Formation of the physical state and carbon stocks in organic matter of agrochernozem under the influence of resource-saving technologies

N L Kurachenko, O A Vlasenko and A A Kolesnik
Krasnoyarsk State Agrarian University, 90, Mira Av., Krasnoyarsk, 660049, Russia

E-mail: kurachenko@mail.ru

Abstract. In the field experiment in the conditions of the Krasnoyarsk forest-steppe, the influence of resource-saving technologies on the physical state of agrochernozem and the carbon reserves of organic substance is studied. It is shown that the productive moisture reserves are satisfactory, in the subsoil layer there is a tendency to increase the moisture reserves by 2-5 mm on the minimum and zero background compared with plowing. Moldboard plowing and minimal tillage by fluffy consistency determined the greatest degree of differentiation of the humus horizon. Resource-saving technologies of main tillage contributed to an increase in bulk density by 0.05-0.08 g/cc while retaining the optimal parameters. The method of the main tillage determined the stocks of the above-ground mortmass. The stock of plant residues on the soil surface at the minimal background increased 1.4 times, at zero - 2.1 times compared with plowing. Stocks of phytomass, roots and underground mortmass were not identified by crop cultivation. The stock rations of carbon in mobile humus of agrochernozem increased 1.4-1.5 times against the background of resource-saving technologies due to newly formed humic acids and water-soluble organic matter.

1. Introduction
Soil cultivation should be considered as an important part of agrotechnologies, which is in close connection with natural and agro-ecological conditions [1]. Recently, the problems of resource saving in agricultural production are becoming more acute. It is known that annual plowing in the traditional version, especially in spring, leads to a severe soil aeration and accelerates the mineralization of humus, resulting in the soil degrading: its structure is destroyed; the soil is sprayed after tillage, over-compacted and requires even greater mechanical action. This soil is even more exposed to erosion. However, a complete replacement of plowing with less energy-intensive tillage methods can have serious consequences. Long-term stationary researches [2] revealed the differentiation of the arable horizon into layers according to various fertility indicators with minimal treatments: the content of organic matter, mobile phosphorus, exchangeable potassium, and the accumulation of silt fraction of soil in the lower part of the arable layer. Therefore, the application of resource-saving technologies of basic tillage raises a number of issues related to changes in soil properties.

The purpose of the current research is to evaluate the effect of resource-saving technologies of the main tillage on the physical state and carbon reserves of the organic matter in agrochernozem of the Krasnoyarsk forest-steppe.
2. Objects and research methods

Research conducted in 2017-2018 in the territory of the instructional farm Minderlinskoye of the Krasnoyarsk State Agrarian University, the land management of which is situated in the central part of the Krasnoyarsk forest-steppe (56’25”N and 92’53”E), located on the south-western outside of Central Siberia. The object of study is a complex of clay-alluvial (typical, podzolized, hydrometamorphosed) agrochernozem and cryogenic-micellar agrochernozem. The soil of the experimental plot was characterized by a high and very high humus content (6.1–11.1%) in a layer of 0–20 cm, a very high exchangeable base status (53.2–62.0 mmol/100 g), neutral, weakly acid and weakly alkaline reaction of the soil solution (pHh2o 6.5-7.9). Evaluation of the impact of resource-saving technologies of primary tillage on the properties of agrochernozem was carried out in the agrocoenosis of maize as follows: I - dumping plowing of PN-5-35 on the depth of 23-25 cm; II - minimal tillage with the disk header BDSh-5.6 on the depth of 12-14 cm; III- zero tillage (direct seeding with a seeder Agrotor 4.8). Maize in variety Katerina was cultivated after the preceding grain crop with the use of ammonium nitrate (1 c/ ha in physical weight) and the herbicide Elumis MD. The total area of experimental plots is 1500 m², and the accounting area is 500 m². Soil samples were taken in June, July and August. The replication of sampling was three-stage. The depth of sampling was 0–20 and 20–40 cm. In soil samples, the following were determined: moisture content - using the thermo-weight method; bulk density according to Kachinskiy [3]. By the moving method, the stocks of the above-ground plant matter were identified in fourfold replication three times during the growing season from June to August, while the reserves of the underground plant matter were identified by the monolith sample method, followed by washing from the soil and fractioning into roots, large > 0.5 mm and small mortmass < 0.5 mm. The carbon content in plant samples was determined by the Anstet method modified by V.V. Ponomareva and T.A. Nikolaeva. The carbon content in humus was determined by the microchromic method according to I.V. Tyurin. The carbon content in water-soluble organic matter (C_{H2O}) was identified by the method of bichromate oxidation. The carbon content in alkaline hydrolysable humus (C_{0.1N NaOH}), carbon in humic acids (C_{HA}) and carbon in fulvic acids (C_{FA}) as its parts were determined in 0.1 normal alkaline extract according to I.V. Tyurin in the modification of V.V. Ponomareva and T.A. Plotnikova [4].

3. Results discussion

Chernozem belongs to soils of entirely atmospheric moistening with a deep position in soil and ground water surface. Therefore, their moisture content is determined by the weather conditions of the growing season. Research has shown that under the conditions of arid June 2017, productive moisture reserves in 0-20 cm layers at the beginning of the maize growing season for all types of tillage had similar quantitative estimates and were characterized as satisfactory (30-32 mm) (p = 0.89). By July and August, there was a replenishment of moisture reserves up to 40 mm by all tillage types (p = 0.94). By harvesting the culture, good soil moisture was formed with the use of resource-saving technologies of basic cultivation (40-42 mm). Compared with plowing on these variants of the experiment, the moisture stock increased by 4–8 mm (p = 0.01). The field season of 2018 was characterized as warm and arid. During the period May-September, 150 mm of precipitation fell. July was the driest, where the amount of precipitation did not exceed 15 mm, and September was the wettest (56 mm). From June to August, there is a sharp decline in the reserves of productive moisture in all types of basic cultivation from 35–37 to 18–20 mm in the 0–20 cm layer and moisture content changed during the summer months from satisfactory to poor (p = 0.04–0.57). A similar pattern was found for the subsurface layer. Significant differences in productive moisture were recorded in the July period and were accompanied by its maximum accumulation during plowing (p = 0.01). The average seasonal reserves of productive moisture formed in maize crops during 2017-2018 were estimated at 0–20 cm layer at a level of satisfactory moisture provision during the basic cultivation (32 mm). In the layer of 20-40 cm, they decreased by some of the cultivation types: zero (33 mm) — moldboard (30 mm) — minimum (28 mm)
(table 1). Thus, the method of primary tillage has not had a significant impact on the accumulation of productive moisture in the 0-40 cm layer of chernozem of the Krasnoyarsk forest-steppe.

### Table 1. Productive moisture stocks in agrochernozem of maize agroecosmos, mm.

| Index figure | 2017 (n = 3) | 2018 (n = 3) |
|--------------|-------------|-------------|
|              | moldboard   | zero        | moldboard   | zero        |
|              | 0-20 cm     | 20-40 cm    | 0-20 cm     | 20-40 cm    |
| X            | 36,2        | 37,0        | 38,1        | 28,0        | 26,9        | 26,6        |
| C<sub>v</sub>, % | 10          | 13          | 13          | 28          | 38          | 33          |

x - arithmetic average.  
<sup>b</sup> C<sub>v</sub> - coefficient of variation, %.

The bulk density is one of the main indicators of the physical properties of soil. This is a very dynamic and at the same time exceptionally informative indicator, depending on the relative position of soil particles-aggregates in space and varying widely depending on the ratio of minerals and organic substances as a part of soil. Tillage determined the quantitative assessment of the indicator and the way it changes during the growing season. The bulk density of chernozem in maize crops during the growing season was not critical (1.25-1.30 g/cc), when the soil lost its ability to get thicker. In addition, in certain periods of the growing season, it did not even reach the optimum value, which is confirmed by research [5]. Low values of the bulk density were recorded in the 0–10 cm layer, where the value of the index did not exceed 0.84 g/cc (table 2).

### Table 2. Bulk density of agrochernozem in maize agroecosmos, g/cc.

| Index figure | 2017 (n = 3) | 2018 (n = 3) |
|--------------|-------------|-------------|
|              | moldboard   | zero        | moldboard   | zero        |
|              | 0-10 cm     | 10-20 cm    | 20-40 cm    |
| X            | 0.73        | 0.84        | 0.82        | 0.76        | 0.77        | 0.80        |
| C<sub>v</sub>, % | 6          | 5           | 7           | 10          | 10          | 13          |
| X            | 0.85        | 0.94        | 0.89        | 0.85        | 0.90        | 0.94        |
| C<sub>v</sub>, % | 2          | 1           | 8           | 5           | 8           | 12          |

Moldboard tillage for maize sowing in 2017 identified a decline in this layer to 0.70-0.77 g/cc. At the beginning of the growing season, this decrease was 0.14 g/cc compared with the minimum tillage. In the July and August periods - by 0.10-0.13 g/cc compared with the minimum and zero tillage. A different character of the dynamics of bulk density is noted in the 10–20 cm layer. Moldboard and minimum tillage determined insignificant seasonal variation of the index, not exceeding 1-2%. During the zero tillage, a significant decompaction of the 10–20 cm layer in the July and August periods (C<sub>v</sub> = 8%) to 0.85–0.86 g/cc was noted. It was revealed that the minimum tillage with a disc header formed a bulk density of 10–20 cm of the soil layer at the level of 0.93–0.94 g/cc during the growing season (p = 0.001). The effect of soil tillage was maintained on the depth of 20-40 cm. The similar nature of the dynamics with a greater intensity reveals that by zero tillage the density of subsurface layer had a normal composition (1.03 g/cc) at the beginning of the growing season followed by a decrease during the period of active growth of maize to 0.81–0.75 g/cc. Minimum tillage and plowing of the soil determined a slight variability of the indicator (C<sub>v</sub> = 3-4%). Moldboard tillage reliably reduced the bulk density of 20–40 cm layer by 0.07–0.16 g/cc in July (p = 0.01) compared with the use of resource-saving technologies. This pattern is due to the ability of soil to decompaction during the growing season. In nature, soils of
chernozem can both be compacted and overcompacted, but also decompacted. It is estimated that the proportion of mechanical tillage accounts for 50% of the total decompaction effect, the proportion of slaking and yield ability is about 35% and the proportion of thermal oscillation is 15% [6].

Moldboard tillage in the growing season of 2018 determined the dynamic changes in the bulk density of a 0-10 cm layer from 0.68 to 0.84 g/cc (Cv = 10%). During the minimum and zero tillage by the August period, the soil under maize crops becomes less compacted to 0.68 g/cc. The reverse nature of the dynamics of the bulk density is noted in the 10–20 cm layer (p = 0.04). Moldboard and minimum tillage caused a slight seasonal variation of the index, not exceeding 5-8%. By the zero tillage, the variation of the index reached 12%.

An assessment of the average statistical indicators of the bulk density in maize sowings made it possible to determine that an increase in the parameter values was observed with depth. Reducing the depth of tilling enhances this trend. The minimum density of soil in the growing season 2017-2018 was marked in the 0-10 cm layer on plowing (0.73-0.76 g/cc). Resource-saving technologies help increase the rate to 0.77-0.84 g/cc. In the layer of 10-20 cm and 20-40 cm, this trend continues. In 2017, the minimum tillage determined the formation of the maximum bulk density (0.94-0.96 g/cc), in 2018 - zero seeding (0.94-0.92 g/cc). The calculation of the average statistical data for the observation period made it possible to identify soil heterogeneity of the 0-40 cm layer according to the studied indicator. Moldboard and minimum tillage by the fluffy consistency determined the highest degree of differentiation of the 0-40 cm layer, when the difference between the 0-20 and 20-40 cm layers was 0.08-0.11 g/cc. Estimation of the average bulk density of a 0–20 cm layer enables to identify the following descending series of soil tillage: minimum and zero (0.87 g/cc)> moldboard (0.79 g/cc). In the subsurface layer, tillage was ranked as follows: minimum (0.92 g/cc)> zero (0.89 g/cc)> moldboard (0.84 g/cc).

According to [7], long-term use of subsoil tillage techniques and their combination with the systematic introduction of chopped straw on the fields of grain crops, contributes over time to changes in soil processes, the ratio of group composition of microorganisms and the overall biological activity of the upper layer. The enrichment of the upper layer with additional organic matter over time creates favorable conditions for the dominance of humification processes over the mineralization of organic matter, which increases the potential fertility of zonal soils, which can noticeably manifest in 5-10 years or more.

The maximum carbon stock in plant matter was formed at the time of harvesting the green mass of maize in August and was concentrated in the upper 0-20 cm soil layer (table 3). It contained 70% of the carbon stocks in the roots, 79% of the carbon stocks in the large mortmass and 89% of the carbon stocks in the small mortmass. Such a pattern is associated with the climatic features of the Krasnoyarsk forest-steppe, the prolonged freezing of the soil on the depth of more than 2.5 m, the heavy soil texture, and the short vegetative period. In this connection, the soil layer from 20 to 40 cm warms up and thaws much later, which leads to the “tightness” of biological processes to the upper layer of agrochernozem.

| Cultivation technology | Phytomass | Above-ground mortmass | Roots | Large mortmass | Small mortmass (VOC) |
|------------------------|-----------|-----------------------|-------|----------------|---------------------|
|                        |           | 0-20 | 20-40 | 0-20 | 20-40 | 0-20 | 20-40 | 0-20 | 20-40 |
| Moldboard              | 9.87      | 0.35 | 7.20  | 3.42 | 4.45 | 1.03 | 0.77 | 0.12 |
| Minimum                | 4.52      | 0.14 | 3.37  | 1.60 | 1.73 | 0.40 | 0.28 | 0.04 |
| Zero                   | 7.56      | 0.48 | 7.67  | 3.19 | 8.28 | 2.34 | 1.42 | 0.19 |
|                        | 3.46      | 0.19 | 3.59  | 1.49 | 3.22 | 0.91 | 0.52 | 0.07 |
|                        | 8.75      | 0.75 | 6.88  | 2.64 | 6.62 | 1.78 | 0.90 | 0.07 |
|                        | 4.00      | 0.30 | 3.22  | 1.24 | 2.58 | 0.69 | 0.33 | 0.03 |
| P-value                | 0.95      | 0.002b | 0.99  | 0.90 | 0.21 | 0.63 | 0.61 | 0.81 |

Table 3. Air-dry plant matter stocks, t/ha¹ (numerator) and carbon stocks in plant matter tf/ha¹ (denominator) in corn agrocoenosis.
a plant matter stocks are shown immediately before harvesting the green mass of maize.
b differences are statistically significant.

Analysis of the data on the effect of cultivation technology on plant matter stocks shows statistically significant (p <0.05) differences only in stocks of the above-ground mortmass, the power of influence in this case was 98%. The stock of plant residues on soil surface by the minimum tillage with a disc header increased 1.4 times, and by the zero tillage - 2.1 times, compared with the moldboard cultivation. The phytomass, roots, and underground mortmass reserves had no significant effect over the two years of using resource-saving technologies. However, during this time, there was a trend to increase the large mortmass reserves in the soil layer of 0-20 cm by the minimal tillage and direct sowing without tillage.

The remains of mortmass and roots formed a carbon pool in soil organic matter (table 4). The humus carbon reserves in agrochernozem averaged 77 t/ha\(^1\) in a layer of 0–20 cm, which corresponds to a high humus content of 8.3%. Spatial variation of humous carbon in the top layer of soil is low; with depth it becomes average and ranges from 10 to 21%, respectively. The increase in the variability of the humus content on the depth of 20-40 cm is due to the arable land of deep types of agrochernozem. However, the results of the analysis indicate the absence of statistically significant differences in humus reserves on the depth of 0–20 and 20–40 cm. The tillage technology also did not have a significant effect on humus reserves. This confirms the fact that humus to a greater extent consists of compounds that are strongly associated with the mineral part of the soil and are weakly biodegradable [8, 9]. In the studied agrochernozem, the proportion of carbon in the humus of stable forms (C stab. Humus) was from 73 to 86%, which is consistent with the data of other authors obtained for chernozem of different agrocoenosis in different natural zones [10, 11, 12, 13, 14].

The easily mineralized part of the soil organic matter is represented by volatile organic compounds (VOC) and mobile organic matter (MOM). VOC mainly consists of small mortmass <0.5 mm [13], and MOM is a part of the newly formed humus. The compounds of C\(_{\text{MOM}}\) are represented by weakly condensed organic molecules located on the periphery of the humus nucleus and easily passing into a soluble state [8]. The composition of C\(_{\text{MOM}}\) contains carbon in newly formed humic and fulvic acids, extracted by a solution of weak alkali, as well as carbon in water-soluble organic matter, which includes organic compounds of individual nature and part of fulvic acids [15].

Table 4. The structure of carbon stocks in organic matter of agrochernozem while the cultivation of maize after the preceding grain crop, t/ha\(^1\).

| Cultivation technology | C of humus | C\(_{\text{MOM}}\) | C\(_{\text{VOC}}\) | C\(_{\text{fa}}\)/C\(_{\text{fa}}\) | C\(_{\text{stab}}\) to C of humus, % | C\(_{\text{fa}}\) to C of humus, % | C of stab humus to C of humus, % |
|------------------------|------------|-----------------|-----------------|-----------------|-------------------------------|-------------------------------|-------------------------------|
| Moldboard              | 75.90      | 4.17            | 3.93            | 0.37            | 1.06                          | 11.16                         | 0.37                          | 85.30                        |
| Minimum                | 84.60      | 4.54            | 4.87            | 0.43            | 0.93                          | 11.63                         | 0.05                          | 86.25                        |
| Zero                   | 84.25      | 6.86            | 5.18            | 0.59            | 1.32                          | 14.99                         | 0.62                          | 82.21                        |
|                        | 79.80      | 8.36            | 2.60            | 0.58            | 3.21                          | 14.46                         | 0.09                          | 81.88                        |
|                        | 70.85      | 7.58            | 5.16            | 0.65            | 1.47                          | 18.90                         | 0.47                          | 73.33                        |
|                        | 79.48      | 6.37            | 4.01            | 0.65            | 1.58                          | 13.88                         | 0.04                          | 82.54                        |
| P – value for the index «depth» | 0.43 | 0.80 | 0.46 | 0.62 | 0.43 | 0.42 | 0.02** | 0.39 |
| P – value for the index «technology» | 0.53 | 0.02** | 0.89 | 0.001** | 0.43 | 0.04** | 0.33 | 0.30 |

\(^{a}\) in the numerator - for the soil layer 0-20 cm, in the denominator - for the soil layer 20-40 cm. 
\(^{b}\) differences are statistically significant.

The C\(_{\text{VOC}}\) stocks in agrochernozem had no significant effect on the tillage technology. However, the C\(_{\text{VOC}}\) stocks reliably decreased by a factor of 7–11 on the depth of 20-40 cm, which is mainly due to the surface flow of plant residues into the soil due to stubble and roots of the preceding grain crops. The
proportion of carbon reserves in mobile humus in the studied agrochernozem ranged from 11.2 to 18.9% and increased with help of technologies while minimization of soil tillage 1.4 times. Such an increase in $C_{MOM}$ reserves was due to newly-formed humic acids, whose carbon reserves in the soil varied from 4.2 to 8.4 tf/ha$^1$, the coefficient of variation was average and amounted to 24 - 28%. The $C_{fa}$ stocks in the soil were significantly affected by the tillage technology, with a power of 44%. The $C_{fa}$ stocks did not change significantly with depth, except for the tillage with a disc header, where the prevalence of humic acids and the humate type of newly formed humus was found. Thus, in maize cultivation, minimizing the tillage enhances the formation of carbon in humic acid and contributes to shifting the $C_{fa}/C_{fa}$ ratio in the newly formed humus to broader values. In general, the newly formed humus was characterized by a fulvate-humate type. The carbon stocks in newly formed fulvic acids varied from 2.6 to 5.2 tf/ha$^1$ and had high variability (up to 4%) both in depth and in the variants of the technologies used, each of these factors and their interaction did not have a significant effect on the volatility of the $C_{fa}$ stocks. It is likely that the high variability of the $C_{fa}$ stocks in soil is associated with spatial variability and depends on a number of other factors. Stocks of $C_{H2O}$ in soil also had a fairly high variability (up to 46%), but in this case it was due to the technology of tillage, the power of influence was 69%. Thus, the carbon reserves in water-soluble chemical agents while minimizing tillage increased 1.5 - 1.6 times.

4. Conclusion

Agrochernozem of the Krasnoyarsk forest-steppe in maize crops cultivated on plowing and resource-saving technologies are characterized by a favorable agrophysical state — satisfactory moisture supply, fluffy and normal consistency. Resource-saving technologies of basic cultivation determined a tendency of moisture accumulation by 2-5 mm on the depth of 20-40 cm, differentiation of a 0-40 cm layer by the bulk density (0.08-0.11 g/cc) and an increase in the parameter by 0.05-0.08 g/cc, while maintaining the optimal value for the cultivated crop. The maximum carbon stock in plant matter was formed at the time of harvesting the maize green mass. In the upper 0–20 cm soil layer, there were 70% of the carbon stocks in roots, 79% of the carbon stocks in large mormass, and 89% of the carbon stocks in small mormass. Minimizing tillage in the maize cultivation after the preceding grain crop did not affect the total carbon reserves in soil humus and the stocks of newly formed fulvic acids, but contributed to the replenishment at 1.4-1.5 times the newly formed humic acids and water-soluble humus.

References

[1] Shabaev A I, Zholinskii N M, Azizov N M and Sokolov N M 2007 Resource-saving soil-protective tillage in agricultural landscapes of the Volga region Agriculture 1 20-2
[2] Smirnov B A 2009 The technology of moldboard tillage of sod-podzolic soil Agriculture 5 25-7
[3] Vadyunina A F and Korchangina Z A 1986 Methods for studying the physical properties of soil (Moscow: Agropromizdat) p 416
[4] Arinushkina E V 1970 Soil chemical analysis guide (Moscow: Moscow State University Press) p 487
[5] Chuprova V V and Erokhina N L 1999 Database on the bulk density of soil in the agricultural territory of the Krasnoyarsk region Bull. of the Krasnoyarsk State Agrarian University 5 84-92
[6] Nemchenko V V 2011 Plant protection system in resource-saving technologies (Kurtamysh) p 525
[7] Yushkevich L V 2012 Long-term use of straw and the effectiveness of tillage techniques in dry farming of Western Siberia Improving the efficiency of soil protecting resource-saving farming systems (Omsk) 40-50
[8] Semyonov V M and Kogut B M 2015 Soil organic matter (Moscow: GEOS) p 233
[9] Chuprova V V 2017 Stocks, texture and transformation of organic matter in soils of Central Siberia Bull. of the Docuchaevo Soil Institute 90 97-116
[10] Kogut B M, Sysuev S A and Kholodov V A 2012 Water resistance and labile humus substances of typical chernozem with different land use Soil science 5 555-61
[11] Semyonov V M and Tulina A S 2011 Comparative characteristics of the mineralized pool of organic matter in soils of natural and agricultural ecosystems Agrochemistry 12 53-63
[12] Vlasenko O A 2015 The dynamics of carbon in mobile humus of agrochernozem while cultivating of spring wheat using resource-saving technologies Bull. of the Krasnoyarsk State Agrarian University 9 60-7
[13] Titlyanova A A and Chuprova V V 2003 The change in carbon cycle due to various land use (on the example of Krasnoyarsk region) Soil science 2 211-19
[14] Sanderman J, Baldock J A and Amundson R 2008 Dissolved organic carbon chemistry and dynamics in contrasting forest and grassland soils Biogeochemistry US.89 181-98
[15] Chuprova V V 2013 The dynamics of carbon in mobile humus of agrochernozem while cultivating of spring Mineralized pool of organic matter in agrochernozem of the south of Central Siberia Bull. of the Krasnoyarsk State Agrarian University 9 83-9