-1654

✉ nadiapopil76@gmail.com

Abstract

Aims. The results generalization of the complex influence of external factors of nature different on the introduced plants and an analysis of the three main types of effects that occur: additivity, synergism, and antagonism were determined as the performed research goal. ***Methods***. Plant stability was studied from the standpoint of systems analysis, according to which any type of plant resistance is formed by not one cause, but a system of limiting factors that interact with each other according to suitable regularity. The line of pessimum as a boundary between the zones of adaptation and discomfort was determined according to Gennadiy Zaytsev (1983) and Petro Bulakh (2010). The energy intensity of the above-ground part of plants in the flowering phase was determined (average sample). Vital indicators for species of the genus *Allium* L. at the individual level were determined visually by the indicator of the power of development of vegetative and generative organs, and at the population level—by the ratio of individuals of different ages. The viability of species of the genus *Lonicera* L. was determined by the growth of plant shoots during their active growth. ***Results.*** Based on the ideas about the effects of the complex impact of new environmental factors on introduced plants, successive stages of the introductory experiment were identified, and it was proved that the pessimum zone is a necessary condition for plant development in culture. It was found that the effect of the complex impact of any factors on plant organisms is manifested in changes in their vital status (vitality) and the concept of "vitality" is considered a reflection of the stability and energy status of plants. Different interpretations of the "stability" and "reliability" concepts were discussed, and ways to find methods for assessing the viability of plant organisms were outlined. ***Conclusions***. In this paper, it is shown that an integrated assessment of the stability of introduced plants under the conditions of the combined impact of environmental factors can be used as indicators of their energy balance, and the optimal in certain conditions of plant vital needs correspond to the minimum value of their energy indicators. The formulated position was tested experimentally by determining the calorific value of plants by the colorimetric method.

Key words: synergism, antagonism, additivity, viability, stability, reliability of plant functioning, energy-dependent nature of stability, minimization of energy costs, calorific value.

Introduction. The generalization of data on the effect of the combined impact of environmental factors on plants shows that there are only three main types of effects from their joint action: additivity, synergy, and antagonism.

It can be argued that additivity is a combined impact of various factors, in which the final resultant effect is always equal to the sum of effects caused by each factor separately. Synergism is a combined impact of many factors, in which the effect of the sum exceeds the effect performed by each component separately. Antagonism is such a combined impact of factors in which the total sum is always less than the sum of the values.

If we are talking about the combined impact of X_1, X_2, …, X_n, factors, then these definitions can be formalized as follows:

$$\text{Additivity} — X_1 + X_2 + \ldots + X_n = \sum X_1, X_2, \ldots, X_n$$

$$\text{Synergism} — X_1 + X_2 + \ldots + X_n > \sum X_1, X_2, \ldots, X_n$$

$$\text{Antagonism} — X_1 + X_2 + \ldots + X_n < \sum X_1, X_2, \ldots, X_n$$

The study and analysis of the effects that characterize the total effect of environmental factors on natural objects has become widespread in many scientific disciplines. For example, the concepts of antagonism and addiction are widely used mainly in philosophy, general biology (struggle for existence and resources), medical and chemical fields of knowledge (including pharmacology), agriculture and the food industry, and so on.

From this triad, the phenomenon of synergism is better studied than others. Even Aristotle, considering the principles of the structural and hierarchical structure of things, noted that the whole is more than the sum of its parts (Naumova, 2013). In the future, the synergy of effects is mentioned first in a religious context, and from the end of the 19th century—in biological and medical disciplines (mainly in human physiology) and social sciences. Though at that time the term "synergism" did not yet exist, however, scientific works mentioned some force that gives an additional effect of combining some structural components of the integer (Iudin & Shchegoleva, 2006). Only in the 60s of last century did Igor Ansoff's concept of synergism and synergistic effect prove to be a classical basis for further research.

At approximately the same time, thanks to the work of Ilya Prigogine dissipative structures theory was formed (Prigogin & Stengers, 2017). Its logical continuation was the formation of a new direction of research on the processes of self-organization in different environments and systems in the early 70s of the last century, called "synergy". The term was proposed by G. Hacken in 1969, and the scientific field itself is the only one that deals with the study of complex systems. G. Hacken explained the use of the term "synergy" as follows:

— I called the new discipline "synergy". It examines the combined impact of many subsystems, resulting in a structure and the corresponding functioning at the macroscopic level (Hacken, 1980).

There is currently no common term for "synergy". The inconsistency in terminology is explained by some differences in the views of individual scientific schools on the complex and multifaceted process of self-organization. In particular, the American inventor and philosopher R. Buckminster Fuller defined "synergy" as the behavior of the whole that is unpredictable based on the study of its parts (Fuller, 1982).

Returning to the concept of "synergy", it should be noted a similar inconsistency in its definition. Different interpretations of this term can be found in dictionaries, and in scientific articles on Internet resources (Campbell & Sommers Luchs, 1998; Holtström & Anderson, 2021; Naumova, 2013; Sanginova & Khodjaeva, 2010). As an example, we can cite definitions from some reviews on the problems of synergy:

— For any system (technical, biological, or social) there is a set of resources in which its potential will always be either significantly greater than the simple sum of the potentials of its resources (technology, personnel, computers, etc.), or significantly less.

— The merged parts are highly dependent on each other and when merging can significantly (positively or negatively) affect each other within the whole. This is called the synergistic effect.

— Any complex dynamic system seeks to get the maximum effect due to its integrity; seeks to make the most of the opportunities for cooperation to achieve effects.

— The features of the organization are greater than the sum of the qualities of its components.

— The sum of the features of an organized whole is not equal to the arithmetic sum of the features of each of its elements separately; or else the sum of the features of the organizational whole exceeds the arithmetic sum of the features of each of its elements separately.

— For any organization, there is a set of elements in which its potential will always be either significantly greater than the simple sum of the potentials of its constituent elements, or significantly less.

— Synergism effect "2 + 2 = 5".

— In the case of groups, synergy means striving to achieve results that are not "zero-sum of effects".

Such representations in general reflect the essence of the effects of factors of different nature on the organism and are considered in the framework of system analysis (Bilyavsky et al, 1995; Bulakh & Shumyk, 2013). The synergistic effect can be considered as a systemic effect because the system as a whole is always characterized by a set of features that exceed the values calculated by the rule of additivity.

A systematic approach in the biological sciences is to identify the main elements of the object of study ("system"), a formal description of their features and rules of interaction (Chernyshenko, 2005; Patten, 1978; Vogel et al., 2018). Introduction of synergistic and antagonistic factors to the extreme factor is a necessary condition for research in the sciences that study the processes occurring in the system "organism-environment" (biogeocenology, soil science, crop production, biogeography, agrochemistry, plant introduction, landscape construction, etc.), as the former enhances, and the second—weakens its effect.

The effect of combined impact of various environmental factors on plants is manifested both in their simultaneous and sequential effects. Finding out the mechanisms of simultaneous action is a difficult task. The final effect will be determined by the ratio and interaction of a significant number of physiological reactions. We understand combined resistance as the ability of plants to maintain their basic qualities relatively unchanged despite the simultaneous action of various extreme factors.

The correctness of finding a quantitative expression of the total effect of environmental factors depends on the feasibility of "addition" or "subtraction" of effects. If the result of the combined impact of factors is equal to the sum of the effects of their separate action, it is sometimes said about the "addition" of effects. Similar views exist in the case of the "subtraction" of effects. However, the mechanisms that ensure the effects of each of the factors may be different. In this case, heterogeneous effects are added and subtracted, which is incorrect and complicates the interpretation of the quantitative expression of the total effect of various factors.

Thus, the mechanism of the combined impact of environmental factors on plants is quite complex, and its study in the introduction of plants will raise the level of theoretical knowledge as a basic foundation for conducting correct practical experiments.

Material and methods. The introduction of plants as an ecological and geographical problem considers the processes occurring in the system "plant–environment–man", and the last element in the system is assigned a control function. Therefore, all processes of interaction in the system can be studied by methods of system analysis. From such positions, it can be argued that the two elements of the system—introduced plants and their new environment—in the process of adaptation approach each other in the direction of perfect mutual correspondence, and this occurs as a result of self-regulation of the system.

At present, there is no doubt about the feasibility of using a systematic approach and the need to study the effect of the combined impact of environmental factors on introduced plants. For example, the effect of zones of optimum (comfort), adaptation, and discomfort due to the action of differences in strength, duration of impact, and combination of environmental factors on plants. The boundary between the zones of adaptation and discomfort is the line of pessimum (Zaytsev, 1983; Bulakh, 2010). Analysis of the results of the complex effect of environmental factors and data on the dependence of ontogeny and phylogeny of organisms on the intensity of existing factors allows us to consider the pessimum zone as a necessary condition for plant development in the new environment (Schmalhausen, 1964; Bulakh & Shumyk, 2013), which mean for the artificial creation of relevant conditions for introduced plants in botanical gardens and arboretums.

To date, there is a lack of experimental research to study the total effect of environmental factors on introduced plants. This is partly due to the lack of awareness of researchers studying the system "organism-environment" with the existing methodological arsenal (including mathematical). For example, introductory botanists, with few exceptions, do not identify limiting factors among the significant number of environmental factors that affect their research objects when engaging in introductory forecasting. This is due as empirical analysis is not always enough for this, and the required regression analysis is little known in botanical disciplines. Thus, in most cases, the frost/drought resistance of plants in culture conditions are almost always determined regardless of whether there is a need for it.

Results and discussion. Analysis of literature sources and personal observations on the effect of the complex impact of new environmental factors on introduced plants from the standpoint of systematic analysis allows us to determine the successive stages of the introductory experiment on the introduction of new useful plants in culture.

1. Isolation of significant by the action (active) on the introduced plants of extreme or pessimic environmental factors by methods of empirical or regression analysis.

2. The study of environmental factors that in relation to the main one(s) increase its impact (synergism) or weaken (antagonism). In cases of synergy between extreme and concomitant environmental factors, measures are taken for its elimination (weakening).

3. The effect of the extreme factor(s) in relation to the object of study is the greatest threat during critical (vulnerable) periods in the ontogenesis of plants, which coincides with the change of stages of their individual development. During this period, plant protection measures are most relevant.

4. Artificial regulation of the zone of optimal development of introducers by differentiated strengthening (weakening) of the influence of optimal and pessimistic environmental factors (watering, shading, substrate optimization, etc.).

5. Implementation of the long-term forecast of stability in the system "alien–environment–man" by extrapolation methods.

The effect of the complex impact of any factors on plant organisms is primarily manifested in changes in their vital conditions (vitality), which directly depends on the intensity of such combined impact, and assessing of the organism's viability of methods are rather imperfect. (except for mathematical modeling). The concept of "vitality" has long been widespread in botanical disciplines and is considered a characteristic of the intensity of life processes (growth, development, reproduction, resistance to adverse conditions and diseases), using a system of material and energy parameters to assess plant stability: "power", "growth", "stage of the photosynthetic surface development", "reproductive effort", etc.

The vital condition of the species is characterized by qualitative indicators of development and quantitative indicators of growth at the level of both individuals and phytopopulations (Uranov, 1975). Considering the individual manifestations of vitality, we can conclude that this feature of organisms is a reflection of their energy state. The volatile nature of living organisms and connected with them their resistance has been recognized through the works of Ivan Schmalhausen (1964) and Dmytro Grodzinskiy (1983), and in the introduction of plants, vitality is considered by us as an indicator of plant stability, which characterizes their energy state (Bulakh, 2001; Bulakh & Shumyk, 2013). Thus, given the existence of such a dependence, the effect of the combined impact of environmental factors on the resilience of organisms can be assessed from the standpoint of their energy status.

The implementation of the proposed approach requires a clear analysis of the concept of "sustainability". When assessing the resistance of plants to the combined impact of external environmental factors, i.e. "resistance to all types of effect" it is necessary to take into consideration that this interpretation of this concept is not entirely correct from the standpoint of plant physiology. In the strict sense, stability characterizes the organism's response to certain environmental factors and refers to one or another form of adaptation of the organism to a particular factor. There are numerous types of resistance (winter, frost, drought, gas, etc.) and to assess each of them proposed certain criteria (Bulakh, 2002), but they are not used to determine the result of the combined impact of environmental factors on plants.

In this regard, Dmytro Grodzinskiy (1983) proposed to consider the resistance of organisms to the combined impact of environmental factors as a manifestation of the reliability of their functioning in such conditions. He understood the reliability of the organism as its ability to perform physiological and biochemical functions that ensure its normal functioning during ontogenesis in certain environmental conditions. This definition is almost identical to the definition of "sustainability". However, the analysis of literature data shows that there are fundamental differences between the two related concepts of "stability" and "reliability". "Sustainability" is a narrower, more specific concept that is defined as the organism's response to a particular factor. "Reliability" is a broader concept, it is a general feature of the organism, the manifestation of which is subject to a particular case—resistance to specific influences. From the standpoint of the principle of reliability explains many biological phenomena, which is reflected in the works of Ivan Schmalhausen (1964).

At the level of individuals and populations, the following systems and mechanisms of reliability play the greatest role:

1) **The height of the threshold of physiological reactions**. It determines the sensitivity of plants to the action of the most significant environmental factors. The height of the thresholds in the ontogenesis of plants varies and is a genetically fixed value;

2) **The number of duplication mechanisms or, in the language of reliability theory, the degree of elements redundancy.** In hereditary information, this system of reliability is manifested in the repetition of the same genes (polygenes), in the repetition of more or less significant parts of chromosomes (duplication), and in the complete repetition of all chromosomes in the diploid organism. The facts show an increase in plant resistance to various environmental factors while increasing their ploidy.

3) **The diversity of solutions to the target program**. Relocation of plants is usually associated with their stay outside the "norm of reactions". In this case, the leading target function of plants is to maintain the stability of their structure as a whole system (Zaimenko, 1998). At different hierarchical levels, there are different mechanisms for its provision, there are specific ways to protect the organism from extreme factors. At the cellular level, there is a wide possibility of combinatorics of the functioning of different compartments and the redundancy of metabolites (depots), which are used as needed, depending on the intensity of external influences. Factors of multivariate provision of normal life in extreme or new conditions (existence of different metabolic cycles, different types of photosynthesis, presence of isoenzymes, ability to harden, etc.) are "included" by the principle of feedback and at the right time.

4) **Heterogeneity of plant structures**. This system of plant reliability is manifested at different hierarchical levels and is determined by the diversity of individual structures in terms of functioning, time, and place of formation. The result of heterogeneity is the different sensitivity of plant organs at different stages of formation to external factors. Forms of plant heterogeneity are very diverse (Bulakh, 2002).

Thus, the search for integrated methods for assessing the total effect of environmental factors on the vital conditions of plants should be carried out from the standpoint of the theory of reliability of organisms. Given the idea of the energy-dependent nature of plant resistance to various environmental factors, we can assume that an objective integrated quantitative indicator of the reliability of plant functioning under adverse external conditions can be calculated based on a study of their energy metabolism. It is known that adaptive changes of introduced plants are associated with the intensification of various life processes, which is always reflected in their energy potential (Bulakh, 2016). Therefore, to select a such indicator of energy metabolism, which adequately characterizes the state of plants in conditions of constant changes in environmental parameters, it is advisable to consider the energy principles of optimal functioning of living organisms. One of the most tested and well-developed is the principle of energy saving, as well as the lesser-known, but the well-founded principle of maximum entropy. In defiance of the fact that there are examples when these principles are violated, and the basic functions of the organism are subject to another, more powerful factor (information), we cannot fail to note their positive role in studying the nature of sustainability of living organisms.

Supporting the idea of energy metabolism as a sensitive indicator of the state of organisms in relation to environmental factors, (Grebinskiy, 1944, p. 187) argued that "a reliable indicator of plant adaptation is the preservation of the ability with the least energy to synthesize in adverse conditions the main components of plasma, i.e. primarily proteins and lipoids, in quantities that ensure normal life." Later, (Kalabukhov, 1946) formulated the idea of energy balance and expressed the idea that the basis of any adaptation is to save energy. The same idea is developed by George Rigel, (1967), noting that "thriving" is always organisms that most efficiently use the source of external energy, in such cases, energy consumption is minimized. In other words, a "thriving" organism works "economically". The increase in the energy "value" of species in adverse conditions can be seen as a consequence of an excessive accumulation of macroergic bonds in plants.

Analysis of modern sources of information confirms the idea of the energy-dependent nature of plant resistance to extreme environmental factors. From the energy positions, owing to the influence of adverse factors of different nature, energy consumption channels should increase significantly, in particular, for the repair of damaged structures (Petrov et al., 1986; Chernyshenko, 2005; Viter, 2016).

Summarizing the energy principles of optimal functioning of organisms, we can formulate the following position: indicators of the energy balance of the organism, which adequately assess its condition, can be used as a criterion of its stability (criterion of optimal functioning), and the best in these conditions corresponds to the minimum of this indicator. This provision, based on extreme principles with the idea of optimality embedded in them, may find prospects for use in the introduction of plants.

Under optimal conditions, there is a minimum level of energy metabolism of introducers, which indicates a balanced state of metabolism. The term "optimization" in the introduction of plants only acquires scientific meaning when used as a synonym for the concepts of "energy minimization" and "entropy maximization". The use of ideas of optimality in solving the problems of plant resettlement allows us to understand many facts and phenomena that have not been explained in the framework of existing theories. In this regard, the principle of optimality in its strict sense (the statement of the minimum or maximum of the functional or objective function) can be used as an effective scientific concept in the introduction of plants (Bulakh, 1999; Bulakh & Popil, 2018). If the minimum energy metabolism is a "metabolic benchmark" that helps the organism choose the optimal vital conditions, the task of the plant introducer is to find a match between the energy metabolism of plants and their environment. Models of artificial cenosis in botanical gardens and arboretums can be built on this principle (Bulakh, 1995) and some provisions of the organization of protection of rare and endangered plants (Bulakh, 2004) can be formulated.

The energy approach to the study of organisms has two aspects: ecological and physiological. The first is to study the patterns of consumption of solar energy by plants and the factors that determine them. Physiological - includes the study of the mechanisms of energy transformation in the organism. The introduction of plants as an ecological and geographical problem involves the use of an ecological approach.

In the conditions of culture, far from optimal, as a rule, energy consumption increases, and some of them are used to support the processes of life (El), and some for providing energy for adaptation to adverse conditions (Ea). The principle of energy minimum in the individual development of introducers should include the minimization of Ea, which together with El is the total energy expenditure of the organism:

$$El + Ea \rightarrow min$$

It can be argued that in cultural conditions, preference is given to those species that solve a particular functional problem at the lowest cost. For plants that are within the norm of reaction to environmental factors, the functional task (target function) is a structure formation aimed at preserving the species. Outside the norm of reaction, the main objective function is to preserve the stability of the structure as a whole system (Zaimenko, 1998; Bulakh, 2000). Therefore, the development of an energy scale of stability of introduced plants is promising.

Currently, living organisms in biology are considered complex functional energy systems. Its biomass is determined in both weight and energy units. However, the energy indicator is used only in isolated cases. The literature provides data on the average calorie content of plant material (4 kcal per 1 g of dry weight). This energy equivalent is sometimes used to calculate energy flows between ecosystem components. However, the analysis of literature data and own long-term results of measuring the energy intensity of herbaceous and shrubby plants in different environmental conditions cast doubt on the validity of the use of this "universal" single indicator.

Thus, the above assumptions can confirm or refute the experiment to determine the rate of energy metabolism, which adequately responds to changing external conditions and is an integral measure of assessing the viability of plants at different levels of living matter. A sufficient idea of it can be obtained by determining the calorific value of plants by calorimetric method (fixation of energy released during combustion (complete oxidation) of plant material). It fairly accurately reflects the relationship between the organism and the environment and can characterize the vital condition of an individual in a population or populations in the phytocenosis.

The study of the energy intensity of plants was conducted at the level of individuals of natural and introductory populations. Material collected in natural conditions (business trips, delectus seminum, exchange of seeds, and planting material) and cultural conditions (exposition areas of the department of landscape construction, botanical and geographical area "Central Asia") are involved. The results of determining the calorific value of plants are presented in tables 1 and 2.

Table 1. **Energy intensity of seeds collected in natural conditions and culture. Power consumption of the seed collected in the wild and culture**

Species	Energy consumption (cal/g absolute dry weight)	
	cultural conditions	natural locations
Allium carolinianum Redouté	4671	4598
A. ramosum L.	4520	4487
A. nutans L.	4327	4300
A. caesium Schrenk	4723	4689
A. caeruleum Pall.	4797	4720
A. altissimum Regel	4205	4190
A. christophii Trautv.	4005	3976
Lonicera korolkowii Stapf	3796	3789
L. tatarica L.	3561	3508
Rosa hissarica Slobodov	3695	3611
R. kokanica (Regel) Regel ex Juz.	3709	3698
Berberis heteropoda Schrenk ex Fisch. & C.A.Mey.	4450	4393

Table 2. **Energy intensity of introduced plants of different vital conditions. The energy introduced plants of different life status**

Species	Energy consumption (cal/g absolute dry weight)	
	high vitality	low vitality
Allium altissimum Regel	4150	4217
A. christophii Trautv.	3921	3986
A. caesium Schrenk	4098	4170
Lonicera tatarica L.	3515	3590
Lonicera korolkowii Stapf	3701	3782

Note: *the energy intensity of the above-ground part of plants in the flowering phase was determined (average sample). Vital indicators for species of the genus Allium at the individual level were determined visually by the indicator of the power of development of vegetative and generative organs, and at the population level—by the ratio of individuals of different ages. The viability of species of the genus Lonicera was determined by the growth of plant shoots during their active growth*.

Quantitative values of caloric content of plants in most cases correlate with the content of organic matter in them. The higher the content of organic compounds, the greater the caloric value of plants and vice versa. This dependence was first established on the example of planktonic organisms (Vladimirova et al., 1979) and, according to our data, is universal. It can be argued that there is a linear relationship between the content of organic matter in plants (X) and their caloric content (Y). It is described by the equation: $Y = 0{,}0635X - 0{,}4332$, calculated by the method of least squares. This equation, considering the standard deviation ($\sigma = \pm 0.27$), can be used for approximate calculations of plant calories. For example, for *Allium christophii* Trautv. the content of total organic matter in the seed (X), calculated by the equation (at a value of Y = 4,005 kcal/g) and determined by our biochemical method, is approximately the same value (about 70%).

Conclusions. The comparative assessment between owned studies and literature sources data allows us to draw the following conclusions**:**

The same type of plant, regardless of growing conditions, accumulates a certain amount of energy. The level of energy intensity is a species-specific indicator and can be used in plant taxonomy. It is characterized by a certain range or species norm with upper and lower limits.

Adverse changes in the conditions of the existence of plants in natural or introductory populations lead to an increase in their energy intensity within the species. Extreme influences can cause exceeding the energy intensity threshold of species, which, in turn, is the reason for their disappearance from the coenosis.

The energy intensity indicator reliably characterizes the vital condition of plants at the levels of individuals and populations and can be used to summarize the introduction. The minimum of this indicator corresponds to the ecological and phytocenotic optimum of the species.

Obviously, the stability of artificial phytocenosis depends on the ability of its components to store a certain amount of energy and the extinction of species from its composition due to their low level of energy potential. The principles of modeling artificial phytocenoses can be built on these provisions and a strategy for the protection of rare and endangered plants in botanical gardens and arboretums can be developed.

For approximate calculations of the caloric content of plants can be used data on the content of organic matter in them, provided that the necessary calculations.

References

Bilyavsky, G. O, Padun, M. M, & Furduy, R. S. (1995). *Osnovy zahal'noi ekolohii*. Kyiv: Lybid'. 368 p. (in Ukrainian).

Bulah, P. Ye. (2010). *Theory and methods of forecasting in plant introduction.* Kyiv: Nauk. dumka. 111 p. (in Russian).

Bulah, P. E. (2004). Sokhranenie fitogenofonda s pozitsii informatsionno-energeticheskoy. *Ohrana redkih vidov rastenij: problemy i perspektivy*: Materialy mezhdunar. nauch. konferencii, posviashchennoy 200-letiiu Botanicheskogo sada

Khar'kovskogo natsional'nogo universiteta im. V. N. Karazina (27–30 sentiabria 2004 g). Kharkov, S. 25–27. (in Russian).

Bulakh, P. Y. (1999). The optimality principle as the most important paradigm of plant introduction. *Bulletin of the Nikita Botanical Garden*. Vol. 79, P. 19–23. (in Russian).

Bulakh, P. E. (2016). Intensification of life processes in plants under culture as a result of their adaptation to new environmental factors. *Plant introduction*. No 2. P. 3–11. (in Ukrainian).

Bulakh, P. E. (1995). Iskusstvennye fitotsenozy v botsadakh v svete energeticheskoy kontseptsii. *Botanicheskie sady—tsentry sokhraneniia biologicheskogo raznoobraziia mirovoy flory*: Tezizy dokladov sessii Soveta botanicheskikh sadov Ukrainy. Ialta: B. i. S. 23–24. (in Russian).

Bulakh, P. E. (2002). The notion *safety* in the plant introduction. *Plant introduction*. No 1. P. 40–48. DOI: https://doi.org/10.5281/zenodo.3333775. (in Russian).

Bulakh, P. E., & Popil N. I. (2018). The concept of "optimization" in the introduction of plants and landscape construction. *Fundamental and applied aspects of plant introduction in the realities of European integration*: Proceedings of the international scientific-practical conference dedicated to the 100th anniversary of the National Academy of Sciences of Ukraine. (Kyiv, October 9–11, 2018). Kyiv. P. 108–110.

Bulakh, P. Ye. (2001). The concept of “vitality” in the introduction of plants as a reflection of the stability and energy status of organisms. *Plant introduction.* No 3–4. P. 13–23. DOI: https://doi.org/10.5281/zenodo.3333842. (in Russian).

Bulakh, P. Ye. (2000). The stability of introduced plants from the standpoint of the general theory of systems. *Plant introduction*. No 1. P. 13–19. DOI: https://doi.org/10.5281/zenodo.3334811. (in Russian).

Campbell, A., & Sommers Luchs, K. (1998). *Strategic Synergy* [Subsequent Edition]. London: Thomson Learning. 327 p.

Chernyshenko, S. V. (2005). *Nonlinear analysis of forest ecosystems dynamics*. Dnepropetrovsk: Oles Honchar Dnipro National University Publishing House. 512 p. (in Russian).

Fuller, R. B. (1982). *Synergetics: explorations in the geometry of thinking*. [in colaboration with E. J. Applewhite]. Estate of R. Buckminster Fuller. New York: Macmillan Publishing Company, Inc. 876 p.

Grebinskiy, S. O. (1944). Fiziologo-biokhimicheskie osobennosti gornykh rasteniy. Uspekhi sovremennoy biologii. Tom 18. No 2. S. 165–193. (in Russian).

Grodzinskiy, D. M. (1983). Nadezhnost' rastitel'nykh sistem. Naukova dumka. Kiev: Naukova dumka, 1983. 367 s. (in Russian).

Haken, H. (1980). Synergetics. *Naturwissenschaften*. Vol. 67. No 3. P. 121–128. DOI: https://doi.org/10.1007/BF01073611.

Holtström, J., & Anderson, H. (2021). Exploring and extending the synergy concept—a study of three acquisitions. *Journal of business & industrial marketing*. Vol. 36. No 13. P. 28–41. DOI: https://doi.org/10.1108/JBIM-09-2020-0420.

Iudin, V. V., & Shchegoleva, S. A. (2006). Strategicheskiy sinergizm i sinergetika. *Izvestiia Dal'nevostochnogo federal'nogo universiteta. Ekonomika i upravlenie*. No 3. S. 99–109. (in Russian).

Kalabukhov, N. I. (1946). Sokhranenie energeticheskogo balansa organizma kak osnova protsessa adaptatsii. *Zhurnal obshchey biologii*. Tom 7. No 6. S. 417–433. (in Russian).

Naumova Yu. A. (2013). Synergism and synergic effects in polymer`s processing technology. *Fine Chemical Technologies*. Vol. 8. No. 3. P. 76–86. (in Russian).

Patten, B. C. (1978). Systems approach to the concept of environment. The *Ohio Journal of Science*. Vol. 78. No. 4. P. 206–222.

Petrov, V. E., Loseva, N. L., Pakhomova G.I. i dr. (1986). Energeticheskie aspekty ustoychivosti rasteniy. Kazan': Izd-vo Kazanskogo universiteta. 136 s. (in Russian).

Prigogine, I., & Stengers, I. (2017) *Order out of chaos. Man's New Dialogue with Nature*. London: Verso. 260 p.

Rigel, Dzh. (1967), *Jenergija, zhizn i organizm*. Moskva: Mir. 198 p. (in Russian).

Sanginova, M. Y., & Khodjaeva, M. (2010) Synergism and consensus solution. *Bulletin of the Tajik State University of Law, Business and Politics*. No. 2. P. 28–33.

Schmalhausen, I. I. (1964). *The regulation of morphogenesis in individual development*. Moskva: Nauka. 132 p. (in Russian).

Uranov, A. A. (1975). Vozrastnoy spektr fitotsenopopuliatsiy kak funktsiia vremeni i energeticheskikh volnovykh protsessov. *Nauchnye doklady vysshey shkoly. Biologicheskie nauki*. No 2. S. 7–34. (in Russian).

Viter, A. V. (2016). Aktual'ni pytannia obminu rechovyn v ekosystemakh. Kyiv: Naukova dumka. 240 s. (in Ukrainian).

Vladimirova, K. S., Zimbalevskaja, L. N., & Pikush, N. V. (1979). *Melkovodja Kremenchugskogo vodohranilishha*. Kyiv: Nauk. dumka. 284 p. (in Russian).

Vogel, H. J., Bartke, S., Daedlow, K., Helming, K., Kögel-Knabner, I., Lang, B., ... & Wollschläger, U. (2018). A systemic approach for modeling soil functions. *Soil*, Vol. 4. No. 1 P. 83–92.

Zaimenko, N. V. (1998). *Strukturno-funkcionalnye osnovy konstruirovanija zamenitelej pochvy*. K.: B. i., 216 p. (in Russian).

Zaytsev, G. N. (1983). Optimum i norma v introduktsii rasteniy. Moskva: Nauka. 271 s. (in Russian).