Classification of the Non-Chernozem Zone regions of Russia by Agro-Climatic and Soil Indicators

E V Egorova¹, M V Semkiv², Yu T Farinyuk¹ and A S Vasiliev¹

¹Tver State Agricultural Academy, ul. Marshala Vasilevskogo, 7, Tver, Russian Federation
²Yaroslav-the-Wise Novgorod State University, 41, ul. B. St. Petersburgskaya, Veliky Novgorod, Russian Federation

E-mail: ikc_tver@mail.ru

Abstract. Agro-climatic and soil conditions are fundamental factors for effective agricultural production, which must be taken into account when determining the priority directions for the development of agriculture in the regions. The Non-Chernozem Zone of Russia includes regions, some of which are similar in agro-climatic and soil conditions, others are very different. To facilitate the task of setting targets, it is advisable to classify the regions. At the same time, to develop a classification, it is sufficient to use a certain number of indicators characterizing agro-climatic and soil conditions. When classifying the subjects of the Non-Chernozem Zone of Russia, two methods of cluster analysis were considered and described in the article: the method of hierarchical tree classification and K-Mean cluster based segmentation method. The results obtained by the two methods almost completely coincided, which indicates the objective existence of the identified groups of regions. The subjects of the Non-Chernozem Zone were divided into four groups; each significantly differs from another in terms of agro-climatic and soil indicators underlying the classification. The suggested classification can serve as a starting point in designing a state program for the development of agriculture, as well as the basis for further analysis of the efficiency of agriculture, while the labor intensity of work will be significantly reduced due to the compression of the information environment.

1. Introduction
The efficiency of agricultural production largely depends on the agro-climatic and soil conditions in which the regions are located [1]. The economic development of a territory, be it a country or a region, largely depends on such areas of activity as the export of products [2]. It is not correct to carry out a comparative analysis and build econometric models of the dependence of output on production factors in the entire set of regions. A preliminary classification of regions should be carried out in order to form groups that are homogeneous in terms of the conditions for carrying out agricultural activities.

Various classifications of Russian regions began in the 18th century. Today there are many classifications, each having its own purpose.

The relevance of research carried out in this direction is confirmed by many scientists [3, 4, 5, 6, 7].

The purpose of this study is to classify the regions of the Non-Chernozem Zone of Russia by agro-climatic and soil indicators; it will provide the basis for further analysis of the efficiency of agricultural land use.
Earlier, we have already made attempts to carry out such a classification. However, the classification did not fully reflect the soil conditions of the regions. In this work, we have refined the method for calculating the indicator of soil conditions, which made it possible to obtain more adequate results.

The developed classification of regions can become a starting point for a comparative analysis of the efficiency of agriculture in the regions of the Non-Chernozem Zone, for identification of the most significant factors for increasing the efficiency of the use of agricultural lands, and for designing regional and federal programs for the development of agriculture.

2. Materials and methods

The study was carried out in regards to official data on the agro-climatic indicators of the Russian Non-Chernozem Zone regions found in the Unified State Register of Soil Resources of Russia, as well as on the basis of the results of assessing soil conditions obtained by other authors.

When classifying, we did not take into account data for 4 regions (Moscow, Saint Petersburg, Nenets Autonomous District, and Murmansk region), because the share of agriculture in the gross regional product in these regions does not exceed 1%. Thus, 28 regions were considered in the classification.

At the first stage of any research, including classification, a specific consistent goal was formulated. At the second stage, we selected agro-climatic and soil indicators that correspond to our goal. From the whole variety of agro-climatic and soil characteristics, we chose a significantly smaller number of indicators, but made sure that they were sufficient to describe the main conditions for carrying out agricultural activities. These indicators included the characteristics of the provision of regions with heat and moisture, as well as the index of soil fertility. Further, using the correlation analysis, we excluded the characteristics that were in a strong statistically significant linear relationship with each other, thereby reducing the factor space, leaving the key indicators of agro-climatic and soil conditions for classification.

Thus, the original data file was generated containing the following information on the agro-climatic and soil conditions of the Non-Chernozem Zone of Russia:

- annual amplitude of air temperatures (T1);
- the sum of average daily temperatures for the period with temperatures above 10°C (T2);
- Selyaninov hydrothermal coefficient (V1);
- height of snow cover, cm (V2);
- soil fertility index (SFI).

The first two indicators characterize the supply of heat to plants, the third and fourth characterize the moisture supply of plants, and the fifth indicator is the total soil fertility in the region.

The indicators of heat and moisture supply of plants were built on the basis of the monthly average agro-climatic data of the Hydrometeorological Center for the period 1961–1990 [8]. Soil fertility indices for each subject of the Non-Chernozem Zone were calculated as the sum of the weighted average values of each soil type. The weighted average value of each soil type was determined as the product of the index of each soil type by its share in the total area of soils of the region. When calculating the weighted average indices of soil fertility in the context of the subjects of the Non-Black Earth Zone, we used the indices of the current main soil types taken by the Federal Districts which were calculated by E.A. Lentyaeva [9]. The share of each type of soil in the total area of the region was determined according to the Unified State Register of Soil Resources of Russia [10].

At the third stage we determined the number of groups into which the regions of the Non-Chernozem Zone should be classified and their preliminary composition. We used the tree clustering method. At the same time, the Ward’s method was used, mostly, for the hierarchical association of subjects with the calculation of the Manhattan distance.

At the fourth stage, we clarified the cluster composition using the K-Means cluster analysis method. In this case, observations with constant intervals were chosen for the initial centers of the clusters, and the Euclidean distance was used as a function of the distance between objects.
3. **Results and discussion**

The results of uniting regions into clusters by the method of hierarchical cluster analysis are presented in the form of a tree diagram (figure 1).

![Tree diagram](image)

**Figure 1.** Tree diagram of uniting the regions of the Non-Chernozem Zone into clusters according to agro-climatic and soil indicators. Source: compiled by the authors.

Based on the visual presentation of the results in the diagram, we can assume that the regions form four natural groups with similar agro-climatic and soil conditions:

- **the first group** – Chuvash Republic, Ryazan region, Republic of Mordovia, Tula region, Orel region;
- **the second group** – Smolensk region, Sverdlovsk region, Tver region, Kostroma region, Kaliningrad region, Kaluga region, Ivanovo region;
- **the third group** – Pskov region, Novgorod region, Udmurt Republic, Yaroslavl region, Moscow region, Vologda region, Republic of Mari El, Vladimir region, Nizhny Novgorod region, Bryansk region;
- **the fourth group** – the Komi Republic, the Perm Kray (region), Leningrad region, the Kirov region, Republic of Karelia, Arkhangelsk region.

To test this assumption, the areas were allocated by the K-Means method into 4 groups, and the significance of the difference between the resulting groups was tested:

- **the first group** – Chuvash Republic, Ryazan region, Republic of Mordovia, Tula region, Orel region;
- **the second group** – Smolensk region, Sverdlovsk region, Tver region, Kostroma region, Kaliningrad region, Kaluga region, Pskov region;
- **the third group** – Novgorod region, Udmurt Republic, Yaroslavl region, Moscow region, Vologda region, Republic of Mari El, Vladimir region, Nizhny Novgorod region, Bryansk region; Ivanovo region;
- **the fourth group** – the Komi Republic, the Perm Kray (region), Leningrad region, the Kirov region, Republic of Karelia, Arkhangelsk region.

The distribution of regions of the Non-Chernozem Zone of Russia by groups by the K-Means method coincided by 92.8% with the distribution performed by the method of hierarchical cluster analysis. Thus,
when classifying regions by two methods, only two regions (Ivanovo region and Pskov region) out of 28 subjects fell into different groups, which indirectly indicate the existence of groups of regions in Non-Chernozem Zone of Russia that differ significantly in average agro-climatic and soil conditions.

A visual analysis of the graph of standardized average values of agro-climatic and soil indicators in the context of the selected groups of regions (Figure 2) also confirms the heterogeneity of the regions of the Non-Chernozem Zone of Russia in terms of agro-climatic and soil conditions. At the same time, the most significant are the differences in indicators of plant moisture supply and soil fertility.

![Figure 2. Graph of standardized average values of agro-climatic and soil indicators.](image)

The natural average values of agro-climatic and soil indicators for the group identified are given in the table 1.

| Group of regions | T1   | T2   | V1   | V2   | SFI  |
|------------------|------|------|------|------|------|
| First group      | 29.96| 2212 | 1.18 | 37.60| 7.46 |
| Second group     | 27.49| 1946 | 1.62 | 28.29| 4.16 |
| Third group      | 29.51| 1977 | 1.37 | 46.50| 4.35 |
| Fourth group     | 29.54| 1400 | 1.57 | 55.50| 3.42 |

The first group unites 5 subjects: the Republics of Mordovia and Chuvashia, Orel, Ryazan, and Tula regions. Most of the territory of these entities is located in the zone of deciduous forests and forest-steppe. The main types of soils on the territory are chernozem (black soil), forest and sod-podzolic soils. Soil fertility is the highest in the Non-Chernozem Zone – the average productivity coefficient is 7.46 which is twice as high as in other groups. At the same time, the value of the Selyaninov hydrothermal coefficient in the regions of this group is significantly lower than in the other groups.

The second group consists of 7 regions: Smolensk, Sverdlovsk, Tver, Kostrama, Kaliningrad, Kaluga and Pskov regions. Their territory is located in the zone of mixed and deciduous forests. The dominant soils are sod-podzolic and forest soils, as well as podzols. The regions of this group, in comparison with other groups, have the lowest annual amplitude of air temperatures and the lowest depth of snow cover, while the value of the Selyaninov hydrothermal coefficient is the highest. The values of the indicators of the sum of average daily temperatures for the period with temperatures above 10 °C and the soil fertility index are at the average level of the regions of the Non-Chernozem Zone.
The third group is the most numerous. It includes 10 regions: Novgorod, Yaroslavl, Moscow, Vologda, Vladimir, Nizhny Novgorod, Bryansk, Ivanovo, as well as the republics of Udmurtia and Mari El. The values of all indicators of agro-climatic and soil conditions are at the average level for the Non-Chernozem zone of Russia. They are located in the zone of southern taiga and mixed forests. The dominant soils are sod-podzolic and forest soils, as well as podzols.

The fourth group includes 6 regions: the Republics of Komi and Karelia, Perm Kray, Leningrad, Kirov and Arkhangelsk regions. Most of the territory of these entities is located on low-productive lands of the taiga and mixed forests zone, where podzols, sod-podzolic and podzolic soils prevail. In the regions of this group, the value of the indicator of the sum of average daily temperatures for the period with temperatures above 10 °C is the lowest in the Non-Chernozem zone, as well as the lowest index of soil fertility. At the same time, the moisture supply of plants is one of the highest.

Thus, the regions included in the first group have the most favorable agro-climatic and soil conditions for agricultural activities. And it is these regions that need to be emphasized when designing a federal program for the development of agriculture. The most unfavorable conditions for the cultivation of agricultural crops are in the regions of the fourth group. It makes no sense to plan high efficiency of agricultural activities in these regions.

4. Conclusion
The research revealed that the regions of the Non-Chernozem Zone of Russia are not homogeneous in terms of agro-climatic and soil conditions. At the same time, the regions are well classified into four groups. The composition of the groups identified is substantiated and includes regions of the same climatic zone.

The results of the classification we have developed can be used as an information base to design a federal program for the development of agriculture. Target indicators of the efficiency of agriculture, in particular the crop production sector, should be determined taking into account the regional characteristics of agro-climatic and soil conditions, which are the basis for the given classification. In addition, the results of this work are a preliminary stage for further identification of the most significant growth factors in the efficiency of agricultural production, which differ in the regions of the selected groups.

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