

Assessment of the Effect of Sunflower Agroecosystem on the Characteristics of the Structural and Aggregate Composition of Typical Black Soil

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ABSTRACT

The research was conducted on the Bila Tserkva National Agrarian University experimental field on a typical deep, low-humus chernozem. The methods of main cultivation in the sunflower agroecosystem of grain-row crop rotation had a major influence on the soil structuring processes. The use of moldboard and no-moldboard tillage increased the number of the most agronomically beneficial aggregates (0.25–10 mm) in the 0–10 cm soil's layer at the beginning of the sunflower growing season by 6.0% compared to shallow no-moldboard tillage of the soil. By the end of the growing season in the sunflower agroecosystem in the 0–30 cm soil layer, compared to the beginning of the crop growing season, the number of agronomically beneficial aggregates (0.25–10 mm) decreased, the number of fractions larger than 10 mm and fractions smaller than 0.25 mm increased. The coefficient of structure for moldboard and no-moldboard tillage significantly increased compared to shallow no-moldboard tillage. The use of shallow no-moldboard tillage and moldboard with no-moldboard tillage was led to an increase in the content of stable aggregates by 1.2–7.5%. The highest yield of sunflower was recorded for the use of moldboard with no-moldboard tillage – 2.72 t/ha, which is significantly higher than other variants. The use of shallow no-moldboard tillage for 10–12 cm with disc tools led to a notable decrease in productivity compared to the control. Improving the water resistance of soil aggregates during moldboard and no-moldboard tillage and shallow no-moldboard tillage helps to preserve the soil's potential fertility.

Keywords: soil's tillage, final harvest, water resistance, crop rotation, fertility, sunflower, agroecosystem, herbicides.

INTRODUCTION

Tillage has a significant influence on the productivity of agricultural crops and growing conditions are mainly used to optimize soil productivity through modification in its physical, biological and chemical capacities [Dekemati, 2019; Hryhoriv et al., 2023a].

Soil structure holds an vital role in both biological and physical processes occurring in the

soil [Gupta, 2015; Bali, 2021]. Soil aggregates, constituting a heterogeneous amalgamation of organic particles and minerals, serve as the fundamental units of soil structure [Tagar, 2020]. Their size, stability, and shape directly influence water availability and soil aeration [Six, 2002; Karbivska et al., 2023]. Biological, chemical, and physical properties of soil are closely linked to crop yield [Ziru Niu et al., 2022]. Organic carbon is a key element which determines soil

quality and its functional characteristics. It significantly contributes to the enhanced aggregation of soil particles and to aggregate structure formation [Six, 2000; Díaz-Zorita, 2002; An, 2008; Lehmann & Kleber, 2015]. Soil aggregates serve as a constant reservoir of soil's nutrients, an increase in the number of these aggregates signifies heightened nutrient storage capacity [Chivenge, 2011a; Guo et al., 2023a].

Modern agriculture is concerned with attempting to replace energy-intensive plowing with simplified tillage, aiming to diminish the number and intensity of soil loosening [Mazurenko et al., 2020; Orzech & Załuski, 2020; Hryhoriv et al., 2023b]. This approach has a protective effect on the soil, helps preserve the natural value of agroecosystems and reduce the cost of production [Tsyuk et al., 2022].

To promote sustainable agriculture, it is imperative to explore the combined effects of structural-aggregate composition, simplified tillage and crop rotation. This research is vital in developing farming systems that have the effects of maximizing harvest and minimizing soil degradation [Chivenge et al., 2011b].

The main objective of our investigation was to assess the influence of different tillage systems on the structural and aggregate composition of sunflower's fields.

MATERIAL AND METHODS

Description of the experimental plot

The research work was conducted throughout the period from 2016 to 2020 on typical deep, low-humus, medium-loam granulometric chernozem within a five-field crop rotation, located at the Bila Tserkva National Agrarian University experimental field. The regional climate is moderately continental, with an average air temperature of +20 °C. The average temperature in January is 7–8 °C, the absolute minimum is – 20.5 °C. The sum of active temperatures is 2800–3000 °C. Annual rainfall averages 500–550 mm, the majority of which occurs between April and September.

Research methods

Long-term field research was conducted in 2016–2020 in order to investigate the impact of different tillage systems in a grain-row crop

rotation on the structural and aggregate soil's composition. The crop rotation sequence was as follows: soybeans – winter wheat and white mustard, siderite – sunflower – barley – corn for grain. The research was in the sunflower agroecosis. The experiment was repeated three times, with the systematic placement of variants. Area placement for the study of tillage system was conducted in one tier. The sown area of experimental plots is 171 m², accounting – 112 m².

The experiment variants were:

1. Differentiated (control) – moldboard system of the soil in sunflower, soybeans and corn fields. Winter wheat fields went through one boardless shallow no-moldboard of tillage, barley – one chisel tillage.
2. Moldboard and no-moldboard of tillage consisted of variable-depth plowing for sunflower; of shallow boardless no-moldboard of tillage for winter wheat and of chisel tillage for barley and corn per crop rotation.
3. Shallow no-moldboard of tillage constitutes soil cultivation with disc tools to a depth of 10–12 cm for all crop of the rotation.

Primary tillage procedures employed such tools as the 3-body plow “Lemken Opal 110”, chisel subsoiler AGCh-4.2; disc harrow AG-2.1-20, combined unit Europack Bomet, cultivator Crain - 5.6.

The experiment featured diverse hybrids and varieties, including alfalfa (variety “Lidia”), winter wheat (“Svitilo”), sunflower (“Kondi NK”), sugar beet (“Vapiti”), spring barley (“Helios”), and buckwheat (“Dikul”). Post-harvest wheat straw remains were crushed and plowed into the soil with a disc harrow across all tillage variants. Following the wheat harvest, the soil was prepared for the planting of white mustard for the siderite mass. In the late September to early October period, post-harvest mustard crops were plowed into the soil in all variants. Each year, following the autumn harvest of winter wheat, manure was applied at a rate of 40 t/ha. In October, a field experiment was carried out on variants and repetitions. Herbicides were used on sunflower crops to control weeds during the spring-summer vegetation period of the crop.

Soil measurements and sampling

Soil structure measurements were carried out according to the method of Vadyunina and Korchagina [Vadyunina and Korchagina, 1986; Lys et al., 2023].

Of note, cells with sizes of 10; 7; 5; 3; 1; 0.5 and 0.25 mm were used to determine the structural-aggregate composition (dry dispersion). The “Bak-sheev” tool was also used to measure the aggregate stability (wet sieving) of the soil. Aggregate size distribution was done using the Kaczynskiy “wet sedimentation” (pipette) method, which is analogous to Bowman and Shvidky’s analysis [Bowman, et al., 2002]. The condition of the aggregate was determined by the coefficient of soil structure (Kst) (equation 1), in which a value >1.5 is considered excellent; 1.0–0.67 considered good, and 0.67 considered unsatisfactory [Vadyunina & Korchagina, 1986]. Aggregative stability was calculated based on the sum of aggregates >0.25 mm and categorized as follows: <30% is considered unsatisfactory, 30–40 as satisfactory; 40–75 as good; and >75 as extremely high (Vadyunina and Korchagina, 1986).

$$Kst = \frac{\sum(10 - 0.25)}{\sum(> 10, < 0.25)} \quad (1)$$

where: numbers are fraction sizes (mm). The sum of fractions in the numerator is from 0.25 to 10 mm; the sum of the fractions in the denominator is > 10 and < 0.25 mm.

Crop harvest

The yield of sunflower was determined in the state of technical ripeness by the method of continuous collection from the variant’s accounting with conversion to standard humidity and purity from each variant separately. The yield of sunflower seeds was calculated based on the moisture content – 11%.

Statistical analysis

Statistical analysis of our indicators was carried out according to the analysis of variance (ANOVA) for randomized complete block design (R.C.B.D), with a split-plot arrangement. The last significant difference test (L.S.D) was also employed to compare arithmetic means of treatment at a level of probability (5%).

RESULTS AND DISCUSSION

The influence of tillage on the soil structure

The best structure in the arable layer (0–30 cm) was observed in the sunflower agroecosystem with moldboard and no-moldboard tillage at the start of the growing season – 91% of valuable aggregates (Fig. 1). The number of blocks in the upper 0–10 cm soil layer under shallow no-moldboard tillage was 13.8%, while in variant with moldboard and moldboard and no-moldboard tillage it was 6.1 and 6.8%, respectively. The formation of numerous of micro aggregates negates the advantage of plow tillage connected with the removal of more structured lumps to the surface. We confirm the conclusions about the need for periodic plow tillage after long-term shelf-less and disc tillage to replace the sprayed upper layer with a lower layer of soil structured over time [Bronick & Lai, 2015; Guo et al., 2023b]. Characterizing the soil’s structural state depending on the main tillage systems, the amount of agronomically valuable aggregates increases in ascending order: shallow no-moldboard – moldboard – moldboard and no-moldboard tillage. The amount of air-dry

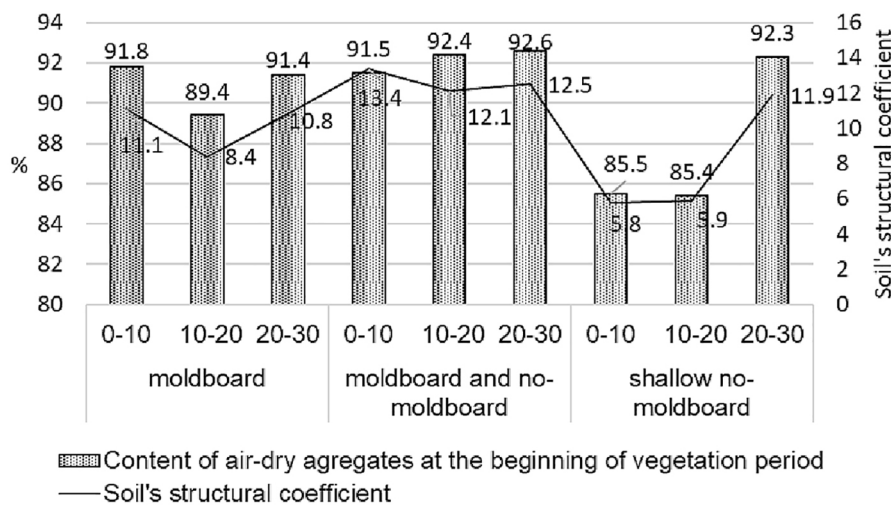


Fig. 1. The structural and aggregate soil’s composition at the beginning of the sunflower growing season in a crop rotation (LSD0.05 = 3.1)

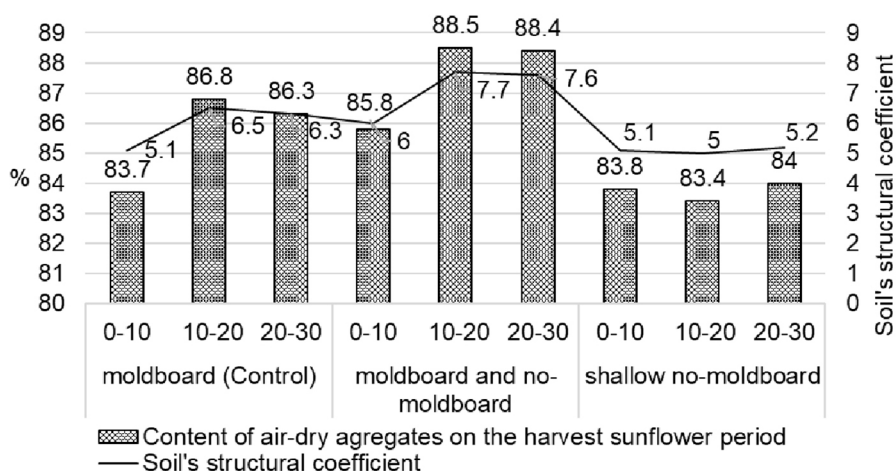


Fig. 2. The structural and aggregate soil's composition in the harvesting period of the sunflower in a crop rotation (LSD0.05 = 2.7)

agronomically valuable aggregates (0.25–10 mm) in the variant of plowing with unplowing tillage in a layer of 0–10 cm at the start of the sunflower cultivation period equaled 91.5%, which exceeded shallow unplowing tillage by 6.0%.

At the end of the growing period in the agrocenosis of sunflower in the arable soil layer, compared with the early spring period, regardless of cultivation measures, the number of agronomically valuable aggregates (0.25–10 mm) decreased, the number of fractions larger than 10 mm and fractions smaller than 0.25 mm increased (Fig. 2). The number of dusty fractions (<0.25 mm) of the soil increased significantly by 2–4 times due to the effect of man-made factors on it and the extremely drying of the soil's top layer at the time of harvesting.

The coefficient of structure in the spring in the variant of moldboard and no-moldboard tillage significantly increases by 1.4–1.7 times compared to shallow no-moldboard tillage. The regularities are also noted at the end of the crop season. This is explained by the significant role of plant

remains left on the surface and partially mixed with the upper soil's layer in the formation and preservation of the soil's optimal structural and aggregate consistence. The use of no-moldboard tillage makes it possible to leave the maximum amount of plant residue on the surface of the soil and reduce the man-made impact on the soil.

The effect of tillage on the aggregate's waterproof

According to scientists, the content of waterproof aggregates over 0.25 mm on virgin lands is 70–80%. Soil development and the use of tillage lead to the loss of this amount, sometimes twice as much. The average value of waterproof aggregates as the main indicator of quality on soil's arable does not exceed 50% [Medvedev, 2008].

The use of shallow no-moldboard and moldboard and no-moldboard tillage contributed to an increase in the content of stable aggregates by 1.2–7.5% (Fig. 3).

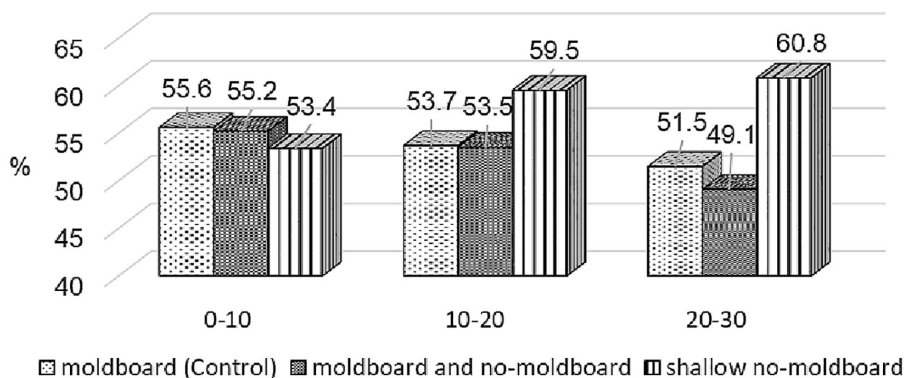


Fig. 3. Percent of aggregate's waterproof dependent of soil tillage, % (LSD0.050-10 = 0.72; LSD0.0510-20 = 0.93; LSD0.0520-30 = 0.67)

The highest value was obtained for shallow no-moldboard tillage. It indicates the important soil protection value of this tillage in contrast to others. The biggest difference in the content of waterproof aggregates was noticed in the 0–10 cm soil layer. For moldboard and no-moldboard tillage, it was 2.2% and for shallow no-moldboard tillage – 1.7% compare to control variant.

The research results indicate an increased influence of the working tools for shallow no-moldboard tillage and atmospheric phenomena on the destruction of soil aggregates. A clear differentiation of the soil's arable layer was established. It consists in increasing the content of waterproof aggregates in the 0–10 cm layer with deepening during shallow no-moldboard tillage. Moldboard and no-moldboard tillage significantly increased the amount of waterproof aggregates in the 20–30 cm layer when compared to the control variant.

Crop yield

The highest yield of sunflower during the years of research was noted for the use of moldboard and no-moldboard tillage – 2.72 t/ha, which is notably ($p < 0.05$) higher than in other variants (Fig. 4). The use of shallow no-moldboard tillage for 10–12 cm with disc tools led to a notable ($p < 0.05$) decrease in productivity when compared with the control variant. The application of the system of moldboard processing led to an insignificant decrease in the yield of sunflower seeds compared to moldboard and no-moldboard tillage. Similar results were obtained on chernozem soils [Malyarchuk, 2021].

The soil's structure is a dynamic value that depends on the characteristics of the cultivated crop, the soil cultivation methods and organic matter content. This indicator can change significantly throughout the growing season. Cultivation leads to the destruction of soil aggregates, on the other hand, on the contrary, it causes the formation of

clods and helps to increase their strength [Suleymanov, 2022]. In field experiments, the processes of destruction and reproduction of the structure operate simultaneously, so important measures aimed at maintaining the soil's structure are the system of soil cultivation, the correct set of crops in crop rotation, and the mineral and organic fertilizers [Horishko, 1997; Papish, 2022].

The use of moldboard system contributes to the optimal parameters of the soil's structure due to the upturning of the lower, most structural soil's layers into the upper part and, conversely, plowing into the lower layers of the less structural upper layer. Good conditions are provided for the growth and development of agricultural crops. According to a number of researchers [Lazarev and Abrashesh, 2000; Moiseev & Romanov, 2004; Smaga, 2008], tillage creates a suitable lumpy state at the level of more than 80% of agronomically valuable aggregates and more than 70% of waterproof ones [Jin, 2021]. All cultivation methods destroy the agronomically valuable soil structure, and this process is most pronounced during the moldboard tillage [Tsyuk, 2018; Voitovyk et al., 2023].

Most scientists believe that no-moldboard tillage contributes to the increase in the number of agronomically beneficial and water-resistant aggregates in the arable parts of the soil, particularly in the upper 0–10 cm layer, compared to moldboard tillage [Kemper et al., 2020; Mishchenko et al., 2022]. Which can be compared with our research results.

The studied soils have undergone changes due to many years of moldboard tillage, fertilization, melioration and other measures. Deterioration of water-physical properties due to global tillage is given in a number of publications [Moreno, 1997; Komissarov & Klik, 2020], including for chernozems [Smirnova, 2006; Medvedev, 2011; Kogut et al., 2019]. Previous studies [Trofimova, 2018] indicate that the number of agronomically

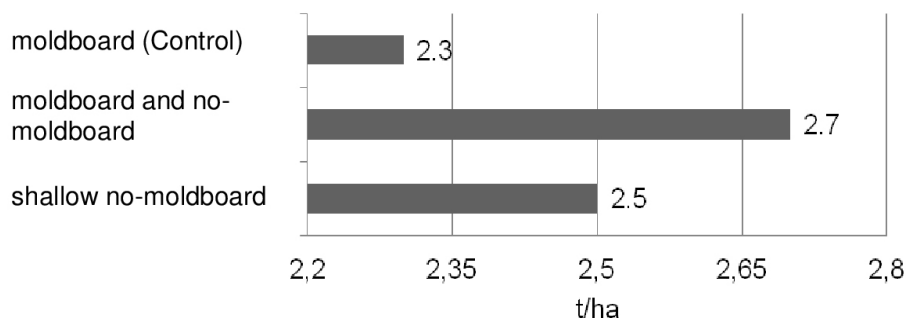


Fig. 4. Sunflower harvest depending on the soil's tillage systems (LSD0.05 = 0.38)

beneficial soil aggregates in the 0–30 cm layer of chernozems, both ordinary and leached, under steam windrows exceeds the number under different tillage systems: moldboard, shallow no-moldboard, and No-till. Similarly, the investigations by Shein [2011] it was noted that arable chernozems had a higher amount of agronomically valuable soil aggregates in fallow fields, with similar contents of physical clay and dust fractions in the arable-fallow field system.

Previous investigations [Brouder and Gomez-Macpherson, 2014; Pittelkow, 2015] suggest that shallow no-moldboard tillage creates a significantly better structural and aggregate composition of the soil with a greater number of agronomically valuable particles. The question of the impact of different tillage types on soil structure remains the focus of researchers' attention.

In our research, the yield of sunflower did not differ significantly according to tillage variants. The results align with similar studies in which little difference in yield was observed for different tillage systems. In one investigation with grain crops, no major differences in grain yield were detected under traditional moldboard and shallow no-moldboard tillage [Glab & Kulib, 2008]. In another investigation, the average harvest obtained after 21 years for traditional moldboard tillage and shallow no-moldboard tillage did not differ significantly in the wheat-sunflower-legume rotation [Ordóñez Fernández et al., 2007]. In the works [Tsentilo, 2019] it was noted that the yield of sunflower was 11.7% lower with shallow no-moldboard tillage than with moldboard tillage.

CONCLUSIONS

The methods of tillage cultivation in the sunflower agrocenosis of grain-tilled crop rotation had a notable influence on soil structuring processes. The use of moldboard and no-moldboard tillage increased the number of the most agronomically beneficial aggregates (0.25–10 mm) in the 0–10 cm layer at the beginning of the sunflower crop season by 6.0% compared to shallow no-moldboard tillage. By the end of the growing season in the sunflower agrocenosis in the 0–30 cm soil layer, compared to the beginning of the crop growing season, the number of agronomically beneficial aggregates (0.25–10 mm) decreased, the number of fractions larger than 10 mm and fractions smaller than 0.25 mm

increased. The coefficient of structure for plowing with moldboard and no-moldboard tillage significantly increased compared to shallow no-moldboard tillage. The use of shallow no-moldboard tillage and moldboard and no-moldboard tillage increased the content of waterproof aggregates by 1.2–7.5%. The maximum sunflower yield was achieved by moldboard and no-moldboard tillage – 2.72 t/ha, which is significantly higher than other variants. The use of shallow no-moldboard tillage for 10–12 cm with disc tools led to a notable decrease in productivity compared with the control variant. Improving the waterproof of soil aggregates during plowing with moldboard and no-moldboard tillage shallow no-moldboard tillage helps to preserve the potential soil's fertility. This occurs as a result of coagulation of soil suspensions or adhesion of the smallest particles. Microstructural particles are formed, from which, by gluing with humic substances, macrostructural waterproof particles are formed.

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