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The influence of agroforestry on Chernozems: a case study of the Central Russian Upland

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The influence of agroforestry on Chernozems: a case study of the Central Russian Upland

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Abstract. Agroforestry is an essential tool for improving soil fertility and sustainable land use. We aimed to reveal the role of the old-growth shelterbelt in changing the basic Chernozem properties under the shelterbelt and at 10, 30, and 60 m distance from its edges (the south of the Central Russian Upland, Belgorod region). Our database includes organic carbon content, storage, and group composition, total nitrogen, exchangeable magnesium and calcium, the soil - water extract composition, and pH from different soil layers up to 3m. We detected the increase in humus horizon thickness, soil organic carbon content and storage, total nitrogen, exchangeable magnesium, acidification, and lowering the effervescence line in shelterbelt soil in comparison to arable ones. Agroforestry leads to the soil transformation - the shelterbelt soils differ from arable at subtype taxonomic level, and the influence of shelterbelts on adjacent arable soils can be traced up to 60 meters distant.

1. Introduction
Shelterbelts improve soil quality; they support sustainable land use and ecosystem health [1-2]. The old-growth shelterbelts functioning has a beneficial effect on chernozems properties: the humus content increases, the diversity of soil biota and the soil moisture improves [3–9]. The influence of shelterbelts on soil properties changes with distance from their edges. However, data on the rate and direction of these changes is limited and it varies for different soil properties [9–13]. The aim of our study is to reveal the role of the old-growth shelterbelt in changing the basic chernozem properties under the shelterbelt and at different distances from its edges. Our study area is located in the south of the Central Russian Upland. We investigated the morphological, chemical, physicochemical, and physical soils properties.

2. Materials and Methods
The study site "Bondarev", is located in Krasnoyaruzhsky district (Belgorod region) at a flat interfluve. The shelterbelt is latitude-oriented, it has 12 double rows of 60 – years old trees: Fraxinus excelsior, Ulmus minor, and Acer negundo. The climate is temperate continental, the mean annual precipitation is 600 mm, and the mean annual air temperature is +6.5°C. Parent material is loess-like loams. The soils are typical chernozems (Haplic Chernozem) on arable fields and leached chernozem (Greyzemic Chernozem) under shelterbelt.

We investigated soils under the shelterbelt and at 10, 30, and 60 meters from its edges to both sites in deep soil peats (up to 3 meters) to reveal the influence of the shelterbelt on soils. We tested such a methodological approach in our early studies conducted in the south of the Central Russian Upland and on the Great Plains of the USA [14, 15].

Our database included organic carbon content, storage, and group composition, the humus horizon (A+ AB horizon) thickness, depth of effervescence line, the content of the CO_2 of carbonates, total nitrogen, exchangeable magnesium, and calcium, the soil-water extract composition, and pH. Soil samples were analyzed in the certified laboratory of the Federal State Budgetary Institution Belgorodsky Center of Agrochemical Service by standard methods. The group composition of humus was analyzed by the pyrophosphate method [16], and the bulk density was determined using standard steel rings [17]. Mathematical and statistical processing was carried out by standard methods [18].

3. Results and Discussion

We identified the changes and trends in humus horizon thickness and depth of effervescence line in forest-steppe soils in the south of the Central Russian Upland (Table 1).

Table 1. Morphological soil properties of soils of the Bondarev key site.

Distance from the shelterbelt	n	Lim	$\bar{x}$ ±t05s $\bar{x}$ / t01s $\bar{x}$	δ	V, %
The humus horizon thickness (A1+A1B), cm					
under the shelterbelt	30	72-91	82.8±2.1/2.8	5.49	6.6
10 meters	30	59-78	67.1±1.8/2.5	4.70	7.0
30 meters	30	62-80	69.4±1.8/2.5	4.72	6.8
60 meters	30	51-82	69.4±2.3/3.0	6.16	8.9
The depth of effervescence line, cm					
under the shelterbelt	15	93-116	106.3±3.9/5.4	7.09	6.7
10 meters	30	37-70	54.9±3.7/5.0	10.11	18.4
30 meters	30	54-95	68.7±4.3/5.8	11.70	17.0
60 meters	30	32-61	43.5±2.8/3.9	7.60	17.5

The humus horizon thickness decreases from the shelterbelt to the arable lands: it is 13.4 cm shorter in the soil at a 60 - m distance than at the shelterbelt (LSD0.5=3.0, LSD0.1=4.0). The effervescence line is deeper in soil under the tree vegetation than in arable; for example, it is 62.8 cm (LSD0.5=4.6, LSD0.1=6.1) closer to the surface in the soil at a 60-m distance than in soil under the shelterbelt. All this difference is statistically significant. Thus, the soils of the studied site are typical chernozem (Haplic Chernozem) in arable lands and leached chernozem (Greyzemic Chernozem) under the shelterbelt according to their humus horizon thickness and the effervescence line depth – which are the main criteria of chernozems subtypes in USSR soil classification system [19]. We considered that the growth of tree vegetation for 60 years leads to the transformation of chernozems at the subtype level.

Organic carbon content and storage are higher in the soil of the shelterbelt in comparison with adjacent arable soils: both within the entire profile and at the same depths (Fig. 1).

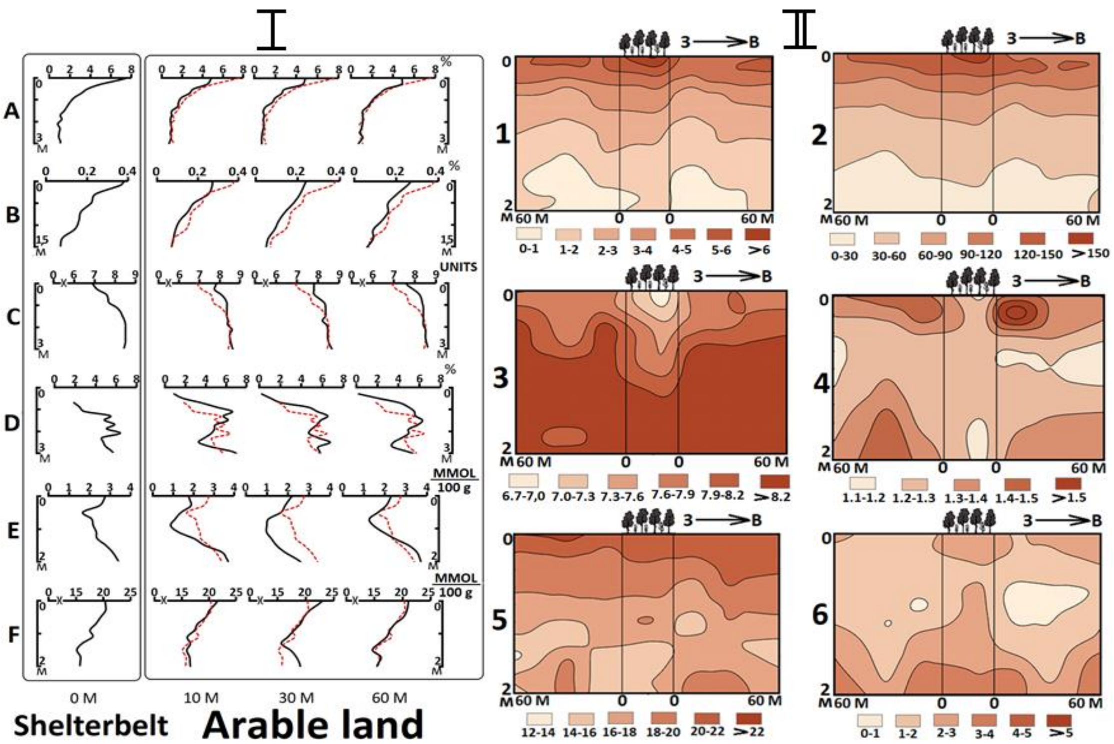

Figure 1. Soil properties of chernozems at the key site "Bondarev" in graphs (I) and maps (II): A - humus, %; B—total nitrogen, %; C – actual acidity; D – ccontent of the CO_2 of carbonates , %; E – exchangeable magnesium, mmol/100 g; F is exchangeable calcium, mmol/100 g; 1 – humus content, %; 2 – humus storage, t/ha; 3 – actual acidity; 4 – soil density g/cm3; 5 – exchangeable calcium mmol/100 g; 6 - exchangeable magnesium mmol / 100 g. The dotted line - the properties of soil under the shelterbelt.

This difference is most explicit in the upper part (0-40 cm) of the soil profile. Soil under the tree vegetation is characterized by higher organic carbon content than arable soils to a depth of 180-200 cm; in deeper layers, the differences are reduced. On average, the humus content in the soil under the shelterbelt is higher than in the adjacent areas of arable lands in the layers of 0–40 (by 1.16 %), 40–60 (by 0.61 %), and 60–100 cm (by 0.40%). In meter layers: 0–100 cm, 100–200 cm, and 200–300 cm, the differences are 0.75, 0.28, and 0.11%, respectively. The humus storage in the 0–40 cm layer in shelterbelt soil is higher by 2.9 kg/m^2 than in adjacent arable lands. At the same time, we indicate a decrease in humus storage in deeper soil layers under the shelterbelt (1.4 kg/m^2 in the 40-60 cm layer, 1.1 kg/m^2 in the 60-100 cm layer, and 0.5 kg/m^2 in the 100-200 cm layer). However, the total organic carbon storage in the 0 – 3m layer is higher in chernozems under the tree vegetation than in the adjacent arable soils; we suppose that less storage in arable soils is due to (1) less favorable moisture and temperature regime for the organic carbon accumulation and (2) the annual alienation of organic matter from harvest in arable soils. We indicate higher concentrations of fulvic acids and humin in shelterbelt soil than in arable ones (Fig. 1, Table 2) due to litter features - different content of hard-to-decompose components in tree and grass residues. The ratio of humic to fulvic acid (C_{HA}:C_{FA}) is lower under the shelterbelt than in arable soils (in 20-40 cm layer) due to vegetation and pedoclimate features.

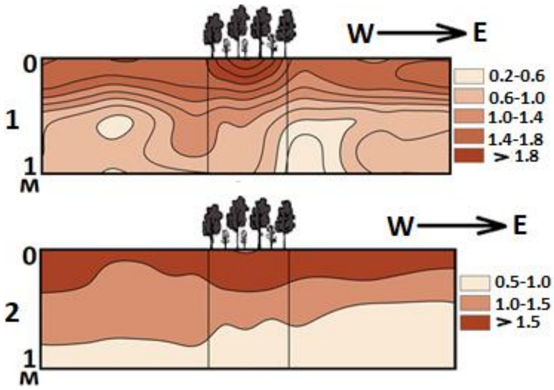

Figure 2. Humus features of soils:1 – C humin, %, 2 – the ratio of humic to fulvic acids.

Table 2. The group composition of humus in chernozems under shelterbelt and arable lands.

Depth, cm	soil under the shelterbelt			arable soils		
	C_{humin} %	C_{FA}, %	C_{HA}:C_{FA}	C_{humin}, %	C_{FA}, %	C_{HA}:C_{FA}
0-20	2.40	0.61	1.49	1.54	0.46	1.71
20-40	1.69	0.43	1.67	1.49	0.47	1.47
40-60	1.08	0.51	1.12	0.80	0.48	1.13
60-80	0.95	0.44	0.97	0.79	0.41	0.92
80-100	0.83	0.32	0.80	0.67	0.30	0.72

The nitrogen distributions in soil profiles are the same as that of organic matter due to the correlation of nitrogen and humus content: the coefficient of determination between these parameters was 0.96 in shelterbelt soil and 0.99 in arable soils.

The trees have an acidifying effect on the soil when compared with arable soils of adjacent fields. We detected the acidification effect on soils to a depth of 1.5 meters; in the 1-meter layer of shelterbelt soil, acidification reaches 0.69 pH in comparison to the arable ones.

Soils under tree vegetation is enriched by exchangeable magnesium and depleted by exchangeable calcium. The topsoil density is more than 0.16 g/cm3 in 0 – 40 cm layer in arable soils than in shelterbelt (due to agricultural machinery) and by 0.13 g/cm3 in deeper soil layers 120–200 cm (due to higher carbonate content in arable soils and tree roots loosening in soils under shelterbelt).

The content of coarse sand (1–0.25 mm) and medium dust (0.01–0.005 mm) is higher in shelterbelt topsoil than in arable ones, but the content of fine sand (0.25-0.05 mm) and fine dust (0.005-0.001 mm) is higher in the topsoil of arable lands. The share of 0.001- 0.005 mm texture class in physical clay increases in arable soils, but in shelterbelt, the share of 0.005-0.01 mm texture class increases according to the correlation coefficient between the texture classes (Table 3). We explain this feature by the lessivage intensification in soils under tree vegetation.

Table 3. The value of the correlation coefficient (R) between the particle size distributions in soils.

Correlated texture classes (class 1 / class 2)	Soil of shelterbelt	Soils of arable lands
0.001 - 0.005 mm/ 0.0001 – 0.001 mm	+0.58	+0.79
0.005 – 0. 01 mm / 0.001 - 0.005 mm	-0.76	-0.34
0.005 – 0. 01 mm /0.0001 – 0.001 mm	-0.55	+0.02
0.005 – 0. 01 mm / < 0.005 mm	-0.55	-0.01
0.001 - 0.005 mm / < 0.005 mm	+0.72	+0.87
0.0001 – 0.001 mm / < 0.005 mm	+0.97	+0.98

Chloride ions predominate in the composition of the soil water extract ($Cl^- / SO_4^{+2} > 2$). The solid residue of the soil water extract is less than 0.15 % in arable soils and in the soil under the tree vegetation over the entire profiles; thus the soils are not saline. We detect a significant change in the content of the bicarbonate and carbonate ions in soils - the content of these anions is higher in arable soils than under the shelterbelt. The content of the bicarbonate ion in soils (at all depths) decreases and the carbonate ion (at 80-140 cm depth) increases with distance from the shelterbelt edges. However, we indicate a higher sulfate ion concentration in deep soil layers (100-200 cm, 200-300 cm) in soil under the tree vegetation in comparison with arable soils. The content of calcium and magnesium ions is strongly contrasting in the soils of the shelterbelt and arable lands: arable soils are characterized by higher concentrations. We detect the accumulation of sodium ion content in the 100-200 cm layer under the shelterbelt and in the area of arable lands close to it (10 meters away), and farther the content of sodium ion decreases with distance.

4. Conclusions

In our study, we identified the changes in properties of chernozems, formed under a 60-year-old shelterbelt and at a distance of 10, 30, and 60 m from its edges. We detected the increase in humus horizon thickness, soil organic carbon content and storage, total nitrogen, exchangeable magnesium, coarse sand (1–0.25 mm) and medium dust (0.01–0.005 mm), acidification, and lowering of the effervescence line in soil under the tree vegetation in comparison to arable ones. Thus, the soils of shelterbelt transform into leached chernozems, while soils on adjacent arable lands remain typical chernozems. The spatial influence of shelterbelt on adjacent arable lands can be traced up to 60 meters, and especially affects the humus features of soils. We do not detect the salt accumulations in the shelterbelt soil, however, we revealed the increase in sulfate and sodium ions concentration in deep soil layers (more than 100 cm) under the shelterbelt, which can be interpreted as the initial stages of salt uplift due to tree root water uptake.

Acknowledgements

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