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Full Length Research Paper

The ways to ecologically balanced development of agro ecosystems in the Forest-steppe zone of Ukraine

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To stop the processes of Soil degradation and to ensure increased reproduction of fertility in Chernozem soils of the Forest-Steppe Zone in Ukraine may be possible by employing only environmentally sound systems of crop production which take count of changes occurring in soil, especially the effects of microorganisms on soil quality in the course of soil use in farming. It is also necessary to increase the role of microorganisms in soil by restricted or minimum soil tillage, rational system of fertilizing and by growing crops which leave enough residues for an increased reproduction of soil organic matter. Ecologically balanced agro-ecosystem may be achieved by self-organization and controlled evolution of soil fertility and by changing the intensity and direction of the processes of energy and matter transformation in soil. Our studies have shown that the best conditions for this purpose were created by employing soil-protecting systems of crop production with non-plough tillage and annual application of 12-14 t ha^{-1} of organic manures and 111-246 kg ha^{-1} of mineral fertilizers. Such systems allow modelling the natural process of soil formation and improving all relations in an agro-ecosystem by increasing the ability of artificially created phytocaenosis to positively affect the processes of soil formation. If plant residues and farm manure are incorporated in the upper 10 cm layer of soil by a non-plough tillage, this increases the humification coefficient of residues by 20-25% and favours the accumulation of newly-formed organic matter in soil. The renovation of soil self-regulation by the systems of a non-plough soil tillage is caused by the increased amplitudes of yearly and seasonal changes in the contents of soil organic matter. The increases in the amplitudes testify to a significant growth in the amount of root exudates and the biomass of soil microorganisms, which remain difficult to detect exactly by the current methods of research. Conservation tillage with sufficient organic fertilizing and the use of plant residues with increased humification coefficients as well as the use of nitrogen-fixing crops allow reduction in the rates of mineral fertilizers which favour the creation of a more ecologically stable agro-ecosystem.

Keywords: Soil degradation, fertility, Chernozem soils, Forest-Steppe Zone**,** Ukraine

INTRODUCTION

To give ecological reasons to the systems of crop production in the Forest-Steppe Zone of Ukraine it is necessary to elucidate the laws governing the changes of soil properties, especially soil biology, occurring under the influence of farming practices. The essence of sustainable farming lies in the strengthening of micro-organisms' role in the reproduction of soil fertility by the systems of fertilizing and soil tillage in crop rotations (Morgun, 1995; Shikula and Nazarenko, 1990).

Fundamental soil investigations must solve a complicated and important task: to detect the laws of energy and mass exchange in agro-ecosystems and to create a theoretical basis for the development of practices and methods of soil management in agricultural systems. Intensity and direction of the transformation of energy and matter in agro-ecosystem are determined by the structure and composition of crops in crop rotation and the systems of fertilizing, soil tillage and plant protection (Vorobyov et al., 1987; Zubenko and Barshtein, 1987).

A system of fertilizing is a means of intensity regulation in a small (biological) cycle of substances pertaining to an agro-ecosystem. The cycle is being disconnected by the subtraction of substances with yields. The level of energy subtraction and its re-supply in an agro-ecosystem is determined by a crop rotation which is a means of formation of structure and composition of a phytocaenosis with a purpose of ensuring maximal productivity and stability in time [5].

Self-organization and self-reproduction of an agro-ecosystem are directly related to the organization and evolution of soil productivity. Therefore, the system of soil tillage is a factor of influence on the changes of potential and effective soil fertility with an optimal energy supply in a man-controlled process of soil formation. It must stimulate a multiparametral self-regulation of soil fertility in time and space so as to sever the connections which function on the principles of self-regulation (Demydenko, 1995; Shikula et al., 1995; Shikula et al., 1996). It means that the system of soil tillage must model the natural processes of soil formation. Such a system allows regulation of the transformation of energy and organic matter in soil controlling its input and losses by mineralization (Shikula and Nazarenko, 1990).

MATERIALS AND METHODS

Our research has been carried out on a stationary field test plot. The dominant soil of the plot was typical chernozem, a clay loam with moderate organic matter content formed in loess. The plot was situated in "Ukraine" farm, Karlivka district, Poltava region. The region represents the southern part of the left-bank province of the forest-steppe zone of Ukraine. The soil was characterized by the following characteristics in the upper 0-10 cm layer: 5.5 % of organic matter (organic carbon content multiplied by 1.724), total nitrogen 2170 and total phosphorus 1500 ppm; soil pH was 7.1. Available P_2O_5 and K_2O extracted by 1% $(NH_4)_2CO_3$ were 180 and 150 ppm respectively. Hydrolysable nitrogen determined in 1 N H_2SO_4 was 70 ppm.

A ten-field crop rotation has been used in experiments with the following crop sequence: occupied fallow, winter wheat, sugar beat, peas, winter wheat, corn for grain, corn for silage, winter wheat, sugar beet and sunflower.

Soil organic matter content has been determined by combustion of soil samples with concentrated H_2SO_4 in a 1:1 mixture with $K_2Cr_2O_7$ (Ponomaryova and Plotnikova, 1975). Humification coeficient of plant residues were determined by using the samples of residues according to the procedure proposed by Chesnyak, 1986. Newly formed organic substances were extracted from the soil by 0.1 N NAOH (Ponomaryova and Plotnikova, 1975). Humic acids were determined by precipitation with 1 N H_2SO_4, heating to 80-90^0 C and subsequent dissolution in O.1 N NaOH. Organic carbon in dried sediments has been determined as a total organic carbon in soil by combustion in a mixture of a concentrated H_2SO_4 and 0,4 N $K_2Cr_2O_7$. A content of detritus in soil samples were determined using CH_3COBr extraction according to Springer (Lykov and Tulikov, 1985). Soil micro-organisms consuming organic and inorganic nitrogen were determined in fresh samples according to procedure described by Tepper et al., 1979 and Babyeva and Zenova, 1989, using respectively meat-and-pepton agar and starch-and-ammonia agar substrates. The amount of ATP in soil samples was determined by method developed by Oades and Jenkinson, 1979. Nitrifying and ammonifying bacteria were determined using, respectively, elective culture medium proposed Vinogradskyi and meat-and-pepton agar according to a procedures described by Zvyagintsev, 1991. The amount of actinomycetes and fungi were determined by methods described also by above mentioned author.

The scheme of field experiment included 4 systems of tillage: (1) mold board ploughing to the depth 20-30 cm depending on a crop grown (CT); (2) non-plough tillage to various depth depending on a crop (NPT_1); (3) shallow non-plough tillage to the depth 10-12 cm for all crops (NPT_2) and (4) minimum tillage to the depth 5-7 cm for winter wheat and 10-12 cm for the other crops(MT). The scheme included 4 systems of fertilizing with the following rates per hectare of a crop rotation per year: (a) control variant without any fertilizers (NF) ; (b) farm manure (12 t ha^{-1}) + N_{37} P_{39} K_{35} (F1); (c) farm manure (12 tha^{-1}) + N_{62} P_{62} K_{55} (F2) and (d) farm manure (12 tha^{-1}) + N_{86} P_{86} K_{74} (F3).

EXPERIMENTAL RESULTS

Humification coefficients of plant residues

The employment of crop rotations always presupposes a well grounded sequence of crops. Soil formation is very much dependent on the chemical composition of plants, especially the content of nitrogen (Ponomaryova and Plotnikova, 1980; Kapshtyk, 1986). The first group is made up by the crops, which contain little nitrogen in their residues (grain crops). The second group includes those crops, which have noticeable nitrogen content in their residues. These are annual and perennial legumes, sugar beet, corn, sunflower and others.

The amount of humus formed from various residues under conditions of conventional (ploughing) and non-plough systems of tillage differ. Conventional tillage (ploughing) causes the coefficient of humification to

Table 1: Coefficients of humification of residues and farmyard manure, %.

Organic Substrates	Soil layers, cm					
	0-10		10-20		20-30	
	CT	NPT_1	CT	NPT_1	CT	NPT_1
	After 6-year period of tillage system application					
Straw of wheat	16.1	17.0	17.6	19.3	17.7	17.9
Residues of alfalfa	17.9	19.3	18.3	20.6	18.9	19.4
	After 8-year period of tillage system application					
Straw of wheat	16.1	16.6	18.0	19.8	18.2	18.4
Residues of alfalfa	17.8	19.0	19.9	22.0	19.6	20.6
Manure	15.8	16.2	18.2	20.0	17.8	18.2

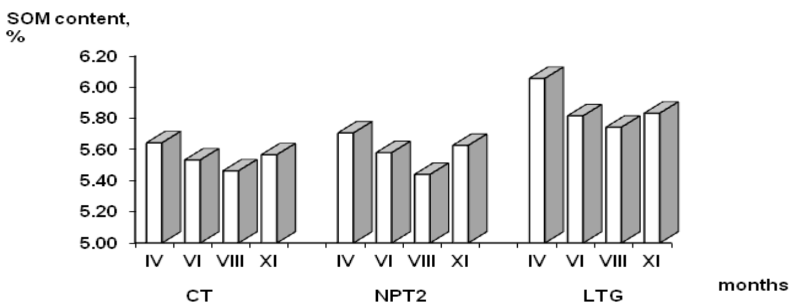

Figure 1: Soil Organic Matter content in 0-20 cm layer of soil under influence of various systems of land management.

grow with depth. On the fields with small grain straw they changed from 17.4 to 18.7, while on the fields with alfalfa they reached 20 to 21.9% (Table 1). Surface tillage was characterised by high humification coefficients in 10-20 cm layer of soil.

For small grain straw it was 20,4 and for alfalfa residues – up to 24%. Soil aeration and wetness are the main factors determining the humification coefficients at various depths on the variants with non-plough soil tillage. On the variants with straw they grew up by 1.6-2.7 % while on the variants with alfalfa they increased by 2.0-2.2 %.

The depth of farm manure incorporation also affected the humification coefficients. On the variants with conventional plough tillage the highest values of these coefficients were observed in 20-30 cm layer of soil (17-17.8 %), while on the plots with a non-plough tillage it grew by 1.6-1.8 % in the 10-20 cm layer and reached 19-20 %. Mineral fertilizers applied with farm manure ($N_{120}P_{120}K_{130}$ +12 tha^{-1} of farm manure) have increased the humification coefficients of both straw and alfalfa by 1.5-2.2 and 1.6-1.8 % respectively. Shallow incorporation of plant residues and manures on a background of the same fertilizing system increases the intensity of humification (K_g) as compared with ploughing in the layers of the soil: 0-10 and 10-20 cm by 1.2-2.2 for alfalfa, by 0.2-1.6 for small grain straw and by 0.4-1.8 % for farm manure.

Seasonal Dynamics of Soil Organic Matter

Soil-protecting crop production systems have increased the content of newly formed organic matter in soil by 2.9-3.7% in 0-20 cm layer compared with conventional tillage (ploughing) where the increases were 1,7-2,0%. There were the increases in the contents of humic and fulvic acids. The ratio between their carbon was 0.76-1.69 at the plots with non-plough tillage and 1.0-3.0 at the plots with mold-board ploughing (Kapshtyk et al., 1980). Shallow incorporation of crop residues did not only increase the humification coefficients, but increased the yearly and seasonal amplitudes of soil organic matter content in soil. On the plots with non-plough tillage this amplitude was 0.22-0,32% in layer 0-20 cm while on the plots with conventional tillage it was within 0.14-0.20%, reaching even 0.30-0.37% on the plots with long-term grassland (Figure 1). The ampli-

Table 2: Amount of soil detritus in soil of plots tilled for 10-year period by various systems and annually fertilized by 15 t·ha^{-1} manure+$N_{80}P_{70}K_{70}$. Absolute values in dt·ha^{-1}; relative values in comparison to CT (=100 %).

Variant	Soil layers, cm 0-20 tha^{-1}	%	0-30 tha^{-1}	%	0-50 tha^{-1}	%
CT	80	100	120	100	190	100
NPT_1	97	121	134	112	205	108
NPT_2	100	125	130	108	210	111
MT	104	130	126	105	190	100

Table 3: Effect of fertilization and tillage systems applicated for 7 years on the population of soil microorganisms. Absolute values in units ·per 1 g of soil (Gnatenco, 1993)

Variant	Microorganisms on SAA × 10^7	Microorganisms on MPA × 10^7	SAA : MPA	Actynomycetes × 10^6	Fungi × 10^3
Layer 0-10 cm					
CT, NF	1.85	0.85	2.18	3.45	3.54
NPT_1, NF	2.37	1.24	1.91	4.15	4.37
CT+ F	37.9	13.9	2.73	45.1	6.58
NPT_1 + F	59.8	23.2	2.58	83.4	8.34
Layer 10-20 cm					
CT, NF	0.687	0.332	2.04	0.315	2.31
NPT_1, NF	0.612	0.327	1.87	0.321	2.75
CT+ F	1.79	0.73	2.45	6.83	3.45
NPT_1 + F	1.48	0.62	2.14	6.1	4.18

CT – conventional tillage; NPT_1 – non-plough tillage
NF – non-fertilized; F 3– manure + NPK

tudes were decreasing with depth on non-plough tillage while on ploughing they reached 0,23-0,24% in the layer of soil 10-20 cm.

Seasonal dynamics of soil organic matter was higher that its possible formation by 80%. We explain this phenomenon by the contribution of root exudates and microbiocaenosis of the soil and by the mechanisms of CO_2 of the soil air transformation in soil humus detected by colleagues from our university (Shykula et al., 1997).

Moreover, soil-protecting crop production systems have increased the amount of soil detritus which may be an “active” products of organic substrates decomposition and available for the saprophytic microorganisms (Table 2).

The dynamics of a calcium salt of ATP in soil was opposite to the dynamics of soil humus (Shikula, 1997). This testifies to the fact of energy transformation from one form to another. The process is self-regulated and optimises the conditions of humus formation in soil. These processes are very pronounced in natural ecosystems and in agro-ecosystems with systematic use of conservation technologies of crop production. A yearly diapason of soil organic matter transformations discovered by us is equivalent to application of 350-400 t ha^{-1} of farm manure (Shikula and Nazarenko,1990)..

The ratio of various groups of soil microorganisms

The system of soil tillage affects the numbers of micro-organisms and their activity in 0-30 cm layer of soil (Table 3). A non-plough tillage, as compared to conventional mold-board ploughing, caused an increased multiplication and activity of microorganisms in 0-10 cm layer of soil.

On the plots with no fertilizers there was an increase in the quantity of nitrogen by 1.3 times compared with ploughing, while on the plots with organic and mineral fertilizing this increase reached 1.6 times. The same was true for the bacteria using organic nitrogen. On the plots without fertilizing their amount increased 1.5 times, while on the fertilized plots the increase was 1.7 `times. Positive effects of mineral fertilizers was observed on the plots which received no more than 280 kg ha^{-1} of NPK. But there was a significant increase in the amount of soil micro-organisms which caused a 1.2-1.5 times increase of organic matter mineralization as compared with plots with no fertilizing. The application of N_{110} P_{110} K_{110} reduced the amount of actinomycetes and ammonifying bacteria in soil and increased the amount of fungi and nitrifying bacteria which caused an activation of mineralization processes.

Table 4: Winter wheat yield (dt ha^{-1}). Average of 7 years during 1st crop rotation period after various previous crops. Absolute values in dt·ha^{-1}; relative values in comparison to CT, non-fertilized (=100 %).

Soil tillage	System of fertilizing							
	non-fertilized		$N_{35}P_{30}K_{30}$		$N_{55}P_{45}K_{45}$		$N_{75}P_{60}K_{60}$	
	dt·ha^{-1}	%	dt·ha^{-1}	%	dt·ha^{-1}	%	dt·ha^{-1}	%
CT	39.2	100	43.4	111	44.5	114	48.9	125
NPT_1	37.6	95.9	45.9	117	47.9	122	48.8	124
NPT_2	37.5	95.7	46.4	118	49.8	127	49.2	126
MT	36.5	93.1	43.4	111	45.1	115	47.6	121

Table 5: Sugar beet yields (dt·ha^{-1}). Average of 6 years during 1st crop rotation period. Absolute values in dt·ha^{-1}; relative values in comparison to CT, non-fertilized (=100 %).

Soil tillage	System of fertilizing							
	non-fertilized		$N_{85}P_{100}K_{70}$		$N_{130}P_{150}K_{110}$		$N_{170}P_{200}K_{140}$	
	dt·ha^{-1}	%	dt·ha^{-1}	%	dt·ha^{-1}	%	dt·ha^{-1}	%
CT	39,3	100	44,2	112	46,7	119	48,0	122
NPT_1	40,1	102	45,6	116	50,0	127	47,6	121
NPT_2	40,2	102	44,7	114	50,9	130	47,6	121

Content of Plant Nutrients

Surface incorporation of plant residues in non-plough systems of soil tillage has changed the regime of nitrogen nutrition of plants. On plant residues incorporated in 0-10 cm layer of soil there was observed an accumulation of proteins and aminoacids. These substances remain intact till the entire decomposition of plant residues. They serve a source of nitrogen for plant nutrition (Shikula et al., 1996; Vostrow, 1989). Systematic use of conservation technologies of crop production increased the accumulation of plant residues in 0-20 cm layer of soil, which improved the nitrogen nutrition of crops. Plants demands have been satisfied at all stages of growth and development. The stages of vegetative growth were accompanied by the formation of nitrate nitrogen while the stages of generative growth – by the formation of ammonium nitrogen in soil (Shikula and Nazarenko,1990; Gnatenco, 1993).

Yields of Crop and Economic Efficiency

The strengthening of biological and microbiological factors of soil fertility in conservation farming does not presuppose any additional expenditures of money or any increase in the price produce. Just the opposite is true: these technologies require less energy for soil tillage. The yields of crops are 15-30% higher as compared with conventional tillage (Table 4,5) and the price of produce – 30-50% lower (Shikula and Nazarenko,1990; Kapshtyk, 1986 ;Gnatenco, 1993). And not only in years with droughts. The accumulation of elements of plant nutrition in organic forms decreases the expenditure of mineral fertilizers and their losses caused by soil erosion and denitrification (Kapshtyk, 1986; Shykula et al., 1997).

DISCUSSION

Soil-protective crop production systems with a non-plough soil tillage model a natural process of soil formation provided there is an optimal supply with energy and fertilizers. They also increase the validity of relations between the various elements of an agro-ecosystem (Shikula et al., 1996; Kapshtyk, 1986; Shykula et al., 1997).

Up to date views on crop rotations (Tscherbakow and Volodin, 1991) try to explain that agricultural crops imitate the natural vegetation to a certain extent, but only during a short period of time. Actually we have an artificially created phytocaenosis in an agro-ecosystem, which regulates the activity of soil microorganisms and thus fulfils the function of a main factor of soil formation. Systematic use of conservation tillage in crop rotations increases the ability of artificially formed phytocaenosis to effect soil formation and to improve the ecological aspects of crop production (Shikula and Nazarenko,1990; Shikula et al., 1996; Kapshtyk et al., 1980).

An inverse relation between the intensity of nitrification and the accumulation of available phosphorus in soil is caused by many factors. The lowering of soil pH increased the amount of available phosphorus. Optimal conditions for the development of nitrifying bacteria were observed at pH 8.0, while at pH 6.5-6.8 their activity was drastically reduced (Shikula and Nazarenko,1990). This, to our mind, is the main reason why the conservation technologies decrease the intensity of nitrification and improve the activity of soil microflora in mobilization of mineral phosphates. Orderly seasonal rhythms of redox conditions and base-acid equilibrium in Chernozem soil subject to soil-protecting crop production technologies regulates the seasonal dynamics of the availability of individual macro- and micro-elements of plant nutrition in soil solution so that the optimal ratios are maintained between them.

To obtain high yields of crops on typical Chernozems is possible at the expense of potential soil productivity created by soil microorganisms in crop rotations, that is, at the expense of root exudates and semidecomposed plant residues.

Total organic matter (humus) content in soil is not so important as the amount of “active” products of decomposition which are available for the saprophytic microorganisms. Soil detritus is available for the microorganisms and may be a source of an “active“ organic matter. The potential productivity of chernozems is directly proportional to the accumulation of detritus in soil.

There exists a close relation between the seasonal changes in soil organic mater content in chernozems and the seasonal physiological rhythms of plant growth [16,18]. It is caused by a dynamic correspondence among the soil, the plant and the atmosphere. The practices of conservation crop production renovate this correspondence and the role of crop rotation can hardly be overestimated in this respect.

CONCLUSION

Soil-protecting systems of crop production based on a non-plough tillage of typical chernozems model a natural process of soil formation, increase the ecological role of a crop rotation and strengthen the soil-forming role of field crops. Systematic employment of soil-protecting tillage systems increases the abilities of artificially created phytocaenoses to effect soil formation and ecologization of a crop production system. Soil formation dynamics is very much affected by the chemical of plants, especially the content of nitrogen. This is achieved by the rational management of natural and anthropogenic energy resources for the creation of optimal conditions for the binding of solar energy by an ro-ecosystem in the form of organic substances which possess ecologically sound quality. All this leads to the formation of ecologically stable agro landscapes.

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