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Supplement of

Reviews and syntheses: Agropedogenesis – humankind as the sixth soil-forming factor and attractors of agricultural soil degradation

Yakov Kuzyakov and Kazem Zamanian

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I. History of the equation S = f(cl, o, r, p, t, ...) in:

Florinsky, I.V. 2012. The Dokuchaev hypothesis as a basis for predictive digital soil mapping (on the 125th anniversary of its publication). Eurasian Soil Science 45 (4), 445-451.

(see full paper at the end of the Supplement).

The "Jenny'" state factor equation for soil genesis: S = f (C, O, R, P, T, . . .) was copy-pasted from the textbook for Russian students published in 1927 by S.A. Zakharov:

Zakharov, S. A., 1927. A Course of Soil Science. Gosizdat, Moscow – Leningrad. [in Russian: Захаров С.А., 1927. Курс Почвоведения. Государственное Издательство Москва - Ленинград].

where П is soil, K is climate, O is organisms, Г is parent material, and B is the age of the soil. Topography was not included into the expression probably due to a stenographer's mistake, because Eq. (3) is preceded by two sentences discussing the important role of topography in soil formation (Fig. 2).

In 1927, Zakharov presented a general soil formation equation in a well-known fundamental textbook [35, p. 8] (Fig. 3). This equation ideally described the Dokuchaev postulate:

$$\pi = f(\text{М.Г.П.}, \text{Р.Ж.Орг.}, \text{Кл.}, \text{Возр.стр.}, \text{Р-ф}), \quad (4)$$

where π is soil, М.Г.П. is parent rock material, Р.Ж.Орг. is plant and animal organisms, Кл. is climate, Возр. стр. is the age of the terrain, and Р-ф is topography. There were three misprints in Eq. (4): two commas were missed and there was an excess close bracket (Fig. 3). The misprints were fixed in the second edition [36, p. 18]. Unlike the rare brochure [8], textbooks [35, 36] were widespread (4000 and 18000 copies of the first and second editions were printed, respectively).

In the summer of 1927, the Dokuchaev hypothesis

where S is soil, M is parent material, C is climate, V is vegetation, T is time, and D is erosion or deposition. Shaw did not mention either the Dokuchaev hypothesis or the equations of Dokuchaev (3) and Zakharov (4). It is interesting that Shaw presented Eq. (5) at the Second International Congress of Soil Science held in the USSR in 1930 [27]. Zakharov took part in the discussion of this presentation. He criticized Shaw for ignoring the role of topography, animals, and humans in Eq. (5) [27, p. 14].

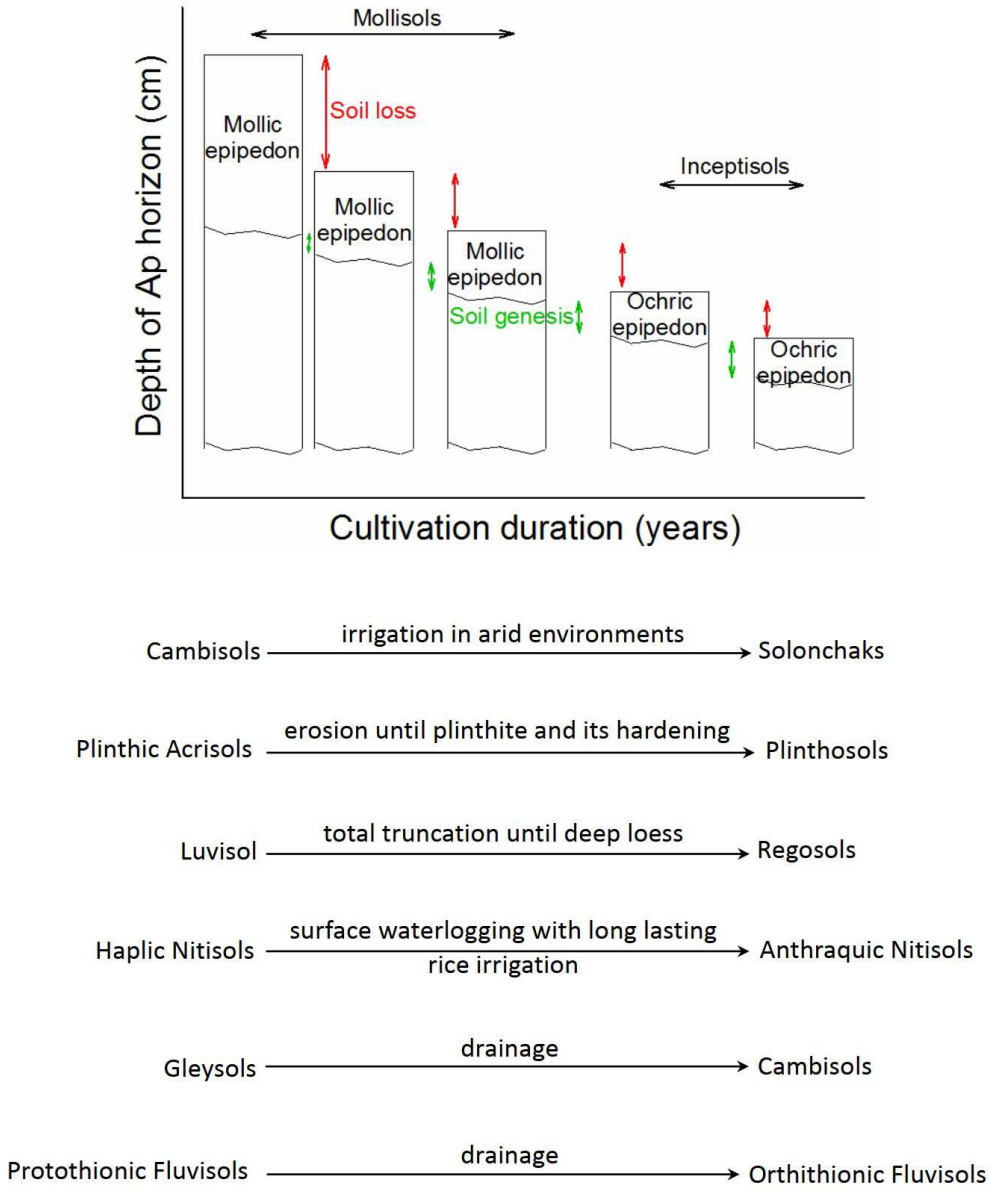
In 1941, Wilde published his equation [33, p. 34]:

$$S = \int (g.e.b.)\, dt, \quad (6)$$

where S is soil, g is geological substratum, e is the environmental influences, b is the biological activity, and t is time. Wilde did not mention Eqs. (3), (4), and (5). Note that Wilde, a Russia-born immigrant, was familiar with the works of Dokuchaev and Zakharov. Indeed, he cited the Dokuchaev postulate right before Eq. (6) calling it "the first basic law of soil science" (Zakharov's expression [35, p. 8]).

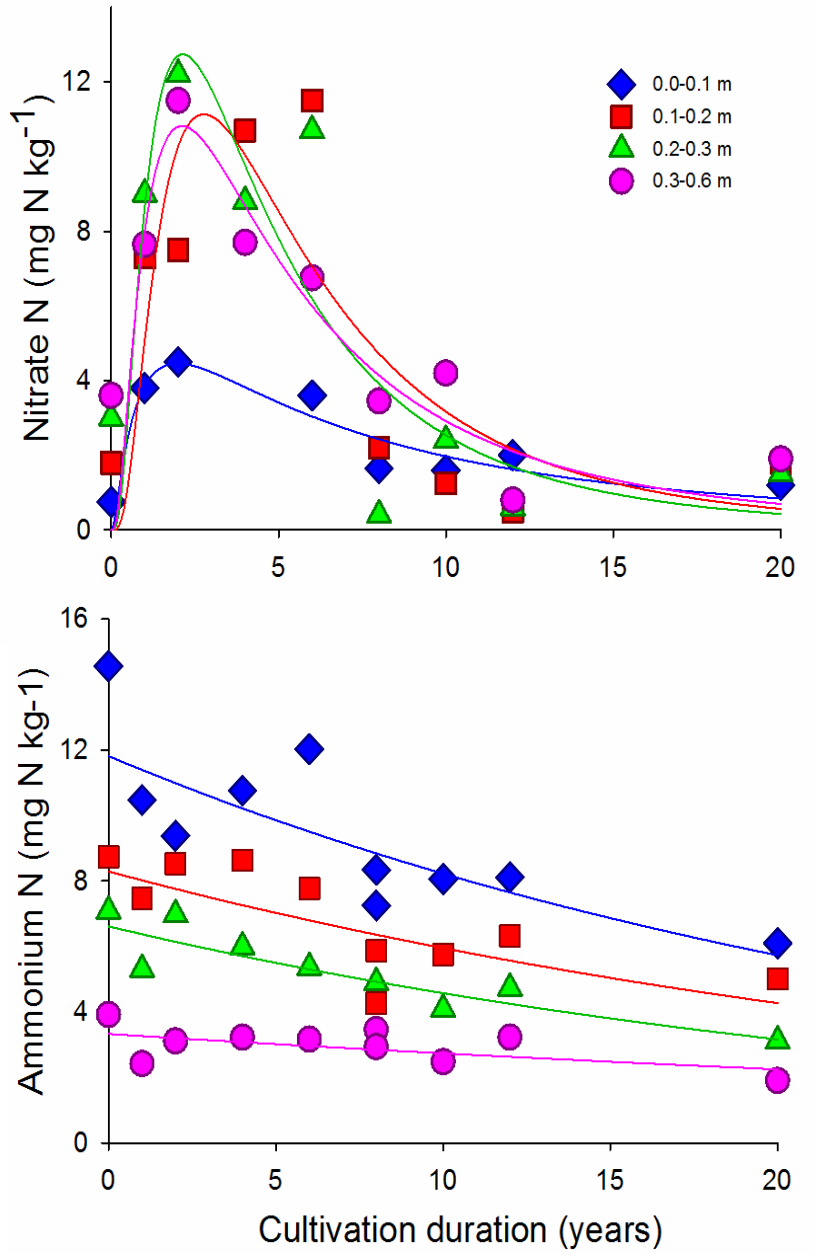
In 1941, Jenny published Eq. (2) [16, p. 16] and selectively cited the Dokuchaev hypothesis (after Afanasiev [1, p. 101]), that is, only a portion of the limiting

II. Fig. S1: Soil depth decrease due to erosion.



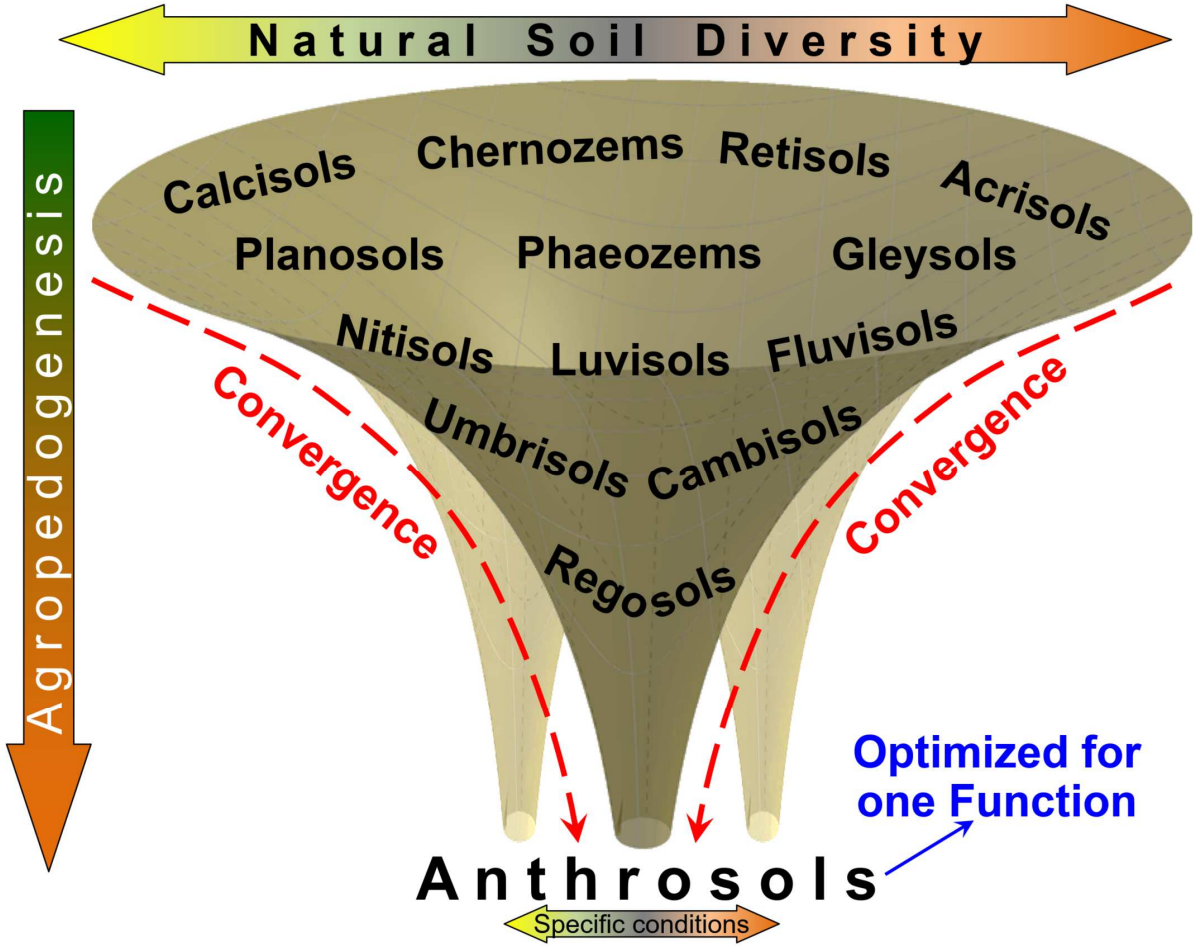
Supplementary Fig. 1: Soil depth decrease due to erosion. The erosion rate decreases with cultivation duration due to depletion of easily erodible materials. It reaches steady state conditions when erosion becomes equal to soil genesis. After major erosion, the soil taxonomic group changed due to a strong decrease in the Ah / Ap horizon depth, which led to new qualifiers and master properties. Other frequent examples of soil class changes are presented in Dudal (2004).

III. Fig. S2: Convergence of soil properties as a result of cultivation duration.



Supplementary Fig. 2: Examples of convergence of soil properties as a result of cultivation duration: (top) Nitrate content, (bottom) ammonium content depending on soil depth during 20 years of cultivation (Jones and Dalal, 2017). The solid lines are added to better visualize the changing trends in nitrate and ammonium contents as a function of cultivation duration.

IV. Fig. S3: Convergence of soil properties as a result of cultivation duration.



Supplementary Fig. 3: Extended conceptual schema of convergence of soil properties by agropedogenesis (see also Fig. 9). The very broad range of natural soils and their properties will be tailored for crop production by agricultural use, resulting in Anthrosols with a very narrow range of properties – the convergence of properties by agropedogenesis. Note that the soils within the funnel are mentioned exemplarily and not all WRB soil groups are presented. The sequence of soils within the funnel does not reflect their transformations during agropedogenesis to Anthrosols. This extended version reflecting multiple pathways to Anthrosols and their variability. Nevertheless, the variability of all soil parameters is much lower compared to natural soils.

The history of the equation S = f(cl, o, r, p, t, ...)

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Original Russian Text © I.V. Florinsky, 2012, published in Pochvovedenie, 2012, No. 4, pp. 500–506.

Note: red underlines are made by Kuzyakov & Zamanian

HISTORY OF SCIENCE

The Dokuchaev Hypothesis as a Basis for Predictive Digital Soil Mapping (On the 125th Anniversary of Its Publication)

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Abstract—Predictive digital soil mapping is widely used in soil science. Its objective is the prediction of the spatial distribution of soil taxonomic units and quantitative soil properties via the analysis of spatially distributed quantitative characteristics of soil-forming factors. Western pedometrists stress the scientific priority and principal importance of Hans Jenny's book (1941) for the emergence and development of predictive soil mapping. In this paper, we demonstrate that Vasily Dokuchaev explicitly defined the central idea and statement of the problem of contemporary predictive soil mapping in the year 1886. Then, we reconstruct the history of the soil formation equation from 1899 to 1941. We argue that Jenny adopted the soil formation equation from Sergey Zakharov, who published it in a well-known fundamental textbook in 1927. It is encouraging that this issue was clarified in 2011, the anniversary year for publications of Dokuchaev and Jenny.

DOI: 10.1134/S1064229312040047

INTRODUCTION

In soil science, predictive digital soil mapping has received wide recognition in the past twenty years [5, 12, 13, 22]. Its object is the prediction of the spatial distribution of (1) soil taxonomic units and (2) the physical, chemical, and biological quantitative properties of soils. The prediction is based on the analysis of the spatially distributed quantitative characteristics of the soil forming factors using various mathematical techniques, such as multiple regression analysis, hybrid geostatistical approaches, fuzzy logic, discriminant analysis, artificial neural networks, etc.

As a theoretical basis for predictive soil mapping, McBratney et al. [24] proposed SCORPAN, a model for empirical quantitative descriptions of relationships between soils and spatially distributed predictors:

$$S_c = f(s,c,o,r,p,a,n), \quad S_a = f(s,c,o,r,p,a,n), \qquad (1)$$

where S_c is soil classes, S_a is soil attributes, s is soil (other properties of the soil at a given point), c is climate (local climatic properties), o is organisms (vegetation, fauna, and human activity), r is relief (topography, morphometric variables), p is parent material (lithology), a is age (time), and n is space (spatial position). The authors of SCORPAN noted that Eqs. (1) are versions of the well-known equation of Hans Jenny, which describes soil as a function of soil forming factors [16, p. 16]:

$$S = f(cl,o,r,p,t,\ldots), \qquad (2)$$

where S is soil; and cl, o, r, p, and t are soil-forming factors (climate, organisms, topography, parent material, and time, respectively). The ellipsis indicates that additional soil formers may be included in Eq. (2). McBratney et al. [24, p. 6] stressed the scientific priority and principal importance of Jenny's book [16] for the emergence and development of predictive soil mapping. At the same time, the early works of the Russian school of soil science were totally ignored.

The subject of this paper is to show that contemporary predictive soil mapping is based on the works of Vasily Dokuchaev and Sergey Zakharov.

THE DOKUCHAEV HYPOTHESIS

In 1886, Dokuchaev [9, pp. 352–353] formulated the following hypothesis (Fig. 1):

> {Any ... soil is always and everywhere a mere *function*[1] of the following factors of soil formation: (1) the nature (content and structure) of the parent rock; (2) the climate of the given terrain; (3) the mass and character of vegetation; (4) the age of the terrain; and, finally, (5) the terrain topography. It immediately follows that (a) if the mentioned *factors* are the same in two different localities (however far apart they might be), the soils in the two localities should also be similar, and vice versa; consequently, (b) if we have thoroughly studied these factors, *we may predict in advance* what the soil itself should be like. Next, (c) it is well known that the *momentum* should not change if one force component increases or decreases by some value, while another force component changes by the oppo-

[1] The italicized text was highlighted by Dokuchaev.

МАТЕРІАЛЫ

КЪ ОЦѢНКѢ ЗЕМЕЛЬ

НИЖЕГОРОДСКОЙ ГУБЕРНІИ.

ЕСТЕСТВЕННО-ИСТОРИЧЕСКАЯ ЧАСТЬ.

ОТЧЕТЪ

НИЖЕГОРОДСКОМУ ГУБЕРНСКОМУ ЗЕМСТВУ.

РАБОТА ИСПОЛНЕНА ПОДЪ НЕПОСРЕДСТВЕННЫМЪ РУКОВОДСТВОМЪ

Проф. СПб. университета В. В. ДОКУЧАЕВА.

Выпускъ I.

ГЛАВНЫЕ МОМЕНТЫ

ВЪ ИСТОРІИ ОЦѢНОКЪ ЗЕМЕЛЬ ЕВРОПЕЙСКОЙ РОССІИ.

СЪ КЛАССИФИКАЦІЕЙ

РУССКИХЪ ПОЧВЪ.

Изданіе Нижегородскаго Губернскаго Земства.

С.-ПЕТЕРБУРГЪ.

Типографія Е. Евдокимова, Б. Итальянская, д. № 11.

1886.

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почему мы встрѣчаемъ въ Россіи *эти*, а не *другія* почвы, *почему* эти послѣднія далеко не одинаковы въ различныхъ частяхъ нашего отечества; — *идя*, наконецъ, искать намъ, въ другихъ странахъ, — почвы, аналогичныя нашимъ?

Что касается *общаго* и *апріорнаго* рѣшенія всѣхъ этихъ вопросовъ, то оно вполнѣ мыслимо и сравнительно легко. И дѣйствительно, въ „Русскомъ черноземѣ", равно какъ и въ предъидущихъ главахъ, мы старались установить, что всякая *растительно-наземная* почва всегда и всюду является простой *функціей* отъ слѣдующихъ почвообразователей: 1) характера (составъ и строеніе) материнской горной породы, 2) климата данной мѣстности, 3) массы и характера растительности, 4) возраста страны [1]) и, наконецъ, 5) рельефа мѣстности. Отсюда прежде всего слѣдуетъ (a), что разъ въ двухъ мѣстностяхъ (какъ бы далеко онѣ ни отстояли бы одна отъ другой) упомянутые *факторы* равны, — должна быть одинакова и почва, и — наоборотъ; слѣдовательно (b), если мы вполнѣ изучимъ эти факторы, то уже *напередъ можно предсказать, какова должна быть* и самая почва? Далѣе (c), какъ всякому извѣстно, *моментъ* не долженъ измѣняться, если одна изъ слагающихъ его силъ будетъ увеличена или уменьшена на столько, на сколько измѣнится, въ обратномъ отношеніи, другая изъ слагающихъ; понятно, тоже самое соотношеніе должно существовать, до *извѣстной степени*, и между *характеромъ почвы* и *характеромъ* ея производителей. Отсюда ясно, что съ теоретической точки зрѣнія является вполнѣ мыслимымъ постановка и рѣшеніе такого, напр., вопроса: измѣнилась-ли бы данная почва, и на сколько именно, если бы, при ея образованіи, температура мѣстности увеличилась, положимъ, на 1—2°, а количество метеорной влаги, за то же время,

[1]) Мы понимаемъ здѣсь подъ *возрастомъ* страны *только* то время, когда слагающія ее горныя породы сдѣлались доступными вывѣтриванію и стали покрываться растительностію; впрочемъ, при дальнѣйшемъ изложеніи, данный *почвенный факторъ*, какъ весьма мало изученный по отношенію къ Россіи, не будетъ покамѣстъ приниматься въ разсчетъ.

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возросло бы на 1—2 дюйма? Измѣнилась-ли бы почва, еслибы приростъ данной растительности увеличился на 20 пудовъ (на десятину), а температура понизилась бы на 1—2°?

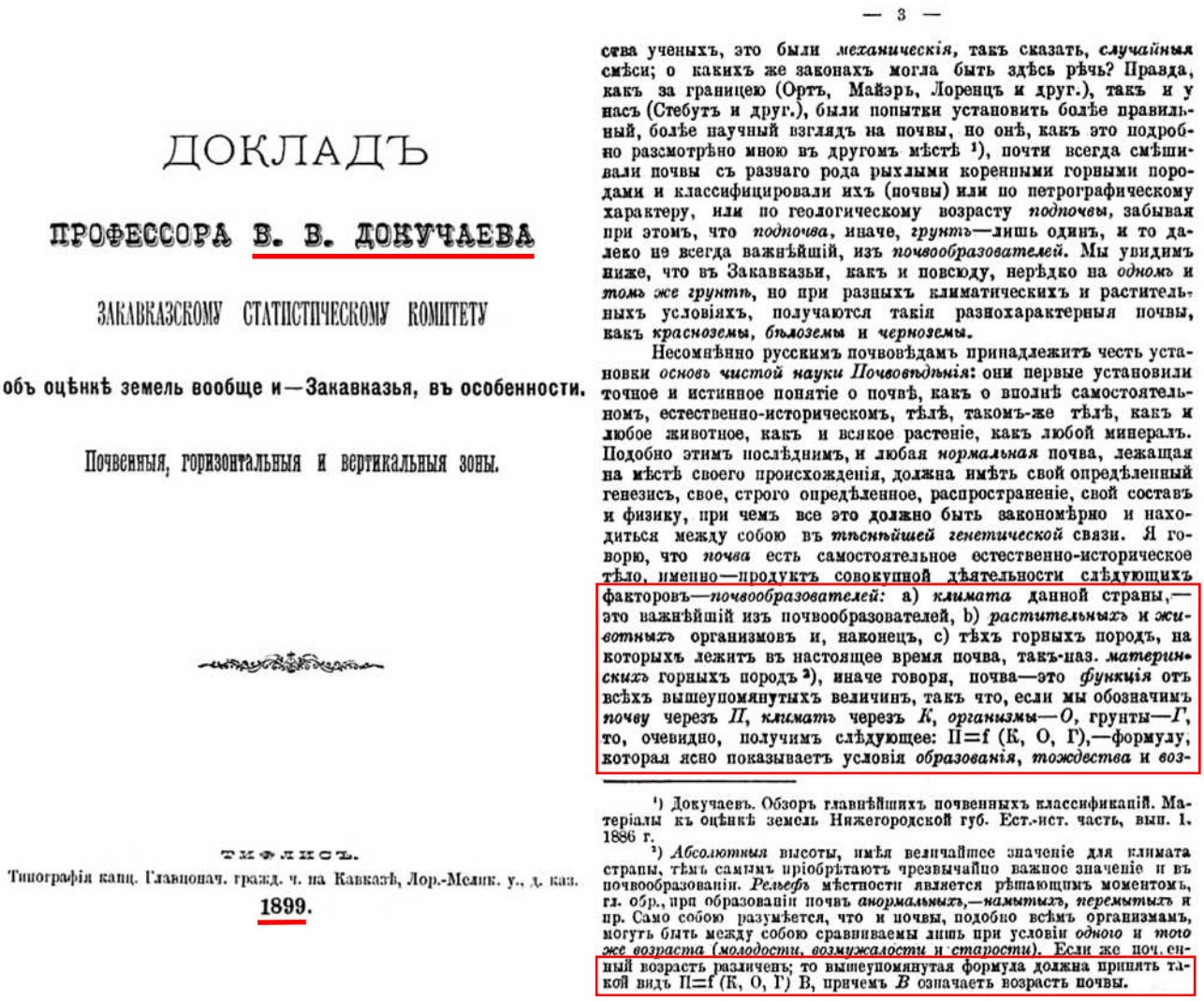
Повторяю, все это такъ ясно, такъ логически законно и даже неизбѣжно, что, вѣроятно, спорить противъ этого *никто* не станетъ.

Къ сожалѣнію, *доказать* всѣ эти положенія *фактически, съ желаемой полнотою*, и — особенно выразить въ *деталяхъ* отвѣтъ на послѣдній вопросъ (c), представляется *пока* затруднительнымъ. Причины совершенно понятны. Безъ сомнѣнія, на первомъ планѣ стоитъ здѣсь крайняя сложность условій, вліяющихъ на почву; во-вторыхъ, эти условія не представляютъ постоянныхъ величинъ, а поэтому и трудно поддаются цифровому обозначенію; наконецъ, по однимъ изъ упомянутыхъ факторовъ у насъ мало данныхъ, а по другимъ и вовсе нѣтъ. Тѣмъ не менѣе будемъ надѣяться, что и эти препятствія современемъ устранятся, и тогда почвовѣдѣніе сдѣлается дѣйствительно точной наукой.

Но такъ какъ *теоретическая* вѣрность вышеупомянутыхъ положеній не можетъ, какъ мы видѣли, подлежать ни малѣйшему сомнѣнію, то сейчасъ упомянутыя фактическія затрудненія не должны останавливать насъ отъ *попытки*, по крайней мѣрѣ, *намѣтить* здѣсь главные пункты, и указать важнѣйшіе факты, которые, по нашему мнѣнію, вполнѣ подтверждаютъ высказанное выше положеніе и могутъ освѣтить *изслѣдователямъ* и *наблюдателямъ* дальнѣйшій путь въ этой еще совершенно нетронутой, но весьма много обѣщающей области...

Климатъ. Какъ замѣчено выше, вліяніе климата на образованіе *растительно-наземныхъ* почвъ не можетъ подлежать ни малѣйшему сомнѣнію: a) онъ обусловливаетъ характеръ и годовой приростъ какъ *наземныхъ*, такъ и *подземныхъ* частей растительныхъ организмовъ; b) отъ него зависитъ количество сгнивающей ежегодно растительности и характеръ продуктовъ гніенія; c) климатъ же весьма ощутительно вліяетъ и на вывѣтриваніе материнскихъ породъ, и при томъ не только механически,

Fig. 1. Title page and pages from book [9] with the Dokuchaev hypothesis.



ДОКЛАДЪ

ПРОФЕССОРА В. В. ДОКУЧАЕВА

ЗАКАВКАЗСКОМУ СТАТИСТИЧЕСКОМУ КОМИТЕТУ

объ оцѣнкѣ земель вообще и—Закавказья, въ особенности.

Почвенныя, горизонтальныя и вертикальныя зоны.

ТИФЛИСЪ.
Типографія канц. Главнонач. гражд. ч. на Кавказѣ, Лор.-Мелик. у., д. каз.
1899.

— 3 —

сева ученыхъ, это были *механическія*, такъ сказать, *случайныя* смѣси; о какихъ же законахъ могла быть здѣсь рѣчь? Правда, какъ за границею (Ортъ, Майэръ, Лоренцъ и друг.), такъ и у насъ (Стебутъ и друг.), были попытки установить болѣе правильный, болѣе научный взглядъ на почвы, но онѣ, какъ это подробно разсмотрѣно мною въ другомъ мѣстѣ [1]), почти всегда смѣшивали почвы съ разнаго рода рыхлыми коренными горными породами и классифицировали ихъ (почвы) или по петрографическому характеру, или по геологическому возрасту *подпочвы*, забывая при этомъ, что *подпочва*, иначе, *грунтъ*—лишь одинъ, и то далеко не всегда важнѣйшій, изъ *почвообразователей*. Мы увидимъ ниже, что въ Закавказьи, какъ и повсюду, нерѣдко на *одномъ* и *томъ же грунтѣ*, но при разныхъ климатическихъ и растительныхъ условіяхъ, получаются такія разнохарактерныя почвы, какъ *краснозем*ы, *бѣлозем*ы и *черноземы*.

Несомнѣнно русскимъ почвовѣдамъ принадлежитъ честь установки *основъ чистой науки Почвовѣдѣнія*: они первые установили точное и истинное понятіе о почвѣ, какъ о вполнѣ самостоятельномъ, естественно-историческомъ, тѣлѣ, такомъ-же тѣлѣ, какъ и любое животное, какъ и всякое растеніе, какъ любой минералъ. Подобно этимъ послѣднимъ, и любая *нормальная* почва, лежащая на мѣстѣ своего происхожденія, должна имѣть свой опредѣленный генезисъ, свое, строго опредѣленное, распространеніе, свой составъ и физику, при чемъ все это должно быть закономѣрно и находиться между собою въ *тѣснѣйшей генетической* связи. Я говорю, что *почва* есть самостоятельное естественно-историческое тѣло, именно—продуктъ совокупной дѣятельности слѣдующихъ факторовъ—*почвообразователей:* а) *климата* данной страны,—это важнѣйшій изъ почвообразователей, b) *растительныхъ* и *животныхъ* организмовъ и, наконецъ, c) тѣхъ горныхъ породъ, на которыхъ лежитъ въ настоящее время почва, такъ-наз. *материнскихъ* горныхъ породъ [2]), иначе говоря, почва—это *функція* отъ всѣхъ вышеупомянутыхъ величинъ, такъ что, если мы обозначимъ *почву* черезъ *П*, *климатъ* черезъ *К*, *организмы*—*О*, грунты—*Г*, то, очевидно, получимъ слѣдующее: П=f (К, О, Г),—формулу, которая ясно показываетъ условія *образованія*, *тождества* и воз-

[1]) Докучаевъ. Обзоръ главнѣйшихъ почвенныхъ классификацій. Матеріалы къ оцѣнкѣ земель Нижегородской губ. Ест.-ист. часть, вып. I. 1886 г.

[2]) *Абсолютныя* высоты, имѣя величайшее значеніе для климата страны, тѣмъ самымъ пріобрѣтаютъ чрезвычайно важное значеніе и въ почвообразованіи. *Рельефъ* мѣстности является рѣшающимъ моментомъ, гл. обр., при образованіи почвъ *анормальныхъ*,—*намытыхъ*, *перемытыхъ* и пр. Само собою разумѣется, что и почвы, подобно всѣмъ организмамъ, могутъ быть между собою сравниваемы лишь при условіи *одного* и *того же возраста (молодости, возмужалости* и *старости)*. Если же почвенный возрастъ различенъ; то вышеупомянутая формула должна принять такой видъ П=f (К, О, Г) В, причемъ *В* означаетъ возрастъ почвы.

Fig. 2. Title page and page from book [8] with the soil formation equation (3).

site value. Thus, there should be a similar, *to some extent*, relationship between the *character of the soil* and the *character* of its forming factors. Hence, it is clear that it is theoretically possible to state and solve, for example, the following problem: How would a given soil change if there were an increase of the terrain temperature by, say, 1–2°, with a synchronous increase of meteoric water by 1–2 inches? How would a soil change if there is an annual increase of the vegetative mass by 20 poods per desyatina[2] with a decrease of the temperature by 1–2°?

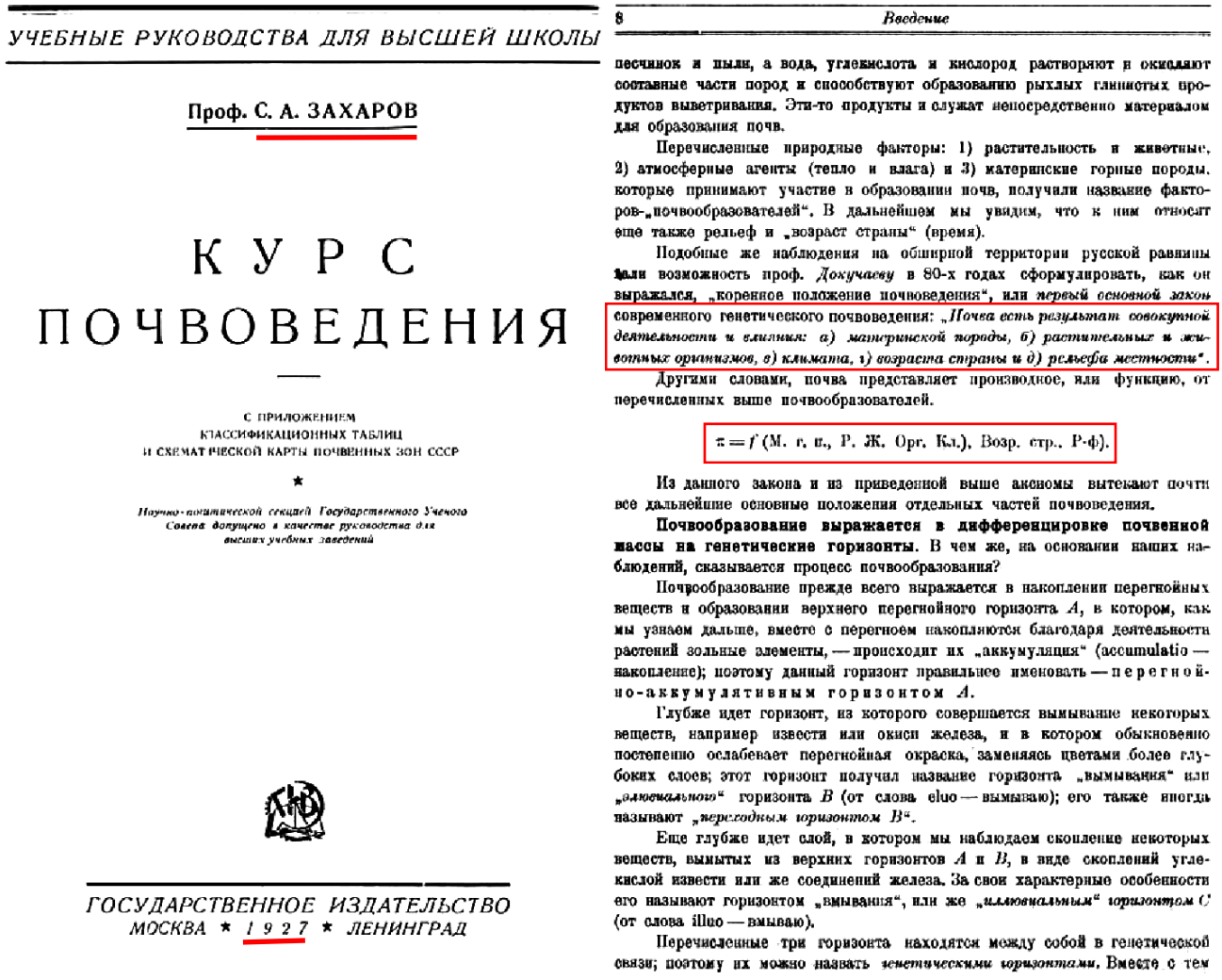
Again, all these are so clear and so logically legitimate and necessary that *nobody* will probably argue with this.

For now, unfortunately, it is difficult to prove all these propositions *using facts* and *with desirable completeness*, particularly to answer the last question (c) *in detail*. The reasons are quite obvious. Firstly, there is a great complexity of conditions affecting soils; secondly, these conditions have no absolute values, and, therefore, it is difficult to express them numerically; finally, we possess very few data for some factors and none whatever for others. Nevertheless, we may hope that all these difficulties will be overcome with time, and then, soil science will truly become an exact science}.[3]

The Dokuchaev hypothesis has the classic three-part structure of a scientific hypothesis, i.e., "postulate – suggestion – limitation." Part I of the hypothesis (the first

[2] Pood is the unit of weight of the Russian Imperial measurement system, 1 pood = 16.38 kg; desyatina is the unit of area of the Russian Imperial measurement system, 1 desyatina = 1.0925 ha.

[3] This translation of the Dokuchaev hypothesis was first published in the author's book [12, pp. 167–168].



УЧЕБНЫЕ РУКОВОДСТВА ДЛЯ ВЫСШЕЙ ШКОЛЫ

Проф. С. А. ЗАХАРОВ

КУРС ПОЧВОВЕДЕНИЯ

С ПРИЛОЖЕНИЕМ
КЛАССИФИКАЦИОННЫХ ТАБЛИЦ
И СХЕМАТИЧЕСКОЙ КАРТЫ ПОЧВЕННЫХ ЗОН СССР

★

Научно-понятической секцией Государственного Ученого Совета допущено в качестве руководства для высших учебных заведений

ГОСУДАРСТВЕННОЕ ИЗДАТЕЛЬСТВО
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8 *Введение*

песчинок и ныли, а вода, углекислота и кислород растворяют и окисляют составные части пород и способствуют образованию рыхлых глинистых продуктов выветривания. Эти-то продукты и служат непосредственно материалом для образования почв.

Перечисленные природные факторы: 1) растительность и животные, 2) атмосферные агенты (тепло и влага) и 3) материнские горные породы, которые принимают участие в образовании почв, получили название факторов-„почвообразователей". В дальнейшем мы увидим, что к ним относят еще также рельеф и „возраст страны" (время).

Подобные же наблюдения на обширной территории русской равнины дали возможность проф. *Докучаеву* в 80-х годах сформулировать, как он выражался, „коренное положение почвоведения", или *первый основной закон* современного генетического почвоведения: *„Почва есть результат совокупной деятельности и влияния: а) материнской породы, б) растительных и животных организмов, в) климата, г) возраста страны и д) рельефа местности".*

Другими словами, почва представляет производное, или функцию, от перечисленных выше почвообразователей.

$$\text{п} = f\,(\text{М. г. п., Р. Ж. Орг. Кл.}),\ \text{Возр. стр., Р-ф}).$$

Из данного закона и из приведенной выше аксиомы вытекают почти все дальнейшие основные положения отдельных частей почвоведения.

Почвообразование выражается в дифференцировке почвенной массы на генетические горизонты. В чем же, на основании наших наблюдений, сказывается процесс почвообразования?

Почвообразование прежде всего выражается в накоплении перегнойных веществ и образовании верхнего перегнойного горизонта *A*, в котором, как мы узнаем дальше, вместе с перегноем накопляются благодаря деятельности растений зольные элементы, — происходит их „аккумуляция" (accumulatio — накопление); поэтому данный горизонт правильнее именовать — перегнойно-аккумулятивным горизонтом *A*.

Глубже идет горизонт, из которого совершается вымывание некоторых веществ, например извести или окиси железа, и в котором обыкновенно постепенно ослабевает перегнойная окраска, заменяясь цветами более глубоких слоев; этот горизонт получал название горизонта „вымывания" или *„элювиального"* горизонта *B* (от слова eluo — вымываю); его также иногда называют *„переходным горизонтом B"*.

Еще глубже идет слой, в котором мы наблюдаем скопление некоторых веществ, вымытых из верхних горизонтов *A* и *B*, в виде скоплений углекислой извести или же соединений железа. За свои характерные особенности его называют горизонтом „вымывания", или же *„иллювиальным" горизонтом C* (от слова illuo — вымываю).

Перечисленные три горизонта находятся между собой в генетической связи; поэтому их можно назвать *генетическими горизонтами*. Вместе с тем

Fig. 3. Title page and page from book [35] with the soil formation equation (4).

sentence of the quotation) includes the definition of soil as a function of the five soil forming factors. This postulate, or "the basic law of soil science" [35, p. 8], was first published in complete form in 1883, three years before the publication of the hypothesis [10]. Part II of the hypothesis (the rest of the first paragraph of the quotation) includes three main suggestions. Part III of the hypothesis (the two latter paragraphs of the quotation) includes limitations to prove the hypothesis, which were critical for the late 19th century.

From the hypothesis, one can see that Dokuchaev explicitly defined the central idea and statement of the problem of contemporary predictive soil mapping in the year 1886. It is hardly necessary to argue that the Dokuchaev hypothesis underlies, in one way or another, all modern approaches of predictive soil mapping and most of the mathematical models used in soil science. For example, Homosoil, a method for extrapolation of soil data [23] is in fact the direct implementation of points (a) and (b) of the hypothesis. In the last decades, the statement of the problem in point (c) of the hypothesis has been in the focus of soil scientists studying the impact of the probable climatic change on soils.

At the same time, except for Part I (a postulate familiar to any soil scientist), the Dokuchaev hypothesis was forgotten. As far as we know, Part II was last cited 84 years ago [1, p. 10], and Part III was last cited 70 years ago [16, p. 17]. Unfortunately, the Dokuchaev hypothesis was not even mentioned in national fundamental studies on the history of soil science [30, 21, 14, 6].

SOIL FORMATION EQUATIONS

In 1899, Dokuchaev [8, p. 3] (Fig. 2) carried out the first step towards the formalization of the problem. He proposed the first soil formation equation:

$$\Pi = f\,(\text{K}, \text{O}, \Gamma)\,\text{B}, \qquad (3)$$

where П is soil, К is climate, О is organisms, Г is parent material, and В is the age of the soil. Topography was not included into the expression probably due to a stenographer's mistake, because Eq. (3) is preceded by two sentences discussing the important role of topography in soil formation (Fig. 2).

In 1927, Zakharov presented a general soil formation equation in a well-known fundamental textbook [35, p. 8] (Fig. 3). This equation ideally described the Dokuchaev postulate:

$$\pi = f(\text{М.Г.П.}, \text{Р.Ж.Орг.}, \text{Кл.}, \text{Возр.стр.}, \text{Р-ф}), \quad (4)$$

where π is soil, М.Г.П. is parent rock material, Р.Ж.Орг. is plant and animal organisms, Кл. is climate, Возр. стр. is the age of the terrain, and Р-ф is topography. There were three misprints in Eq. (4): two commas were missed and there was an excess close bracket (Fig. 3). The misprints were fixed in the second edition [36, p. 18]. Unlike the rare brochure [8], textbooks [35, 36] were widespread (4000 and 18000 copies of the first and second editions were printed, respectively).

In the summer of 1927, the Dokuchaev hypothesis and Eq. (4) became known in the West due to two circumstances. First, Afanasiev [1, p. 10] printed an English translation of almost the entire quotation cited above (without referencing book [9]) in the reprint of his report on the First International Congress of Soil Science held in Washington DC in June 1927. Second, Zakharov took part in the Congress. The reprint of his report to the Congress [34] did not include Eq. (4). We do not know the exact publication date of book [35]; therefore, we cannot state that Zakharov was able to present the book at the Congress or to give it to other participants. However, although the first review and information on this book were published in early 1928 [11], one of them was printed in the congress's proceedings [31, p. 33]. This is indirect evidence that Zakharov could have brought at least the proofs of the book to the Congress. Many western soil scientists, including Jenny [31], had an opportunity to learn about this equation in personal contacts with Zakharov during the Congress and the transcontinental soil excursion. It is well known that the very active exchange of scientific ideas between the participants from different nations was an outstanding feature of this congress [32]. The unique role of the Soviet delegation, which included several direct students of Dokuchaev, was acknowledged almost immediately [20]. One of the outcomes of this communication was a series of soil formation equations, such as the Shaw equation, the Wilde equation, and the Jenny equation (Eq. (2)).

In 1930, Shaw published the following equation [28, p. 244]:

$$S = M(C+V)^T + D, \quad (5)$$

where S is soil, M is parent material, C is climate, V is vegetation, T is time, and D is erosion or deposition. Shaw did not mention either the Dokuchaev hypothesis or the equations of Dokuchaev (3) and Zakharov (4). It is interesting that Shaw presented Eq. (5) at the Second International Congress of Soil Science held in the USSR in 1930 [27]. Zakharov took part in the discussion of this presentation. He criticized Shaw for ignoring the role of topography, animals, and humans in Eq. (5) [27, p. 14].

In 1941, Wilde published his equation [33, p. 34]:

$$S = \int (g.e.b.)\,dt, \quad (6)$$

where S is soil, g is geological substratum, e is the environmental influences, b is the biological activity, and t is time. Wilde did not mention Eqs. (3), (4), and (5). Note that Wilde, a Russia-born immigrant, was familiar with the works of Dokuchaev and Zakharov. Indeed, he cited the Dokuchaev postulate right before Eq. (6) calling it "the first basic law of soil science" (Zakharov's expression [35, p. 8]).

In 1941, Jenny published Eq. (2) [16, p. 16] and selectively cited the Dokuchaev hypothesis (after Afanasiev [1, p. 10]), that is, only a portion of the limiting Part III of the hypothesis [16, p. 17]. The following fact is more indicative: it is obvious that the Jenny equation (2) is almost identical to the Zakharov equation (4). However, Jenny did not mention Zakharov either in [16] or in subsequent papers [15, 17]. Jenny began to cite the Dokuchaev equation (3) only in 1961 [15], after its reproduction in the *Collection of Works* of Dokuchaev [7].

This year marks the 70th anniversary of the publication of Jenny's book [16]. During these years, the question of authorship of the soil formation equation was tangled due to several circumstances. First, the Zakharov equation (4) was forgotten. As far as we know, it was never cited both in foreign [29] and national studies of the history of soil science [6, 14, 21, 30]. Second, the Dokuchaev equation (3) was repeatedly quoted with errors [14, p. 61; 26, p. 296]. Third, different authors proposed different precursors of the Jenny equation. For example, Bockheim et al. [4, p. 26] stated that the Shaw equation (5) was the first soil formation equation.

Finally, there was the constant problem of the incorrect citation of primary sources. For instance, Jenny repeatedly wrote that the Dokuchaev equation "was printed in 1898 in an obscure Russian journal" [15; 17, p. 203], though, in fact, Eq. (3) was printed in 1899 in brochure [8]. In the second edition of *Pedology*, Joffe noted the following [19, p. 124]: "In mathematical form, the Dokuchaev proposition was expressed as follows:

$$S = f(pm, c, b, a, \text{and } t), \quad (7)$$

where S = soil, f = function, pm = parent material, c = climate, b = biosphere, a = age of land (time factor),

Chronology of events related to the Dokuchaev hypothesis

Year	Event
1883	The Dokuchaev postulate
1886	The Dokuchaev hypothesis
1899	The Dokuchaev equation
1927	The Zakharov equation
	Translation of the Dokuchaev hypothesis into English
	The First International Congress of Soil Science
1930	The Shaw equation
1941	The Wilde equation
	The Jenny equation
2003	SCORPAN model

and t = topography." Joffe did not cite a source for Eq. (7) that has a similar structure with the equations of both Zakharov (4) and Jenny (2). It is interesting that the first edition of *Pedology* [18], which was repeatedly cited by Jenny [16], did not include this sentence and Eq. (7). It is well known that Joffe, a Russia-born immigrant, was a supporter of the Russian school of soil science. Probably, in the second edition [19], which was published eight years after Jenny's book [16], Joffe wished to protect the scientific priority of Dokuchaev and Zakharov in the derivation of the soil formation equation. However, in terms of citation, he did this incorrectly and so increased the confusion.

As a result, many Western soil scientists ignore, as a rule, analogues or precursors of Eq. (2) and acknowledge Jenny as the author of this equation. The apology of the imaginary scientific priority of Jenny can be found elsewhere [3, 2]. Most national soil scientists believe that Jenny adopted Eq. (2) from Dokuchaev. This is also wrong because the structure of Eq. (2) differs significantly from the structure of Eq. (3). Sometimes, the expression "the Dokuchaev–Jenny equation" is used [25], but this is also incorrect because the structures of Eqs. (3) and (2) are different. For the same reason, it is incorrect to call Eq. (2) "the Dokuchaev–Zakharov equation."

Equation (2) should be called the Zakharov equation. It is encouraging that this issue was clarified in 2011, the anniversary year for the publications of Dokuchaev and Jenny (table).

CONCLUSIONS

(1) The central idea and statement of the problem of the contemporary predictive soil mapping were explicitly defined in the Dokuchaev hypothesis in the year 1886.

(2) The equations of Dokuchaev (3) and Zakharov (4) became the first experience in mathematical formalization in soil science and laid the foundation for mathematical modeling in this science. Dokuchaev and Zakharov themselves (like most of their contemporaries) did not pay much attention to these equations. Being written too early, they were finally appreciated in the last third of the 20th century.

(3) Jenny adopted the soil formation equation from Zakharov. Equation (2) should be called the Zakharov equation.

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