[1.]A.I. TSYLIURYK, [1.]S.M. SHEVCHENKO, [1.]N.V. GONCHAR, [1.]YA.V. OSTAPCHUK,
[2.]O.M. SHEVCHENKO, [2.]K.A. DEREVENETS–SHEVCHENKO

# AGROPHYSICAL AND BIOTIC FACTORS OF REGULATION OF BIOLOGICAL ACTIVITY OF SOIL IN THE CROP ROTATION

[1.] Dnipro State Agrarian and Economic University, Dnipro, UKRAINE
[2.] State Institute of Grain Crops NAAS of Ukraine, Dnipro, UKRAINE

**Abstract:** In the field stationary experiment, the dynamics of the general biological activity of chernozem, depending on the biomass of plant residues, methods of the basic soil tillage under different hydrothermal conditions was studied. It was established, that the release of carbon dioxide by microorganisms from the soil more intensively occurred on the background of deep tillage, where the best conditions for aeration and distribution of plant residues in the profile of the arable layer were found. Minimization of soil tillage, in consequence of the compaction of the arable layer by more than 1.3 g / cm$^3$ limited the volume of active zone of biotic activity and growth processes of field crops in crop rotation while inhibiting the overall biological activity and reducing the amount of carbon dioxide released. However, small soil tillage contributed to the enhancement of the anti–erosion resistance of the chernozem surface from the shock energy of rain drops, and also provided more favorable conditions for the humification of organic residues instead of undesirable intensive mineralization, especially humus.
**Keywords:** crop rotation, soil tillage, biological activity, plant residues, soil hardness, volume mass, field crops

## INTRODUCTION

The issue of arable layer differentiation at different methods of the basic soil tillage in the crop rotation on fertility and biological activity and dynamics of these parameters depending on the intensity of mechanical action on the soil and the cycle of organic matter is a very important aspect for the theoretical study of innovative soil protecting technologies of growing of field crops (Tsyliuryk et al. , 2015, 2017, 2018, Chumak et al., 2011; Tsyliuryk & Kozechko, 2017, Tsyliuryk & Sudak, 2014, 2016, Tsyliuiryk, Desyatnik, 2016, Tsyliuryk, Sudak, Shapka, 2015; Hadzalo, 2017).

By numerous investigations on the study of the nutrient regime of the soil during the transition to mouldboard–free methods of soil tillage in different zones has been established an actual increase of the concentration of basic nutrients (phosphorus and potassium) in the upper layer, decrease the biogenesity and effective fertility of the lower layers, with its long application (Tanchyk, 1999; Pabat, Shevchenko 2000; Tsyliuryk, 2017; Sayko, 2007). At the same time, in some cases, the localization of the elements of fertility is considered as a satisfactory fact, since near the weakly developed root system of plants in the beginning of the vegetation there is an increased content of elements of nutrition (Tsyliuryk & Shapka, 2016, 2017), in others – as negative, so long as in the conditions of drought, the elements of nutrition in the upper layer become positionally and physiologically unavailable to plants (Shevchenko & Rybka, 2002).

Mineralization and immobilization processes in the soil have a cyclic nature, reflecting the dynamic equilibrium between them at a certain point in time. The nitrogen of the soil substrate is constantly transformed from inorganic to organic form by means of assimilation processes, from organic to inorganic form – by decomposition and mineralization (Tsyliuryk, 2014, 2016; Lebid and Tsyliuryk, 2014). It is also established, that the increased amount of plant residues (mulch) leads to the decrease in the availability of nitrogen.

At the decomposition of plant residues, which have the broad correlation of carbon to nitrogen, there is a biological absorption of the latter by rapidly developing microorganisms for the synthesis of their own proteinic bodies (Desyatnik, 2017).

The intensification of mineralization processes to a certain level can be considered as positive phenomenon, because in parallel with such agrocenosis there is an increase in the productivity of field crops. Excessive activity of soil microorganisms can lead to rapid mineralization of humus and the growth of unproductive losses of gaseous nitrogen in the processes of denitrification and nitrification, accumulation of nitrates in the soil and further their washing with groundwater. At the same time, the coefficient of use of field crops of nitrogen from fertilizers is reduced whose content in the soil is not sufficiently high (Hordiyenko et al., 1991).

## MATERIAL AND METHOD

The research was carried out at the State Enterprise "Experimental Farm of Dnipro" of the State Institution of the Institute of Grain Cultures of the National Academy of Sciences of Ukraine in the stationary field experiment of laboratory of the crop rotation and environmental protection systems of soil tillage in five–year crop rotation: peas – winter wheat – sunflower – barley spring – corn according to generally accepted techniques of experimental work (Yeshchenko, 2005), during 2010–2017.

The scheme of the experiment also consisted of three radically different systems of basic soil tillage, namely, moldboard soil tillage (for all crops of crop rotation, a moldboard soil tillage is executed), differentiated soil tillage (a combination of different methods of moldboard–free soil tillage (disking, subsurface cultivation, chiseling) and moldboard cultivation in the crop rotation), and zero cultivation (direct sowing). Soil cultivation was carried out by the following implements:

# Moldboard soil tillage – by a plough PO–3–35 at a depth of 20–22 cm for spring barley and sunflower, 23–25 cm for corn, 25–27 cm for bare fallow (in autumn)
# Chiseling – by Chisel Plow at the depth of 14–16 cm for sunflower and spring barley (in autumn);
# Harrowing – by disc harrow BDVP (БДВП) – 6.3 at the depth of 10–12 cm for barley spring and bare fallow (in autumn);
# Subsurface cultivation by subsurface cultivator – by means of combined unit KSHN (КШН)–5.6 "Resident" or KR (КР)–4.5 at the

depth 14–16 cm in corn and 12–14 cm in sunflower (in autumn) in the early fallow (in the spring).

As organic soil fertilizers were used the post–harvest residues of predecessors, which, after mineralization, are known, return to the soil epy significant part of previously alienated elements of plant nutrition ($N–NO_3$, $P_2O_5$, $K_2O$). In view of this, the experimental scheme included three fertilizer systems from the calculation per hectare of crop rotation:

- without fertilizers + after harvest residues;
- $N_{24}P_{18}K_{18}$ + after harvest residues;
- $N_{48}P_{18}K_{18}$ + after harvest residues.

Mineral fertilizers were applicated in the spring by means of broadcasting for pre–sowing cultivation.

The conventional generally accepted techniques of experimental work have been used in the process of carrying out of research by B.A. Dospekhov. As well as special methods of research have been used, in particular, the hardness of the soil was determined by the Revayakin hardness gauge, the density – by the cutting ring method, the surface coating of the plant residues and their mass by Shyiatyi, the biological activity of the soil by the method of Shtatnov, and others like that.

The soil of the experimental site is common chernozem heavy–clayey loam with content in the arable layer: humus – 4.2%, nitrate nitrogen–13.2 mg/kg, mobile phosphorus & potassium compounds (according Chirikov), respectively 145 and 115 mg/kg.

Weather conditions during the research years were sufficiently favorable for the growth and development of field crops, except for the abnormally arid 2012, when the hydrothermal coefficient during the period of the largest water consumption of plants (May–July) was 0.6.

The hydrothermal coefficient less than 0.7 indicates the presence of soil drought and air drought, which have bad influence on the formation and swelling of grain and seeds. In all other years, the hydrothermal coefficient did not decrease below the indicated figure and was 0.8–0.9.

The purpose of the work is to establish the biological activity of the soil in accordance with volume of the release of CO2 in crop rotation, depending on the amount of plant residues left under the influence of soil tillage due to changes in agro–physical parameters and soil moisture.

## RESULTS

According to the results of the research, the minimization of soil tillage causes the significant changes in the differentiation of the arable layer (0–30 cm) relative to the positional disposition of nutrients, the concentration of potential humus substances in the aerobic zone and the intensification of microbiological activity, as evidenced by the volumes of carbon dioxide releases.

The transformation of the mulch coverage of surface of the soil with plant residues was carried out under the influence of mechanical mixing with soil by means of soil tillage implements and decomposing by microorganisms (Table 1).

The largest organic mass in crop rotation naturally left itself corn, and the minimum – barley spring and sunflower. Substantial redistribution of the projective coverage of the surface of the field with plant residues and their mixing with the soil in the profile of the arable layer was carried out by various methods and systems of basic soil tillage. For example, after harvesting of corn and carrying out of soil tillage on the surface of the field, the minimum number of plant residues remains for the moldboard soil tillage system – 0.61 t/ha. The intermediate position was occupied by the differentiated (discing) cultivation system – 3.12 t/ha, and the maximum amount of vegetative substrate was logically marked for zero soil tillage – 4.34 t/ha.

Table 1. Dynamics of biomass of mulching coverage of the field surface for different systems of basic soil tillage, on average for 2010–2017, t/ha

| Cultures of crop rotation | Terms of definition | Soil tillage system | | |
|---|---|---|---|---|
| | | Mouldboard | differentiated | zero |
| Peas | in autumn | 0.30 | 2.10 | 3.21 |
| | in the spring | 0.11 | 1.62 | 2.41 |
| Winter wheat | in autumn | 0.39 | 2.48 | 3.91 |
| | in the spring | 0.23 | 2.01 | 3.36 |
| Sunflower | in autumn | 0.28 | 1.87 | 2.24 |
| | in the spring | 0.21 | 1.42 | 2.03 |
| Barley spring | in autumn | 0.24 | 1.96 | 2.60 |
| | in the spring | 0.10 | 1.58 | 1.85 |
| Corn | in autumn | 0.61 | 3.12 | 4.34 |
| | in the spring | 0.35 | 2.88 | 4.05 |

According to the results of studies, soil tillage minimization contributes to the greater localization of plant residues in the upper layers of the arable layer (0–20 cm) and on its surface, while the application of moldboard soil tillage system leads to the wrapping of almost the entire biomass in the lower layers of the soil (20–27 cm).

As is known from literary sources (Hordiyenko et al., 1991), the degree of decomposition of plant residues largely depends on the microbiological activity of the rhizosphere zone, which in its turn is changed under the influence of agro–physical parameters (density and hardness of the soil) which are regulated by methods of basic soil tillage. The conducted agro–physical monitoring of soil condition showed that at growing of different crops in crop rotation, the arable layer was heterogeneous according to indicators of density and hardness in a vertical section.

In all fields of crop rotation in the spring, a clear pattern of differentiation of zone distribution have been appeared between the upper less hard pan of 10–15 kg / $cm^2$ and the deeper packed horizon with mechanical counteraction for plant roots at 25–30 kg / $cm^2$. That is, the depth of occurrence of a hard pan of soil significantly depends on the methods of basic soil tillage and biological peculiarities of crop rotation crops (Table 2).

During the vegetative period there was the gradual compaction of the arable layer, but the tendency continued to be characteristic for the spring determination. So and in the beginning of June, the deepest occurrence of the compacted layer was by the mouldboard system of soil tillage – 24 cm especially in the fields of sunflower and corn, while at the differentiated system of soil tillage (especially for discing – 8 cm) the compaction was detected at the depth of 8–16 cm in the sowings of peas, spring barley and winter wheat. For zero soil tillage system, there was no significant differentiation of the arable layer on density indicators, where it was maximum and was 1.35 g / $cm^3$.

In general, the minimization of the soil tillage was accompanied by the compaction of the arable layer of soil (0–30 cm) deeper than 8–16 cm, while in the background of the mouldboard ploughing more favorable conditions for growth and development of the root system up to 27 cm were noted.

Table 2. Depth of occurence of compacted layer of soil under different systems of basic soil tillage in crop rotation for 2010–2017

| Field cultures of crop rotation | Phase of development of plants of field crops | Soil moisture in arable layer (0–30 cm) % | Soil tillage system | | |
|---|---|---|---|---|---|
| | | | mouldboard | differentiated | zero |
| Peas | Formation and ripening of grain | 15.3 | 14/66 | 9/60 | 8/55 |
| Winter wheat | Formation and ripening of grain | 13.4 | 14/94 | 10/90 | 8/87 |
| Sunflower | 4 pairs of leaves | 19.4 | 24/42 | 14/38 | 12/32 |
| Barley spring | Formation and ripening of grain | 13.5 | 14/73 | 10/67 | 8/62 |
| Corn | 6–7 leaves | 20.3 | 24/61 | 12/50 | 9/43 |

Note: Numerator – the depth of the compacted, hard pan of soil, see. Denominator – the height of plants of field crops, cm.

On zero backgrounds, as well as the decrease in the depth of the main soil tillage to 8–16 cm after the small soil tillage, with leaving the compacted layer in the lower horizons, all crops of crop rotation slowed the linear increase. In particular, for example, winter wheat plants had the lower height for zero soil cultivation, not exceeding 87 cm in comparison with the mouldboard soil tillage system, where the plant height was 94 cm. In the cotn sowings at the 6–7 leaf phase, the above indicators were 43 cm and 61 cm accordingly.

One of the most powerful levelling factors for reduction of soil hardness is the level of soil and plant water supply. So, the hardness of the soil was in the inverse multiple correlation dependence with the soil moisture, that is, with increase of soil moisture the hardness decreased and the height of the plants of field crops increased. The correlation coefficient here was quite high and was 0.85.

After intensive heavy showers at the level of 45 mm of rainfall in the summer, at the time of harvesting of early cereal crops, as well as in the phase of milky–waxy ripeness of corn and flowering of sunflower, the most favorable layer of soil with respect to its hardness for plants significantly expanded to the depth of its aspiration. After heavy rains, the depth of the line of differentiation of the separation of the hard and loosening layers in the early cereal crops was deepened to 16–23 cm, and in fields of tilled crops (sunflower, corn) up to 21–27 cm, which was on 3–9 cm deeper, and then before rainfalls.

However, even in spite of the substantial moisture of the arable layer of soil, the advantage of the mouldboard soil tillage system over the differentiated and zero soil cultivation in terms of the ability to loosen the arable layer at the expense of a better soil digestion function was also manifested after the intense rainfall (Table 2). These processes are especially intensive in the autumn–winter period due to maximum moisture of the soil, as well as mutually opposite processes of its freezing and thawing, when the destruction of coarse fractions is > 10 mm to the most valuable aggregates of smaller sizes (from 0.25 to10.0 mm) .

The methods of basic soil tillage also had the significant influence on the indications of projective coverage of the soil surface with plant residues after each field crop in the crop rotation, which is of paramount importance in control of erosion processes (water and wind erosion) during the absence of vegetative cover.

The dynamics of the projective coverage of the surface of the field with plant residues showed that the methods of basic soil tillage differed significantly in the nature of anti–erosion efficiency and microbiological destruction of straw under the influence of moisture, temperature and mechanical action. At the same time, the methods of minimal soil cultivation contributed to the enhancement of the anti–erosion stability of the chernozem surface from the shock energy of rain drops, and also provided more favorable conditions for the humification of organic residues instead of undesirable intensive mineralization.

During the winter period, plant residues also undergone a slow stage of destruction and decomposition. In particular, for the differentiated system of cultivation on the background of small discing before the beginning of spring field operations, the reduction of biomass residues in different fields of crop rotation was within the range of 0.24–0.48 tons / ha, and in the case of zero cultivation and direct sowing 0.21–0.80 t / ha.

The intensity of the decomposition of organic matter in the soil is a heterogeneous process, which primarily depends on the determining factors – moisture, temperature and aeration level of the treated layer of chernozem. The intensity of the processes of breathing of soil microorganisms makes it possible to estimate the total biological activity of the soil, which is based on the amount of carbon dioxide released, depending on the different methods of soil tillage per unit area of the field surface (Table 3).

Table 3. Influence of crop rotation and soil tillage on the general biological activity, mg $CO_2$ / kg soil / day on average for 2010–2017

| Field cultures of crop rotation | Terms of definition (number, month) | Soil tillage system | | |
|---|---|---|---|---|
| | | mouldboard | differentiated | zero |
| Peas | 01.05<br>01.06 | 37.1<br>50.3 | 34.7<br>46.3 | 32.0<br>40.5 |
| Winter wheat | 01.05<br>01.06 | 31.7<br>40.9 | 30.2<br>38.0 | 28.9<br>35.1 |
| Sunflower | 01.05<br>01.06 | 35.0<br>49.2 | 34.7<br>43.9 | 29.5<br>42.0 |
| Barley spring | 01.05<br>01.06 | 32.8<br>43.3 | 31.3<br>39.7 | 29.6<br>36.0 |
| Corn | 01.05<br>01.06 | 33.1<br>47.5 | 31.4<br>45.8 | 28.2<br>41.1 |

As our studies have shown, the biological activity of the soil depended on the phases of development of plants of field crops and had a sufficiently wide amplitude of variation. Thus, as an example of the mouldboard plowing, it is evident that insufficient soil warming at normal humidification at the time of corn sowing has led to the decrease in biological activity to 33.1 mg $CO_2$ / kg of soil / day.

The maximum intensity of soil respiration (47.5 mg $CO_2$ / kg of soil / day) occurred at 30 days after corn sowing, when the optimal combination of temperature and humidity of the soil was noted. Similar regularities and tendencies in the release of $CO_2$ from the soil during certain phases of maize development are also noted for differentiated and zero cultivation systems, but with somewhat lower overall $CO_2$ release, respectively, by 1.7–5.3 mg $CO_2$ / kg ha / day (10–12%) and 5.8–9.8 mg $CO_2$ / kg ha / day (12–22%) compared to the mouldboard soil tillage system. Generally, this tendency took place both in the maximum and at the minimum amplitude of the activity of respiration processes, that is, the indicators of the general biological activity of the soil were higher in the background of plowing and prevailed other systems of mechanical cultivation of chernozem (differentiated, zero system).

One of the reasons for reduction the biological activity of the soil, depending on the methods of basic soil tillage, is the different profile dislocation of plant residues. That is why, the availability of oxygen, moisture, optimal agrophysical properties of the soil and the presence of a significant amount of plant residues in the profile of the arable layer over the mouldboard soil tillage system creates the most favorable medium for microorganisms. At the same time, when at zero soil cultivation, all plant residues are located on the soil surface and are isolated from the zone of vigorous activity of the soil biota.

## CONCLUSIONS

Thus, the biological activity of the soil is the derived indicator, which depends on the features of the technology of growing of cultures in the crop rotations, the presence of organic matter of plant residues in the chernozem, the level of compaction of arable layer and the methods of basic soil tillage. The use of deep plowing due to the creation of favorable conditions for the expansion of the root system of crops with sufficient aeration and moisture absorbtion properties provides maximum biological activity under all crops of crop rotation, decomposition of residues and intensive mineralization processes. However, methods of unploughed treatment of the soil contributed to increasing the anti–erosion stability of the surface of chernozem from the shock energy of rain drops, as well as providing more favorable conditions for the humification of organic residues instead of undesirable intensive mineralization.

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