Dependence of apple yield on soil parameters in the conditions of the north of the Central Black Earth Region

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Abstract. The purpose of our research was to establish the correlation between individual soil parameters and the apple yield on low-growing rootstocks. Of the studied soils the gray forest soil was distinguished by the smallest thickness of the humus horizon, while the largest was leached chernozem. The upper line of the typical chernozem carbonate site was closest to the soil surface, while on gray forest and chernozem-moist meadow soil carbonates were the deepest. The lowest bonitet score belonged to gray forest soil (bonitet class 7), the highest – to leached chernozem (bonitet class 9). Typical chernozem podzolized, meadow-chernozem, chernozem-meadow, chernozem-moist-meadow and meadow-chernozem soils belonged to the 8th class of bonitet. Only the gray forest soil was of average quality, the rest of the soils were the best. Apple varieties grafted on semi-dwarf rootstocks 62-396 give the highest yield when grown on typical chernozem, and varieties on medium-sized (54-118) and vigorous (seed) stocks - on podzolized chernozem. Of the three given rootstocks the seed rootstocks suffer the most from the proximity of groundwater, while the semi-dwarf rootstocks - the least. As the groundwater approaches the soil surface, apple yield decreases in varieties grafted on medium-sized rootstocks 54-118. This is due to the vigor of the rootstock growth. The higher the vigor of growth, the more dangerous soils become with similar groundwater levels for rootstocks. Apple seed stocks are less demanding on soil fertility than 62-396 and 54-118. With an increase in the amount of exchange bases in the soil, absorption capacity, degree of saturation with bases, total porosity and bonitet, the yield of apple varieties on stocks 62-396 and 54-118 increases. The varieties on the stock 62-396 prefer soils with close carbonates sites, and on seed ones - with a deep one.

1. Introduction
In the literature much attention is paid to the role of soil conditions for apple productivity [1-5]. For optimal photosynthesis of apple trees in soils underlain by covering silt, soil moisture should be 60-86% of the lowest moisture capacity [6], on other soils - at 60-90% of the field moisture capacity in the 0-60 cm layer [7]. Moderate watering of the apple tree to moisture content of 50-70% of the field moisture capacity of the soil provided the highest quality fruit [8]; the deficiency of soil moisture caused the formation of small apple fruits with a higher content of ascorbic acid, polyphenols and dry substances [9]. When designing gardens, it is essential to have data on the moisture content of the soil [10]. It is of great importance to use intrasoil infiltration [11] in the irrigation of apple orchards and apply the method of soil pits [12]. It is important to know the moisture reserves in the soil of apple orchards when studying mulching [13] and water consumption of the garden [14]. The capillary moisture capacity of the soil determines the movement of water through the capillaries up, down and horizontally. Meanwhile, it is the horizontal movement of water that affects the salt balance of soil [15]. The most intensive apple root
system consumption occurred in a layer of 40-60 cm of the following elements: N, P, K, Ca, Mg, Na, Al, Si, Fe [16]. Availability of certain mineral elements for apple tree roots included in the sum of exchangeable bases (Ca and Mg) depends on the biological activity of the soil [17]. In some experiments application of mineral fertilizers under an apple tree did not affect the quality of the fruit, but the content of phosphorus, potassium and magnesium in the leaves [18], in others, such as fertilization in combination with zeolite, lowered the soil acidity, increased the level of humus and increased fruit yield [19]. The introduction of nitrogen and phosphorus in the form of fertigation under the apple tree increased the phosphorus content - first in the leaves, then in the fruit, with the yield increased by 20% [20]. Soil electrical conductivity closely correlates with apple yield (r = 0.94) [21]. When replanting two-year-old apple seedlings took root better on light texture soils [22]. The contact of the apple tree root system with the soil depends on the soil structure [23]. The apple yield on virgin, more fertile soils is 10 times higher than on soils that have just been freed from apple monoculture [24]. There was an experience in predicting apple yield based on a digital camera mounted on a tractor frame, which records the number of fruit set on the example of the varieties Golden Delicious, Brayburn [25] Gala [26]. In Germany and Latvia it was proposed to model the apple-tree yield on the basis of the cross-sectional area of the trunk and the planting density of trees [27]. In Belgium it is proposed to predict the yield of apple trees by the percentage of reproductive buds on different fruit formations. The higher these formations on the trunk are, the greater the yield is [28]. As a result of 15-year observations of apple yield and soil analyzes, we have developed, digitized and patented a program for predicting apple yield depending on soil parameters and the selected stock (62-396, 54-118 and seed) [29]. In the literature there is a number of examples of the effect of mineral, organic fertilizers and ameliorants on an apple tree yield, however, there is very little information on the mathematical dependence of the yield on a specific soil parameter. Therefore, the purpose of our research was to establish the correlation between individual soil parameters and apple yield on weak rootstocks.

2. Objects and methods of research

The studies were carried out between 2004 and 2019 on industrial apple trees plantations at the age of heavy fruiting in Lipetsk (2 farms) and Tambov regions (8 farms). Row spacing system - black steam. Apple varieties: Melba, Mantet, Pervenets, Sinap Orlovsky, Northern Sinap, Lobo, Zhigulevskoe, Welsey, Pepin saffron, Venyaminovskoe, Stroevskoe, Bogatyr, Pobeda, Antonovka ordinary, Berkutovskoe. Layouts of trees: 5x3, 6x4, 6x8 m. On each of the considered soil types there were 24 accounting trees (6 in a block). The number of blocks is 4. The arrangement of blocks is randomized. Crop counts were carried out according to the methodological provisions of Yu.A. Markov [30]. Agrochemical analyzes of the soil were done according to Central Research Institute of Agrochemical Services guidelines [31]: the content of alkaline hydrolysable nitrogen - according to A.Kh. Kornfield, the humus content - according to the method of I.V. Tyurin modified by V.N. Simakova, the pH of the salt extract was measured by the ionometric method on an EV-74 ion meter [32]; easily hydrolyzable nitrogen - applying the method of I.V. Tyurin and M.M. Kononova [33]; mobile phosphorus and exchangeable potassium - applying the method of F.V. Chirikov [34] using a KFK-2 photoelectric colorimeter and an FPA-2 flame photometer, hydrolytic acidity and the sum of exchangeable bases — by the Kappen titrimetric method. The lowest moisture capacity of soils was determined by the method of plaster casters and pouring of plots, capillary moisture capacity - using cylinders and sieves with a mesh bottom, soil density - applying the method of cutting cylinders, solid phase density - by pycnometric method, aggregate analysis (dry and wet sieving) - by N.I. Savinov, granulometric composition by pyrophosphate method modified by S.I. Dolgov and A.I. Lichmanova [35]. 70% of apple roots are contained in the 0-100 cm layer [36]. However, according to our data, the roots of low-growing apple rootstocks on industrial plantations in the north of the Central Chernozem region develop in a soil layer of 10-200 cm, therefore all data on soil properties are given on average over a layer of 10-200 cm. Soil bonitization was carried out applying the method of F.Ya. Gavrilyuk [37].
3. Research results
Of the studied soils the gray forest soil was characterized by the smallest thickness of the humus horizon, and leached chernozem - by the largest (table 1).

Table 1. Morpho-hydrological characteristics of the studied soil types.

| Soil subtype         | The thickness of the humus horizon (A+AB), cm | Carbonate site depth, cm | Groundwater depth, m |
|----------------------|-----------------------------------------------|--------------------------|----------------------|
| Typical chernozem    | 80                                            | 60                       | 9.0                  |
| Leached chernozem    | 95                                            | 136                      | 7.0                  |
| Podzolized chernozem | 80                                            | 200                      | 7.0                  |
| Meadow-chernozem     | 90                                            | 150                      | 6.3                  |
| Meadow-chernozem     | 80                                            | 134                      | 4.0                  |
| Chernozem-meadow     | 80                                            | 90                       | 2.5                  |
| Chernozem-humid-meadow | 50                        | 255                      | 0.5                  |
| Gray forest          | 35                                            | 255                      | 6.3                  |

Leached chernozem along with meadow-chernozem soil was a powerful soil, gray forest soil was of a shortened thickness, chernozem-wet meadow soil was thin, and the rest of the soils were medium-thick. In gray forest and chernozem-moist-meadow soil carbonates were the deepest (deep-carbonated). According to this parameter, podzolized chernozem was also deeply carbonated, meadow chernozem and leached chernozem were deeply carbonated, and chernozem-meadow demonstrated shallow carbonated soil. The closest groundwater level (very high) was characterized by hydromorphic chernozem-moist-meadow soil, while the typical automorphic chernozem had the deepest water level (low level). In leached, podzolized chernozem, gray forest and meadow-chernozem soils the level of groundwater was also low; in meadow-chernozem soils it was low; and in chernozem-meadow soils - average.

Chernozem-meadow soil (very dense) was distinguished by the highest density and low porosity of the soil profile; all chernozems were the least dense and more porous (medium-dense). All other soils were classified as dense (table 2).

Table 2. Physical and mechanical properties of soils.

| Soil subtype         | Soil density, g/cm³ | Soil porosity, % | Content of air-dry aggregates 0.25-10 mm, % | Content of physical clay, % |
|----------------------|---------------------|------------------|---------------------------------------------|----------------------------|
| Typical chernozem    | 1.32                | 47.8             | 56.43                                       | 62.1                       |
| Leached chernozem    | 1.33                | 47.3             | 51.7                                        | 40.8                       |
| Podzolized chernozem | 1.3                 | 49.1             | 53.0                                        | 35.1                       |
| Meadow-chernozem     | 1.47                | 44.2             | 51.3                                        | 63.4                       |
| Meadow-chernozem     | 1.43                | 47.0             | 38.1                                        | 47.3                       |
| Chernozem-meadow     | 1.6                 | 37.6             | 47.6                                        | 42.7                       |
| Chernozem-humid-meadow | 1.4            | 45.3             | 33.3                                        | 52.6                       |
| Gray forest          | 1.5                 | 42.0             | 33.6                                        | 25.6                       |

Of all the soils the least agronomically valuable aggregates in their profile were demonstrated by chernozem-moist-meadow and gray forest soils, whilst the most structural was typical chernozem. The structural state of gray forest, chernozem-meadow and meadow-chernozem soils was characterized as unsatisfactory, the rest of the soils - satisfactory. The highest content of physical clay is noted in typical chernozem and meadow-chernozem soils, which makes it possible to classify them as medium clay in
terms of granulometric composition. Chernozem-wet meadow soil was light clay, leached chernozem, meadow-chernozem and chernozem-meadow soils were heavy loamy, podzolized chernozem was medium loamy, and gray forest soil was light loamy.

The most hygroscopic soil was leached chernozem, while gray forest soil was less hygroscopic. The soil with the highest capillary moisture capacity was typical chernozem, and with the lowest - gray forest soil. All chernozem except for podzolized one had the highest value of the field limit, or the lowest moisture capacity. The lowest level of this indicator was in the gray forest soil. Only the chernozem-moist-meadow soil was characterized by an average water resistance of the aggregates, the rest of the soils were low (table 3).

Table 3. Soil hydrophysical properties, %.

| Soil subtype             | Hygroscopicity | Capillary moisture capacity | Lowest moisture capacity | Water resistance coefficient |
|--------------------------|----------------|-----------------------------|--------------------------|------------------------------|
| Typical chernozem        | 5.2            | 40.1                        | 44.0                     | 13.2                         |
| Leached chernozem        | 5.8            | 35.1                        | 45.2                     | 12.5                         |
| Podzolized chernozem     | 4.9            | 27.3                        | 38.9                     | 17.0                         |
| Meadow-chernozem         | 5.5            | 30.3                        | 44.9                     | 8.2                          |
| Meadow-chernozem         | 3.9            | 31.0                        | 43.3                     | 11.8                         |
| Chernozem-meadow         | 4.2            | 29.7                        | 33.5                     | 14.0                         |
| Chernozem-humid-meadow   | 3.5            | 34.5                        | 38.5                     | 25.5                         |
| Gray forest              | 3.3            | 20.5                        | 30.1                     | 2.7                          |

Judging by the exchangeable acidity, the gray forest soil was moderately acidic, meadow-chernozem, chernozem-meadow and chernozem-moist-meadow - slightly acidic, meadow-chernozem and podzolized chernozem - close to neutral, and leached and typical chernozem - neutral (table 4).

Table 4. Agrochemical properties of soils.

| Soil subtype             | pHKCl | Hydrolytic acidity | The sum of exchange bases mg-eq/100 g soil | Absorption capacity | Degree of saturation bases, % |
|--------------------------|-------|--------------------|-------------------------------------------|--------------------|-----------------------------|
| Typical chernozem        | 6.6   | 2.2                | 52.2                                      | 55.0               | 96.3                        |
| Leached chernozem        | 6.5   | 2.8                | 50.1                                      | 52.8               | 94.4                        |
| Podzolized chernozem     | 5.7   | 5.2                | 14.7                                      | 47.0               | 87.3                        |
| Meadow-chernozem         | 5.4   | 2.9                | 26.0                                      | 29.3               | 88.2                        |
| Meadow-chernozem         | 5.8   | 3.6                | 40.4                                      | 43.0               | 86.9                        |
| Chernozem-meadow         | 5.4   | 6.3                | 32.3                                      | 37.0               | 80.0                        |
| Chernozem-humid-meadow   | 5.2   | 8.1                | 25.4                                      | 32.0               | 74.4                        |
| Gray forest              | 4.85  | 3.1                | 12.3                                      | 15.4               | 80.1                        |

The hydrolytic acidity of typical, leached chernozem and meadow-chernozem soils is low, gray forest and meadow chernozem soils are medium, and in other soils it is high. The sum of exchange bases in forest soils (gray forest and podzolized chernozem) is at an average level, while in other soils it is at a
high level. The absorption capacity of gray forest and meadow-chernozem soils was at a low level, in chernozem-moist-meadow, chernozem-meadow and meadow-chernozem soils - at an average level, and in other soils - at a high level. Gray forest, chernozem-humid-meadow and chernozem-meadow soils were characterized by an average degree of saturation with bases, and the rest of the soils were high.

All soils, except for chernozem-moist-meadow, were slightly humus. It contained the most humus and was classified as low-humus. The least amount of humus was found in meadow chernozem and gray forest soils (table 5).

| Soil subtype                  | Humus, % | N easily hydrolyzable | N leach-hydrolyzable | P₂O₅ | K₂O | Bonitet, quality scores |
|-------------------------------|----------|-----------------------|----------------------|------|-----|------------------------|
| Typical chernozem             | 3.2      | 8.4                   | 30.5                 | 5.9  | 14.8| 80.0                   |
| Leached chernozem             | 3.4      | 5.5                   | 16.2                 | 9.6  | 14.2| 83.3                   |
| Podzolized chernozem          | 2.6      | 7.6                   | 14.1                 | 3.4  | 11.1| 80.2                   |
| Meadow-chernozem              | 2.7      | 5.7                   | 7.1                  | 2.1  | 12.4| 74.1                   |
| Meadow-chernozem              | 2.0      | 5.5                   | 11.9                 | 9.0  | 11.3| 80.3                   |
| Chernozem-meadow              | 3.4      | 6.4                   | 20.0                 | 3.9  | 12.7| 76.9                   |
| Chernozem-humid-meadow        | 5.0      | 6.9                   | 19.7                 | 15.3 | 9.2 | 72.3                   |
| Gray forest                   | 2.1      | 2.8                   | 3.0                  | 2.8  | 4.2 | 67.0                   |

The gray forest soil was not supplied with easily hydrolyzable nitrogen and needed nitrogen fertilizers. Meadow chernozem soils and leached chernozem were, according to this indicator, moderately supplied and moderately needing nitrogen, the rest were highly supplied and needed little nitrogen. Alkaline hydrolyzable nitrogen was also the least in gray forest soil, and the most detected in typical chernozem (10 times more). Gray forest, chernozem-meadow, meadow-chernozem soil and podzolized chernozem were unsupported mobile phosphates and needed phosphorus fertilizers. Typical, leached chernozem and meadow chernozem soils were moderately supplied with phosphorus and experienced an average need for this macronutrient. The rest of the soils were fully provided with this element and needed little. The gray forest soil was not provided with exchangeable potassium and needed it. The chernozem-humid-meadow soil was moderately supplied with potassium, and the rest of the soils were provided with little need for potassium fertilizers. The lowest bonitet score belonged to gray forest soil (bonitet class 7), the highest - leached chernozem (bonitet class 9). Typical chernozem, podzolized, meadow-chernozem, chernozem-meadow, chernozem-moist-meadow and meadow-chernozem soils belonged to the 8th class of bonitet. Only the gray forest soil was of average quality, the rest of the soils were the highest.

Apple varieties on a semi-dwarf rootstock 62-396 showed the highest average annual yield when grown on typical and leached chernozem, and the least on meadow-chernozem soil. Apple varieties grafted on a medium-sized rootstock 54-118 gave the highest fruit yields when the trees were placed on podzolized chernozem, and the smallest - on chernozem-moist meadow soil. Apple varieties on a vigorous seed stock showed the highest productivity on podzolized chernozem, and the lowest - on chernozem-moist meadow soil. Of the three given rootstocks the seed rootstocks suffer the most from the proximity of groundwater, and the semi-dwarf rootstocks the least. This is due to the vigor of the
rootstock growth. The higher the vigor of growth is, the more dangerous the soils with a similar groundwater level for rootstocks become (table 5).

Table 6. Apple yield depending on the soil subtype in the North of the Central Chernozem soil region and stock (on average by varieties).

| Soil subtype                      | Stock 62-396 | Stock 54-118 | Seeding stock |
|-----------------------------------|--------------|--------------|---------------|
| Typical chernozem                 | 192.1        | 103.0        | 47.5          |
| Leached chernozem                 | 117.4        | 107.3        | 60.0          |
| Podzolized chernozem              | 73.2         | 138.1        | 146.2         |
| Meadow-chernozem                  | 31.1         | 97.5         | 126.0         |
| Meadow-chernozem                  | 84.5         | 109.6        | 126.0         |
| Chernozem-meadow                  | 68.2         | 64.4         | 126.0         |
| Chernozem-humid-meadow            | 86.8         | 36.5         | 15.0          |
| Gray forest                       | 55.0         | 81.0         | 108.9         |

We carried out a correlation analysis of each soil parameter in the 10-200 cm layer and the apple yield. For varieties on stock 62-396 it was found that the yield increases with an increase in the sum of exchangeable bases (r = 0.74), absorption capacity (r = 0.73), saturation with bases (r = 0.6), pH$_{KCl}$ value (r = 0.8), capillary moisture capacity (r = 0.77), alkaline hydrolysable nitrogen (r = 0.83), easily hydrolysable nitrogen (r = 0.6), exchangeable potassium (r = 0.52), and bonitet (r = 0.52). The yield of varieties on this rootstock also increased with a decrease in soil density (r = -0.6) and with a decrease in carbonate depth (r = -0.6).

For varieties grafted on stock 54-118 it was found that the yield increases with an increase in the sum of exchange bases (r = 0.55), absorption capacity (r = 0.51), saturation with bases (r = 0.74), total porosity (r = 0.62), pH$_{KCl}$ (r = 0.5), hygroscopicity (r = 0.58), agronomically valuable aggregates (r = 0.6), groundwater depth (r = 0.76) and bonitet (r = 0.6). The yield of varieties on this stock also increased with a decrease in soil density (r = -0.55) and its hydrolytic acidity (r = -0.62). It was found that the deeper the carbonates lay is, the higher the yield of apple varieties on seed stocks are (r = 0.53).

4. Conclusions

Apple varieties grafted on semi-dwarf rootstocks 62-396 give the highest yield when grown on typical chernozem, varieties on medium-sized (54-118) and vigorous (seed) stocks - on podzolized chernozem.

With an increase in the amount of exchange bases, absorption capacity, degree of saturation with bases, general porosity and bonitet in the soil, the yield of apple varieties on stocks 62-396 and 54-118 increases.

Varieties on the stock 62-396 prefer soils with an approximate carbonates site, while on seeding stock - with a deep one.

As the groundwater approaches the soil surface, apple yield decreases in varieties grafted on medium-sized rootstocks 54-118. The higher the vigor of growth, the more dangerous soils become with similar groundwater levels for rootstocks.

Apple seed stocks are less demanding on soil fertility than 62-396 and 54-118.

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