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## AGROCHEMISTRY. PEDOLOGY

# Significance of Individual Components of Organic Matter in the Formation of the Water-Stable Structure of Light Gray Forest Soils of the Northern Forest Steppe

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**Abstract**—The effect of humus, readily decomposable organic matter, and carbohydrates of a nonspecific nature on the formation of water-stable aggregates in field rotation members has been studied. It has been established that the degree of effect of organic matter on aggregation of particles is determined by the character of use of the plots and crop being grown.

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The leading role of humus in soil structure formation has been pointed out repeatedly by many researchers [1–5]; however, there is virtually no comprehensive assessment of the effect of specific organic substances and compounds of an individual nature on the formation of water-stable aggregates. Under conditions of field crop rotations, structure formation depends not only on the properties of the soils (humus content and

**Table 1.** Content of organic matter components in water-stable aggregates

| Variant | Organic matter components | Content in soil, % | Content (%) in aggregates with size (mm) | | | | |
|---|---|---|---|---|---|---|---|
| | | | >3 | 3–1 | 1–0.5 | 0.5–0.25 | <0.25 |
| 1 | Humus | 1.30 | 2.20 | 1.70 | 1.10 | 0.50 | 1.30 |
| | RDOM | 1.26 | 2.39 | 1.04 | 1.26 | 0.92 | 1.06 |
| | Carbohydrates | 0.36 | 0.92 | 0.77 | 0.61 | 0.30 | 0.58 |
| 2 | Humus | 1.80 | 1.80 | 1.50 | 0.80 | 0.70 | 0.80 |
| | RDOM | 0.98 | 2.17 | 1.52 | 1.24 | 1.03 | 0.78 |
| | Carbohydrates | 0.34 | 0.85 | 0.53 | 0.47 | 0.45 | 0.34 |
| 3 | Humus | 1.70 | 1.80 | 1.70 | 1.00 | 0.90 | 0.90 |
| | RDOM | 1.09 | 2.68 | 1.87 | 0.62 | 1.65 | 0.77 |
| | Carbohydrates | 0.33 | 0.72 | 0.59 | 0.50 | 0.34 | 0.48 |
| 4 | Humus | 2.20 | 2.70 | 1.70 | 0.70 | 0.90 | 1.00 |
| | RDOM | 1.08 | 1.74 | 1.59 | 1.58 | 1.70 | 0.61 |
| | Carbohydrates | 0.36 | 0.87 | 0.73 | 0.44 | 0.26 | 0.46 |
| 5 | Humus | 1.80 | 2.10 | 1.60 | 1.20 | 1.20 | 1.20 |
| | RDOM | 1.03 | 1.14 | 1.20 | 1.00 | 0.85 | 1.03 |
| | Carbohydrates | 0.46 | 0.45 | 0.39 | 0.31 | 0.20 | 0.23 |
| 6 | Humus | 2.20 | 2.50 | 1.70 | 1.20 | 0.90 | 1.00 |
| | RDOM | 1.28 | 1.50 | 1.61 | 1.05 | 1.01 | 1.28 |
| | Carbohydrates | 0.55 | 0.68 | 0.58 | 0.38 | 0.23 | 0.37 |
| $LCD_{05}$ | Humus | 0.40 | 0.90 | 0.70 | 0.40 | 0.30 | 0.20 |
| | RDOM | 0.28 | 0.13 | 0.21 | 0.44 | 0.35 | 0.28 |
| | Carbohydrates | 0.10 | 0.27 | 0.27 | 0.13 | 0.13 | 0.13 |

**Table 2.** Regression analysis of effect of organic matter components on formation of water-stable structure

| Aggregate size, mm | Regression equation | | | | | | | $R$ | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|
| Variant 1 | | | | | | | | | |
| >3 | Y = | 10.934 | + | 2.178 (humus) | – | 1.322 (RDOM) | + 1.242 (carbohydrates) | 0.54 | 0.30 |
| | β = | | | 0.496 | | –0.258 | 0.899 | | |
| 3–1 | Y = | 17.410 | – | 6.700 (humus) | – | 5.257 (RDOM) | + 1.477 (carbohydrates) | 0.95 | 0.90 |
| | β = | | | –1.331 | | –1.228 | 0.606 | | |
| 1–0.5 | Y = | 11.897 | + | 5.441 (humus) | – | 11.256 (RDOM) | + 29.700 (carbohydrates) | 0.79 | 0.63 |
| | β = | | | 0.395 | | –0.332 | 1.071 | | |
| 0.5–0.25 | Y = | 66.366 | + | 11.107 (humus) | – | 38.955 (RDOM) | – 27.465 (carbohydrates) | 0.98 | 0.97 |
| | β = | | | 0.362 | | –1.341 | –0.476 | | |
| <0.25 | Y = | 83.870 | – | 3.995 (humus) | – | 5.799 (RDOM) | – 57.512 (carbohydrates) | 0.89 | 0.79 |
| | β = | | | –0.147 | | 0.286 | –1.131 | | |
| Variant 2 | | | | | | | | | |
| >3 | Y = | –23.400 | + | 0.140 (humus) | + | 10.596 (RDOM) | + 1.897 (carbohydrates) | 0.76 | 0.58 |
| | β = | | | 0.182 | | 0.361 | 0.492 | | |
| 3–1 | Y = | –4.905 | + | 0.109 (humus) | + | 0.170 (RDOM) | + 14.688 (carbohydrates) | 0.98 | 0.97 |
| | β = | | | 0.109 | | 0.032 | 0.933 | | |
| 1–0.5 | Y = | –2.178 | + | 7.100 (humus) | – | 8.062 (RDOM) | + 21.770 (carbohydrates) | 0.93 | 0.86 |
| | β = | | | 0.862 | | –0.688 | 0.440 | | |
| 0.5–0.25 | Y = | 53.494 | – | 115.600 (humus) | + | 32.335 (RDOM) | – 0.637 (carbohydrates) | 0.93 | 0.87 |
| | β = | | | –0.464 | | 1.188 | –0.011 | | |
| <0.25 | Y = | 83.983 | – | 0.653 (humus) | – | 24.610 (RDOM) | + 0.189 (carbohydrates) | 0.79 | 0.63 |
| | β = | | | –0.032 | | 0.772 | 0.002 | | |
| Variant 3 | | | | | | | | | |
| >3 | Y = | –5.805 | + | 20.186 (humus) | – | 10.779 (RDOM) | + 0.940 (carbohydrates) | 0.99 | 0.99 |
| | β = | | | 2.415 | | –3.000 | 0.248 | | |
| 3–1 | Y = | 361.677 | – | 9.550 (humus) | – | 188.324 (RDOM) | + 18.732 (carbohydrates) | 0.93 | 0.87 |
| | β = | | | –6.773 | | –4.814 | 6.411 | | |
| 1–0.5 | Y = | 11.983 | + | 2.271 (humus) | + | 5.237 (RDOM) | – 12.437 (carbohydrates) | 0.99 | 0.99 |
| | β = | | | 0.515 | | 0.601 | –1.250 | | |
| 0.5–0.25 | Y = | 11.277 | + | 0.925 (humus) | – | 1.051 (RDOM) | + 32.494 (carbohydrates) | 0.99 | 0.99 |
| | β = | | | 0.141 | | –0.167 | 0.961 | | |
| <0.25 | Y = | 76.820 | – | 33.388 (humus) | – | 20.730 (RDOM) | + 61.057 (carbohydrates) | 0.99 | 0.99 |
| | β = | | | –1.338 | | –0.797 | 1.698 | | |
| Variant 4 | | | | | | | | | |
| >3 | Y = | 9.804 | + | 0.328 (humus) | – | 3.585 (RDOM) | – 2.403 (carbohydrates) | 0.99 | 0.99 |
| | β = | | | 0.863 | | –0.392 | –0.582 | | |
| 3–1 | Y = | 2.659 | – | 2.233 (humus) | – | 1.174 (RDOM) | + 10.981 (carbohydrates) | 0.99 | 0.99 |
| | β = | | | –1.242 | | –0.069 | 0.248 | | |
| 1–0.5 | Y = | 25.933 | + | 0.890 (humus) | – | 17.683 (RDOM) | + 28.921 (carbohydrates) | 0.99 | 0.99 |
| | β = | | | 0.105 | | –0.859 | 0.855 | | |
| 0.5–0.25 | Y = | 1063.825 | – | 19.368 (humus) | – | 602.087 (RDOM) | – 8.679 (carbohydrates) | 0.99 | 0.99 |
| | β = | | | –1.625 | | –1.957 | –0.326 | | |
| <0.25 | Y = | 90.861 | + | 19.033 (humus) | – | 66.952 (RDOM) | – 19.100 (carbohydrates) | 1.00 | 1.00 |
| | β = | | | 0.632 | | –0.902 | –0.737 | | |

**Table 2.** (Contd.)

| Aggregate size, mm | Regression equation | | | | | | | R | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|
| Variant 5 | | | | | | | | | |
| >3 | Y = | –5.036 | + | 0.246 (humus) | + | 3.517 (RDOM) | + 6.392 (carbohydrates) | 0.99 | 0.99 |
| | β = | | | 0.136 | | 1.114 | 1.393 | | |
| 3–1 | Y = | 5.927 | – | 0.765 (humus) | – | 1.119 (RDOM) | + 4.069 (carbohydrates) | 0.99 | 0.98 |
| | β = | | | –0.181 | | –0.335 | 0.893 | | |
| 1–0.5 | Y = | 1.329 | + | 7.539 (humus) | + | 0.925 (RDOM) | – 0.037 (carbohydrates) | 0.96 | 0.93 |
| | β = | | | 0.968 | | 0.081 | –0.037 | | |
| 0.5–0.25 | Y = | –8.332 | + | 11.583 (humus) | + | 12.084 (RDOM) | + 19.719 (carbohydrates) | 0.97 | 0.95 |
| | β = | | | 0.814 | | 0.922 | 0.600 | | |
| <0.25 | Y = | 56.061 | + | 8.686 (humus) | – | 7.979 (RDOM) | – 0.049 (carbohydrates) | 1.00 | 1.00 |
| | β = | | | 0.249 | | –0.855 | –0.002 | | |
| Variant 6 | | | | | | | | | |
| >3 | Y = | 1.539 | + | 1.434 (humus) | + | 0.410 (RDOM) | – 0.747 (carbohydrates) | 0.70 | 0.49 |
| | β = | | | 0.514 | | 0.055 | –0.251 | | |
| 3–1 | Y = | 5.317 | + | 0.864 (humus) | + | 0.280 (RDOM) | + 0.175 (carbohydrates) | 0.98 | 0.95 |
| | β = | | | 1.180 | | 0.183 | 0.134 | | |
| 1–0.5 | Y = | 16.748 | – | 0.670 (humus) | + | 0.122 (RDOM) | – 0.925 (carbohydrates) | 0.62 | 0.39 |
| | β = | | | –0.387 | | 0.255 | –0.489 | | |
| 0.5–0.25 | Y = | 14.217 | – | 9.333 (humus) | + | 16.565 (RDOM) | + 7.770 (carbohydrates) | 0.94 | 0.89 |
| | β = | | | –3.012 | | 3.237 | 1.662 | | |
| <0.25 | Y = | 44.780 | – | 2.483 (humus) | + | 5.537 (RDOM) | – 3.148 (carbohydrates) | 0.81 | 0.65 |
| | β = | | | –0.313 | | 0.675 | –0.327 | | |

composition, content of clay fraction, composition of soil absorption complex) but also of the crops being grown and farming practices being employed. The purposes of the present work were to analyze the content and composition of organic matter in fractions of water-stable aggregates and to determine the degree of effect of each component on aggregation of soil particles.

## METHODS

The objects of investigation were light gray sandy loam forest soils (silt and clay content 27.0–29.6%) formed on loesslike loams in the right-bank region of the Nizhni Novgorod oblast. Soil samples were taken in 1998–2000. Six plots of a field crop rotation in the land-use territory of the OAO Kud'minskaya Poultry Plant were selected for study: (1) clean fallow with application of poultry manure (200 t/ha) in a liquid form with a 32% dry matter content, (2) winter wheat after fallow with poultry manure, (3) fourth-year perennial grass, (4) vetch–oat mixture, (5) first-year Caucasian goat's rue, and (6) eleventh-year Caucasian goat's rue. One main cross section and 4–5 half-pits were laid out on each plot. Laboratory analyses were carried out of the structural composition of humus by N.I. Savinov's method and of the content of humus by I.V. Tyurin's method as modified by Nikitin [6], soil carbohydrates by the Dubois phenol-sulfuric acid method [7], and readily decomposable organic matter (RDOM), detritus, by the method of flotation in a gravity solution [8]. The data were processed by means of correlation and regression analyses with the use of the MS Excel computer program and with additional determination of the standardized regression coefficient (β), showing the degree and direction of the effect of variation of factor $x_i$ on variation of the resulting feature $y$.

## RESULTS AND DISCUSSION

To study the effect of organic matter components on stability of the soil structure to the eroding action of water, we determined their content in soil and water-stable aggregates of different size (Table 1). The largest humus content was noted in fraction >3 mm, it decreased with decreasing size regardless of the variants and crop being grown. For the most part the content of detritus in water-stable aggregates was higher than in soil and was more in large fractions, which is explained by its structure-forming role. First, detritus provides soil with nonspecific organic matter, which is indicated by its increase in soil as a whole with a simultaneous increase of the content of water-stable aggregates after applying poultry manure (plot 1) and decrease in the aftereffect year (plot 2). Second, RDOM in aggregates is a residual product of the plant root systems; therefore, a lower water stability of aggregates was observed in soils of plots with perennial gramineous grasses and vetch–oat mixture (unlike Caucasian goat's rue), despite the high detritus content. Accordingly, there is a greater content of plant roots per unit mass of aggregates in aggregates forming under the effect of annual and perennial gramineous grasses with a fibrous root system, which determines RDOM.

The content of soil carbohydrates was higher in water-stable aggregates than in soil as a whole, especially in variants with poultry manure and its aftereffect, as well as under fourth-year perennial grasses. The significance of carbohydrates in aggregation of soil particles is explained, probably, by the formation of "protoaggregates" (during sticking together of mechanical elements), which, becoming saturated with carbohydrates, enlarge and acquire stability. The decrease in content of carbohydrate components with decreasing fraction size of the aggregates is because the formation of large aggregates requires a greater number of mechanical particles and, accordingly, adhesive material for their sticking together into firm water-stable aggregates, represented, along with humus, by polysaccharides and other carbohydrate components [9]. Furthermore, large soil aggregates contain more micropores in which carbohydrates can survive longer, not being subjected to microbial decomposition.

Organic matter components jointly affect the formation of agronomically valuable aggregates, which is indicated by the close positive relation between total organic matter content and quantity of aggregates ($R$ = 0.79–0.99; $R^2$ = 0.63–0.99).

To determine the proportion of the effect of each organic matter component in the formation of water-stable aggregates, we used regression analysis of their content in fractions differing in size (Table 2). The multiple correlation results confirm conclusions about the great significance of RDOM and carbohydrates in creating in light gray forest soils a water-stable structure of the agronomically most valuable fractions, especially in variants with the application of poultry manure (in the year of effect and aftereffect) and under annual grasses. In accordance with the value of the $\beta$ coefficient, the role of humus is ambiguous under various crops, which is probably related to the quantity and quality of plant residues entering the soil and farming practices being used, but increases under fourth-year perennial grasses and eleventh-year Caucasian goat's rue.

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