Evolution of scientific views at factors of chernozem soil formation and development

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Abstract. Based on the comparative-historical method, we considered scientific theories about factors of chernozem formation (soil-forming material, relief, climate, vegetation and animal life, time, human) in the paper, their interrelated impact on the formation and evolution of steppe soils reflected in works of F.I. Ruprecht, V.V. Dokuchaev, P.S. Kossovich, S.S. Nestruev, P.A. Kostychev, V.R. Williams, H. Jenny, S.A. Waksman, and other researchers. Taking into account ecosystem significance in the functioning of the steppe landscapes and the high degree of agricultural development of chernozem soils, intensification of degraded processes, a necessity of understanding of the real influence of natural and anthropogenic factors on chernozem evolution is urgent as it serves a basis for the design of ways of steppe soils restoration. Therefore, in the scientific community, an interest was arisen to solve Dokuchaev and Jenny's equations identifying the functional relation between earth and soil formation factors. At the degree of accumulation of informational data on chernozem changeability in time and space, it has emerged conditions to develop approaches contradicting soil degradation processes.

1. Introduction

The concept of factors of formation and evolutional development of chernozem soils was worked out at the end of the XIX century by V.V. Dokuchaev; later, it was resumed by his followers. Since the study of the impact of soil formation factors on the soil cover formation has occupied one of the central places in researches of foreign and domestic scientists for 140 years, they pay special attention to steppe soils – chernozem as besides biospheric and ecosystem functions, it is a basis for the production of crops. The food security and welfare of Russia depends on this soil's productivity.

Particular problems of evolution of scientific views on the impact of factors on formation and development of chernozem were considered by V.V. Dokuchaev [1], P.A. Kostychev [2], N.M. Sibirtsev [3], P. Kossovich [4], V.R. Williams [5], S.S. Neustruev [6], L.I. Prasolov [7], H. Jenny [8], I.P. Gerasimov, M.A. Glazovskaya [9], V.A. Kovda [10] and others. The studies' analysis showed that the development of Dokuchaev's concept on soil formation had passed into the direction of studying soil-forming factors' interaction and their impact on soil formation, identifying the dominant factor with the following definition of the type of soil-forming processes.

Undirected attention of the scientific community for the two last decades to issues of influence of soil-forming factors, and the solution of V.V. Dokuchaev [11] and H. Jenny's equation [8] is connected with the wide use of computers, program complexes of GIS, and modeling methods in scientific researches. At present, new opportunities are opened in this sphere; they promote learning of
notions on the evolution of chernozem soil in the future.

The aim of the study is to analyze the scientific opinion on the formation and evolution of chernozem and steppe landscapes in Eurasia in the historical retrospective review.

The following tasks were formulated to achieve the set goal:
- to learn a conceptual basis, peculiarities of its development in the part of the interconnected influence of separate factors on steppe soil formation;
- to analyze the scientific activity of domestic scientists made an enormous contribution into the study of the soil system—aspects of soil formation, identification of the principal factor of soil formation with the following detection and information filling of the soil-forming process of the steppe type;
- to detect future directions to the development of scientific notions on the impact of soil-forming factors on the generation of principal signs and properties of chernozem soils.

2. Material and Methods

Scientific work of foreign and domestic researchers (V.V. Dokuchaev, N.M. Sibirtsev, P.S. Kossovich, S.S. Neustruev, S.A. Waksman, H. Jenny, V.R. Williams, L.I. Prasolov, V.A. Kovda, etc.) reflecting the formation of principal regulations of the concept of factors forming chernozem soil, served the data for the study. The comparative-historical method was used as the primary method of developing scientific notions on aspects of chernozem formation and evolution. Monographs and papers in peer-reviewed journals and little known publications with a valuable context were analyzed to achieve more information coverage and reliability.

3. Results and Discussion

The famous scientist and founder of soil science as the scientific branch, V.V. Dokuchaev, formulated, for the first time, doctrine about soil formation and development factors in studying the chernozem belt of Russia. Dokuchaev's concept of spatio-temporal coordination of the soil system in a landscape stipulated definite relations between soil and parent rock material, vegetation and animal organisms living on soil, the climate of a country, relief (height above sea level and shapes of the surface), and soil age of a country (partly, geological). Interaction of factors of soil formation promoted to generate soils of the steppe zone—chernozem.

Scientists [12-15 et al.] had studied different natural factors of soil formation, as chernozem, before Dokuchaev. V.V. Dokuchaev's innovation consisted in a fact that he considered soil, not from the point of view of the influence of one factor on another (for example, organisms' impact on rocks), but thought the ground was a reflection of the total equal activity of five environmental factors (climate, parent rock material, living and mortified organisms, age and relief). It was Dokuchaev's the "nonstandard approach" to such the complex composition as soil.

The idea of the impact of factors on soil formation, for the first time, was expressed by V.V. Dokuchaev in his report "Resume of Russian chernozem" in 1877, before the start of field studies. This report was based on literature sources [1, p. 24]. Later, this notion was accurately formulated in 1881, when he wrote that soils "are the surface laying mineral-organic composition that always more or less visibly colored by humus; these bodies have its origin, they always and everywhere is the result of the total activity of parent rock material, living and mortified organisms (plants and animals), climate, age of the country and relief of an area..." [16, p. 260].

V.V. Dokuchaev considered chernozem soils of Nizhegorodskaya, Kazanskaya, Poltavskaya guberniyas as the aggregated impact of environmental factors. Later, the entire chernozem belt of the European part of the country entered into the sphere of his interests. Using the geomorphological method, he divided the examined "chernozem area" into a line of regions collected broad information on geological features, relief, climatic conditions, vegetation, productivity, etc., adding data on the morphogenetic composition of the soil profile, physical and chemical properties of the soil cover. All materials were logically grouped according to the principles of their resemblance and differences. Based on the given results, the generalized resume was made about the purposive character of using
one or another soil. The introduction of such innovative methods promoted V.V. Dokuchaev to study chernozem soils and conduct a thorough systematic landscape examination of a vast natural area – the European part of the steppe zone of Eurasia.

V.V Dokuchaev verified the vital capacity of the concept of the impact of soil-forming factors on the example of chernozem soil from two positions: the aggregated participation of environmental components (climate, parent rock material, vegetation, and living organisms and relief) in the soil-forming process and soil development in time (the age of a country). V.V. Dokuchaev represented his reasoning about the functional relation between the soil cover and factors of soil formation (landscape components) [11, p. 3] as the following mathematical equation (table 1).

Table 1. A functional relation between soil and factors of soil formation.

| The author of the formula, year | Formula |
|--------------------------------|---------|
| V.V. Dokuchaev, 1899 | \( \Pi = f(K, O, G, \rho)T \), where \( \Pi \) – soil, \( f \) – function, \( K \) – climate, \( O \) – organism, \( G \) – rocks, \( \rho \) – relief, \( T \) – time. |
| S.A. Zakharov, 1927, referred to V.V. Dokuchaev | \( \pi = f(M, G, \Pi, R, Орп, Кл, Восп. стр., P – \phi) \), where \( \pi \) – soil, \( f \) – function, \( M \) – parent rock material, \( G, \Pi \) – plant and animal organisms, \( Кл \) – climate, \( Восп. стр. \) – age of the country, \( P, \phi \) – relief. |
| Ch. Shou, 1930 | \( S = M(C + V)^T + D \), where \( S \) – soil, \( M \) – matrix, \( C \) – climate, \( V \) – vegetation, \( T \) – time, \( D \) – erosion and accumulation. |
| S.A. Vilde, 1941 | \( S = f(g, e, b, d)dt \), where \( S \) – soil, \( g \) – geologic substratum, \( e \) – environment, \( b \) – biological activity, \( t \) – time. |
| H. Jenny, 1941 | \( S = f(cl, o, r, p, t, ...) \), where \( S \) – soil, \( f \) – function, \( cl \) – climate, \( o \) – organisms, \( r \) – relief, \( p \) – parent rocks, \( t \) – time. |
| SCORPAN model, 2003 | \( S_e = f(s, c, o, r, p, a, n) \), \( S_o = f(s, c, o, r, p, a, n) \), where \( S_e \) – soil of taxonomic units, \( S_o \) – quantitative soil descriptions, \( s \) – soil (other descriptions of soil), \( c \) – climate (local climatic characteristics), \( o \) – organisms, vegetation, fauna, human, \( r \) – relief (morphometric values), \( p \) – parent rocks, lithology, \( a \) – age, \( t \) – time, \( n \) – spatial position. |

Considering Dokuchaev's formula, we should note the procedure of American soil scientist H. Jenny well-known in Russia [8, p. 32] (table 1), who all soil-forming factors, including time, divided into a group of independent variables defining a formation of the soil system. Transferring parameter \( t \) (time) under brackets, he made the equation of soil formation, the emergence of which promoted to conduct of formal and mathematical analysis [17]. H. Jenny made an essential addition to the formula of soil interaction and soil formation factors. It was dots that created an opportunity to include in the formula adding elements. These grounds promote such parameters as a human activity to be entered into the formula, what academician V.P. Williams considered [5] in the first part of the XX century. A.A. Rode [18] offered to add three factors to the five characteristics of Dokuchaev's soil formation set: terrestrial gravitation, water (surface, soil, and underwater), and human economic activity. At present, the last of these three factors moved at the forefront making the significance of climate, organisms, parent rock material, relief, and time auxiliary.
The bitter fight of scientific approaches to the formula of soil formation between Russian and American soil scientists described in details in I.V. Florinsky's paper [19] was exacerbated since the middle part of the XX century and reached the maximum for the two last decades. The reason was in the appearance of computers and opportunities to solve these equations using logical-functional apparatus facilities, with the following development of information models and geo-informational system using in soil science. All these mechanisms would be promoted to solve the H. Jenny and V.V. Dokuchaev's equations. Accumulated in the course of fieldwork a considerable bulk of analytical material on the construction of chernozem soils, V.V. Dokuchaev, except solution of other tasks, took a unique occasion to ground revealed features of the effect of soil-forming factors on the formation and the further evolution of chernozem, that was represented by humus accumulation in the upper part of the profile, eluviations of the under humus horizon and calcareous invasion of the soil profile.

N.M. Sibirtsev, the V.V. Dokuchaev's follower, [3] defined the primary feature of soil as a mixture of outer dynamics geological phenomena (eolation) and biochemical (invasion of plants and animals into the parent rock material, decomposition of their residuals, vital functions of microorganisms, humus accumulation), i.e., the combination of geological and biological processes. Papers of S.S. Neustruev "Elements of soil geography" [6], H. Jenny "Factors of soil formation" [8], V.A. Kovda "Bases of soil learning" [10] have continued V.V. Dokuchaev and N.M. Sibirtsev's works regarding the influence of a complex of factors on soil formation. The result of scientists mentioned above described in detail the effect of each factor on the soil.

We should note S.S. Neustruev's work concerning the landscape approach to soil studying and the thorough examination of a relief impact, particularly watersheds, river valleys, and erosion cycles on soil formation [6]. I.P. Gerasimov and M.A. Glazovskaya, in the monograph "The Grounds of Soil Science and Soil Geography," highlighted the significance of this soil-forming factor [9].

It is necessary to mention that V.V. Dokuchaev [1] considered climate as one of the equivalent soil creators. Still, the scientist assumed it was a crucial factor to define various and considerable differences in soil formation, i.e., the climate impact were the universal factor subordinated to the total zonal transformation.

N.M. Sibirtsev made an effort to identify a specific weight of different soil formation factors and single them out of the entire list. Most parts of the factors marked by V.V. Dokuchaev belonged to the climate impact. On N.M. Sibirtsev's opinion, the soil type represented itself as a climate function from geological preconditions [3].

P.S. Kossovich, keeping on the work regarding the interaction of soil – factors, considered that the climatic factor was the principal. The scientist noted that "climatic factors are primary and the nearest creators which germinate the soil-forming process and the strongest effect on a character of its further development" [4, p. 14].

G. N. Vysotskiy [20] spoke that vegetation and its living area were a function of the principal abiotic factors – climate and material. At the same time, Vysotskiy considered not climate on the whole but an amount and ratio of warmth and humidity. Rocks material, - thought Vysotskiy, provided plants of fertilizer elements. Defining principal interconnected factors – warm, moisture, food, there was a solution of V.V. Dokuchaev's equation. Besides G.N. Vysotskiy, S.S. Neustruev [6], L.I. Prasolov [7] underlined the determinative role of climate in soil formation.

P.A. Kostychev, who criticized V.V. Dokuchaev in the relation of almost all principal issues of soil formation, was an opponent of the climatic hypothesis. P.A. Kostychev [2] and his follower V.P. Williams [5] considered biological processes the leading factors in soil formation. They emphasized the construction of the fundamental property of soil – fertility. As academician V.R. Williams noted, a life represented itself as a repeated change of processes of construction and destruction of organic substances [5] from the point of view of soil science. Development of regulations about "little biological rotation of podzolic and nitrogen food of plants" that "happened on the part of a trajectory of the large geological rotation of substances in the environment" continued this direction. S.S. Waksman [21] and D.G. Vilenskiy [22] supported the hypothesis of the dominant role of a biological factor.
N.M. Sibirtsev [3], the same as V.V. Dokuchaev [11], offered to define the combinations of priority factors leading to specific results – could identify a type of soil-forming process (tundra, forest, steppe, meadow, etc.). For example, conditions to form chernozem are climate and grassy vegetation. Pedologists I.P. Gerasimov and M.A. Glazovskaya [9] and French soil scientist Ph. Duchaufour [23] held to this view. In Duchaufour’s opinion, soil-forming rocks could cause only a subtype systematization level. The same as relative was a reason for the isolation of different intrazonal soils (alluvial, poic, saline soil). V.R. Volobuev [24] supported this conclusion underlining the significance of hydrothermal conditions to form chernozem. Intensification or weakening of one, or another component of these conditions emerging in different parts of the chernozem belt are reasons to appear special features in chernozem defining the subzonal or facies-provincial division of the zone.

Academician L.I. Prasolov [7] made a systematization of all former soil studies and marked out five principal subtypes of chernozem, four of which corresponded to a subzonal change of bioclimatic conditions and reflected soil properties caused by the evolution of these conditions from the north to south. Leached and typical chernozem is developed under meadow-herb steppe plots in forest-steppe zone. Common and south chernozem is formed, correspondingly, under forbs- grass and grass steppe in the steppe zone. Podzolized chernozem (subtype 5) is created at the same conditions as leached soils, accompanying it, but not developing an independent subzone. A primary subtype of chernozem the better corresponded to notions on the chernozem-forming process is common chernozem. It is characterized by a well-expressed humus horizon with a stable water structure, high content of humate-calcium humus (5-8%), a neutral reaction of the milieu, a considerable capacity of absorption (40-55 mg/ equivalent unit), and the absorbing complex entirely saturated by grounds. Distinctive chernozem features that differed from soils of other natural zones are humus, carbonate, and salt horizons.

There were long arguments in soil science what a factor (climate or vegetation) played a more significant role in soil formation. The resume of all long-term discussions, in our opinion, is the idea expressed by A.A. Rode [25] about inequivalence of factors of soil formation on its influence on the soil. Parent rock material, climate (atmosphere), living organisms, water, and human economic activity are sources of substance and energy; terrestrial gravitation – a source of life; a relief – a kind of the surface of the division between atmosphere and lithosphere that redistributes substances and power; a role of time does not demand any explanation.

A scheme of chernozem evolution generated since the second part of the Holocene defines a formation of these soils on upland plots under cover of perennial long-living sod grasses adapted to "prevent" intensive water evaporation. The root system of steppe grasses is well developed and maximally adapted to "catch" soil moisture and mineral nutrition elements. High zonality of plant residues and high content understructure in it is one of the principal reasons to conserve neutral reaction of the milieu in the upper horizons of chernozemic soils that, in its turn, promote microflorae development. The total surface of little roots and root fibrils is 230 km² at 1 km² of the area. Such a root system enables plants to absorb water quickly and efficiently. The total reserve of phytomass reaches 11-35 t/ha on average, 65-95% of which belongs to roots. Annually steppe vegetation gives 1-2 kg/m² of fallen leaves for the following processing of this mass to humus. Chernozem is formed only in continental climate conditions under the average temperatures from −2 to +5°C and 300-650 mm of precipitation. V.O. Targulian and I.A. Sokolov’s concept [26] continues doctrines on soil-forming factors in the present. According to the idea, soil reflects the influence of factors "recording, memorizing, coding" in the genetic profile information on these influences – "soil- memory," and on the other hand, a rapid reflection of changes of this environment happens: "soil-moment." It is necessary to note that soil speeding to turn into product equilibrium to indicators of such combination of soil-forming factors does not migrate on the heels of factors as it depends on the environmental conditions.

One of the main factors of chernozem evolution is a human being from the time of the XIX century's first ecological crisis, reflected in V.V. Dokuchaev's paper "Our Steppes Before and at Present" and to our days. The presence of sizeable open upland spaces and high fertility of chernozem
soils always attracted a plowman who rushed to receive the highest harvest at the least cost, "to take everything from a land.” The cultivated area's increase (to 50% of the total amount of the land resources), deforestation, intensification of load on pastures broke the water balance of steppes, led to the development of erosion processes and loss of the humus content. The last reserves were exhausted after increasing the cultivated area by the 1980s of the XX century. At present, approximately 80% of agricultural products are produced on 53% chernozem [27]. The current condition of black soil is characterized as catastrophic due to total agricultural development. The steppe today is recognized as one of the most anthropogenically broken ecosystems of the world.

4. Conclusion
After V.V. Dokuchaev's development of a concept concerning factors of soil formation, P.A. Kostychev, N.M. Sibirtsev, P.S. Kossovich, S.A. Zakharov, S.S. Neustruev, V.R. Williams, L.I. Prasolov, V.A. Kovda, and H. Jenny, and other representatives of the American soil science school began to research the impact of these factors on each other and soil. Later, it promoted to design of a line of fundamental works on the influence of climate, relief, geological conditions, the role of organisms in soil-forming process, identification of types of united soil-forming process (podzolic, steppe, poic, etc.).

In the modern stage of development of soil science, taking into account mass involvement of chernozem in agriculture and intensive display of degradation processes, priorities in studies of the system "soil-factors of sol formation" should be replaced in the side of the study of the mechanism of interconnected soil impact with factors of soil formation. Knowledge of these mechanisms would promote to identify ways of management of processes in steppe and agrarian ecosystems occurring in chernozem, their productivity, and stability to anthropogenic and natural factors of influence. The result of this task's solution should be the development of mathematic models of chernozem soil functioning under the interconnection with climatic parameters, parent rock material, relief, animals and vegetation organisms, and time.

Based on the functional models, we should solve the second task: soil parameterization as the ecosystem's structural-functional components. Formation and approbation of this complex (integral and informative) will promote to measure and quantitatively estimate soil changeability in time and space with an equal detail in the unified system and the united scale.

The third task summarizes and consists in developing the united methodology and technology of soil measurement in time and space. New information accumulation will promote to formulate a concept of soil changeability in time and space under the impact of soil transformations, understand mechanisms of degradation of chernozem and develop approaches required to resist these processes. To the degree of development of this direction, the model system will be corrected and complicated, including more details important for understanding the components of education and development of chernozem soils.

Aknowlegements
This work was done as part of the Steppe Institute Theme (#GP AAAA-A21-121011190016-1).

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