Bulgarian Journal of Agricultural Science, 22 (No 3) 2016, 381–385
Agricultural Academy

YIELDS OF FIELD CROPS AND SOD-PODZOLIC SOIL FERTILITY OF WEST URAL DEPENDING ON FERTILIZER SYSTEM

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Abstract

KOSOLAPOVA, A., V. YAMALTDINOVA, E. MITROFANOVA, D. FOMIN and I. TETERLEV, 2016. Yields of field crops and sod-podzolic soil fertility of West Ural depending on fertilizer system. *Bulg. J. Agric. Sci.,* 22: 381–385

Sod-podzolic soils are characterized by low level of natural fertility. The systematic fertilizers application is necessary condition of their fertility improvement and obtaining high yields of crops. Experimental data on influence study of fertilization systems on crop capacity, eight-course rotation productivity (bare fallow, winter rye, wheat with clover undersowing, clover first year of use, clover second year of use, barley, potatoes, oat) and fertility of sod-podzolic clay loamy soil were presented in the article. Research conducted in 2002–2010 years based on the experimental field of Perm Agricultural Research Institute in the long-term field experiment, established in 1967 year. Studied following fertilization systems in experiment: organic (FYM 10 and 20 t ha^{-1} average annual rate, actually – 80 and 160 t ha^{-1}); mineral, at rate equivalent to content of nutrients in FYM; organic-mineral with FYM 5, 10, 20 t ha^{-1} (actually – 40, 80 and 160 t ha^{-1}) and mineral fertilizers at rate equivalent to FYM. Joint application of FYM and mineral fertilizers contributed to accumulation of humus from 2.35% in treatment with low rates of organic and mineral fertilizers to 2.70% with high rates. Application of high doses of organic and mineral fertilizers led to acidification of soil – increase of hydrolytic acidity and decrease of total exchange bases. All fertilization systems led to higher content of mobile phosphorus and exchange potassium in the soil. Comparative evaluation of these fertilization systems revealed significant increase of grain crops and potatoes yield. The largest gains of spring wheat grain (1.55 t ha^{-1}), barley (0.55 t ha^{-1}), oat (1.02 t ha^{-1}) and potatoes (9.95 t ha^{-1}) were obtained by application of organic-mineral fertilization system. The productivity of crop rotation increased when using of mineral fertilizer by 14–20%. The maximum effect was obtained from organic-mineral fertilization system (3859 FU ha^{-1} per year). Significant heavy metal contamination of soil was not observed in these studies after long-term (about 40 years) use of FYM and mineral fertilizers.

Key words: fertilization system, sod-podzolic soil, yield, heavy metals
Abreviations: FU – food units

Introduction

The main problem of modern husbandry is the preservation and increasing of soil fertility, as well-being base of any country and whole of mankind on our planet (Mineev, 2008). Dominant part of arable lands in Perm Region (69%) set on sod-podzolic soils defining by poor natural fertility. Systematic and complex fertilization of these soils proved to be the compulsory condition of any crop high yields (Popova et al., 2013). Even on the cultivated soils considerable decline of field crops yields and content of basic nutrient elements in soil were observed without fertilizers application (Ailincăi et al., 2012; Dasci and Comakli, 2011; Mineev et al., 2007; Yang et al., 2011).

Long application of fertilizers together with their positive impact on agricultural crops productivity and soil fertility has also negative influence on the agricultural biocenoses, caused by heavy metals accumulation in soils and vegetative

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production (Alexeev, 1987; Czarnecki, 2015; Jones, 2002; Trots et al., 2015; Tiller, 1989; Yargholi and Azarneshan, 2014; Kalantari et al., 2006). However, such fears are not always justified (Vodyanitskii, 2013). Results of long-term field experiments in Leningrad Research Institute (Nebolsin and Nebolsina, 2005; Yakovleva, 2009) show that farming impact in soils pollution by heavy metals is insignificant (1–2%). There are publications in scientific literature about application of organic fertilizers reducing content of heavy metals in soil and plant production (Angelova et al., 2013; Gomonova, 1994; Chernych et al., 1995; Nosovskaya et al., 2000).

The objective of given experimental work is to compare the influence of long-term application of various fertilizers systems on arable crops yields, fertility of sod-podzolic heavy loam soil, and heavy metals content in soil.

Materials and Methods

Experimental work was fulfilled in 2002-2010 in long-term stationary field experiment on the experimental farm of Perm Scientific Research Institute. The experimental plots located on sod shallow-podzolic heavy loam soil with humus content 2.1–2.2%, pH_{KCl} 5.4–5.5, P_2O_5 content 125 and K_2O – 170 mg kg^{-1} (1969, before experiment foundation).

Field trials were executed in fallow grain grass rotation with following rotation scheme: clean fallow, winter rye, spring wheat as shelter crop for meadow clover, first year clover, second year clover, spring barley, potato and oat. Certified seeds were used for sowing.

The following fertilization systems were studied in the experiment: organic (farm yard manure total rates 40; 80; 160 t ha^{-1} within rotation); mineral, (fertilizers rates are defined according the nutrients quantity in FYM; complex (Manure total rates 40; 80; 160 t ha^{-1} within rotation with equivalent rates of mineral fertilizers).

Experimental scheme: 1. No fertilizers; 2. Manure 80 t ha^{-1}; 3. Manure 160 t ha^{-1}; 4. NPK rates equivalent manure 80 t ha^{-1}; 5 NPK rates equivalent manure 160 t ha^{-1}; 6. Manure 40 t ha^{-1} + NPK rates equivalent manure 40 t ha^{-1}; 7. Manure 80 t ha^{-1} + NPK rates equivalent manure 80 t ha^{-1}; 8. Manure 160 t ha^{-1} + NPK rates equivalent manure 160 t ha^{-1}.

Manure was applied two times during crop rotation: for winter rye and potato (20, 40, 80 t ha^{-1} before plowing). The mineral fertilizers rates, defined according the nutrients quantity in manure, were distributed between winter rye, wheat, barley, potato and oat. Meadow clover was not fertilized. Treatment placing is randomized; each treatment has four replications on field area and two replications in time. In 2008–2009 the fifth rotation ended for both according replications.

Soil and plant chemical analyses were fulfilled in analytical laboratory of Perm Agricultural Research Institute according national standards: humus content – GOST 26213-84; pH_{KCl} – GOST 26483-85; hydrolytic acidity – GOST 26212-91; exchange bases sum – GOST 27821-88); mobile phosphorus and exchange potassium – GOST 26207-91. Heavy metals soil content – defined in Perm agrochemical service center. Data processing included analysis of variance and correlation coefficients determination.

Results and Discussion

Long-term application of fertilizers, within 40 years, had essential impact on change of soil agrochemical properties (Table 1). So, arable land treatment without fertilizers led to considerable decrease of humus and potassium content, then, to some increase of soil acidity. Mineral fertilization

Table 1

The influence of fertilization systems on soil chemical properties. The end of fifth rotation (2008-2009), average for two replications in time

Treatment	Humus, %	pHKCI	S	Ha	V,%	P_2O_5	K_2O
			mmol/100 g of soil			mg/1000 g of soil	
1. No fertilizers	2.12	4.9	19.2	3.07	86	173	163
2. Manure 80 t ha^{-1}	2.22	5	20.1	2.83	88	208	222
3. Manure 160 t ha^{-1}	2.43	5.3	20	2.54	89	210	262
4. NPK rates equivalent manure 80 t ha^{-1}	2.23	4.8	18.8	3.81	83	197	251
5. NPK rates equivalent manure 160 t ha^{-1}	2.31	4.4	17.2	4.43	80	256	316
6. Manure 40 t ha^{-1} + NPK rates equivalent manure 40 t ha^{-1}	2.35	4.9	18.5	3.26	85	201	268
7. Manure 80 t ha^{-1} + NPK equivalent rates	2.46	5.1	19.6	2.95	87	248	339
8. Manure 160 t ha^{-1} + NPK equivalent rates	2.7	5.1	17.9	3.7	83	333	433
LSD_{05}*	0.23	0.3	1.3	0.71		60	41

* LSD_{05} – least significant difference

systems, especially high fertilizers rates, caused base saturation decreasing and, vice versa, exchange and hydrolytic acidity raising. Humus content was relatively stable.

Manure application provided humus content preservation or moderate increasing, up to 2.43% from highest rate 160 t ha^{-1}. Soil pH_{KCl} reached 5.3. The tendency of hydrolytic acidity decline was noted under organic and complex fertilization systems treatment.

The most favourable soil conditions were worked out from application of Manure highest rate – 160 t ha^{-1}. NPK high doses caused acidity raising and base saturation decreasing in spite of manure high rates using.

All fertilization systems have led to essential increase of exchange potassium content, especially high mineral fertilizers rates and complex systems (up to 433 mg/1000 g of soil). Situation with mobile phosphorus content was not so evident. Only combination of Manure at least 80 t ha^{-1} with NPK and, also highest NPK rates promoted significant P_2O_5 increasing, in other treatments only the raising tendency was noted.

All studied systems of fertilizers have raised productivity of agricultural cultures compared with control treatment (no fertilizers). The most essential supplements of winter rye grain yield were obtained from organic fertilization systems and NPK rates equivalent manure 160 t ha^{-1} – 0.46–0.54 t ha^{-1} (Table 2). Application of 80 t ha^{-1} Manure guaranteed winter rye yield equal to the one from higher fertilizers rates. Mineral and complex fertilization systems, en bloc conceded the organic system. The difference between these treatments has not exceeded LSD_{05} value. The supplements of winter rye grain yield were due to raising individual ear productivity, correlation coefficients (r) between total yield and grain quantity; grain mass from one ear were 0.6 and 0.64, accordingly. Spring grain crops have also positively responded on all studied systems of fertilizers. Spring wheat grain yield rose from 2.30 to 3.85 t ha^{-1}. The greatest supplements 1.17–1.55 t ha^{-1} of grain yield were gained from combination of Manure and mineral fertilizers (treatments 7, 8).

All studied treatments have provided essential increase of clover hay yields compared with control. The maximum total (for two years) gain of clover hay 1.35 t ha^{-1} was received from Manure ha^{-1} application, but the variances between treatments were insignificant, within $LSD_{05.}$

Complex fertilization systems with medium and high fertilizers rates showed some benefits for barley yields. Grain supplements were about 0.45-0.55 t ha^{-1} without significant difference between treatments 7 and 8 (Table 2). Grain yield rise was provided by stem thickness increase (r = 0.8±0.02) and 1000 grains mass (r = 0.79±0.03).

Potato like all tuber cultures positively responds on manure application, yield gain were about 4.9 t ha^{-1}, but effect from mineral fertilizers was just the same. Combination of manure and mineral fertilizers provided father rising of tubers yield, up to 29.35 t ha^{-1}. This may be explained by high offtake of nutrients by potato tubers yields and heavy nutrients demand of this culture. Application of manure 80 t ha^{-1}+ NPK in equivalent rates provided getting yield approximately equal to those from fertilizers rates two times greater compared with this treatment. Yield rising was provided by tubers mass and quantity in the clone.

Significant supplements of oat grain were noted in all studied fertilization systems – from 0.54 to 1.02 t ha^{-1}. The efficiency of organic and mineral fertilization systems was roundly equal. Yield gains obtained in these treatments were within $LSD_{05.}$ Formation of the highest oat grain yield 3.44-3.48 t ha^{-1} was provided by complex fertilization system with fertilizers rates no less than manure 80 t ha^{-1}+ NPK.

Table 2
The influence of fertilization systems on crop yields in fifth rotation, average for two replications in time

Treatment	Crop yields, t ha^{-1}					
	Winter rye 2002–2003	Spring wheat 2003–2004	Clover 2004–2006	Barley 2006–2007	Potato 2007–2008	Oat 2008–2009
1. No fertilizers	3.12	2.30	8.28	2.26	19.4	2.46
2. Manure 80 t ha^{-1}	3.60	2.77	9.03	2.42	24.11	3.00
3. Manure 160 t ha^{-1}	3.66	2.76	9.63	2.52	24.31	3.21
4. NPK rates equivalent manure 80 t ha^{-1}	3.36	2.89	9.41	2.42	24,96	3.25
5. NPK rates equivalent manure 160 t ha^{-1}	3.56	3.48	9.09	2.55	25.04	3.22
6. Manure 40 t ha^{-1} + NPK rates equivalent manure 40 t ha^{-1}	3.31	3.13	9.31	2.47	26.62	3.15
7. Manure 80 t ha^{-1} + NPK equivalent rates	3.39	3.47	9.41	2.71	28.1	3.48
8. Manure 160 t ha^{-1} + NPK equivalent rates	3.26	3.85	9.31	2.81	29.35	3.44
LSD_{05}	0.24	0.25	0.69	0.22	2.61	0.31

Table 3
The influence of fertilization systems on the soil content of heavy metals mobile forms in the end of fifth rotation, 2009 (mg/kg)

Treatments	Cu	Zn	Pb	Cd
No fertilizers	0.33	1.20	0.32	0.05
Manure 80 t ha^{-1}	0.23	1.29	0.24	0.04
Manure 160 t ha^{-1}	0.29	1.35	0.43	0.03
NPK rates equivalent manure 80 t ha^{-1}	0.20	0.95	0.35	0.02
NPK rates equivalent manure 160 t ha^{-1}	0.22	1.43	0.28	0.04
Manure 40 t ha^{-1} + NPK rates equivalent manure 40 t ha^{-1}	0.24	2.25	0.34	0.05
Manure 80 t ha^{-1} + NPK equivalent rates	0.24	2.25	0.34	0.05
Manure 160 t ha^{-1} + NPK equivalent rates	0.25	2.38	0.25	0.05
LSD_{05}	0.04	0.8	Fф<Fт	0.01
MPC*	3	23	6	-

*MPC – maximum permissible concentration

Average crops productivity in fifth rotation varied from 2831 to 3859 FU as influenced by fertilization systems. The maximum yields, but minimum crop returns were obtained from combination of manure total rate 160 t ha^{-1} within rotation and equivalent mineral fertilizer' application. The highest crop returns were obtained after mineral fertilizers application.

Mineral fertilizers and manure may be the sources of heavy metals soil contamination. So, heavy metals content evaluation was one of the aims of given experimental work. All studied fertilization systems have not led to soil pollution by mobile forms of heavy metals (Cu, Zn, Pb, Cd). Their content in soil was far from maximum permissible concentration (Table 3). Fertilizers application caused small rising of Zn content – from 1.20 to 2.38 mg/kg. Some decreasing of copper content was noted: from 0.33 mg/kg (control) to 0.20–0.25 mg/kg, without express tendency according the treatment. Probably, it was caused by Cu off take with greater yields. Variations of Pb and Cd concentration were insignificant.

Conclusion

Joint application of manure and mineral fertilizers in rates nor less than manure 40 t ha^{-1} + NPK in doses equivalent manure 40 t ha^{-1} promoted humus accumulation in soil, guaranteed mobile phosphorus and exchange potassium content raise, soil status quo in regard to acidity and base saturation.

All studied fertilization systems have increased crops yields in field eight-course rotation, but the highest supplements were obtained by application of complex fertilization systems with manure rates 80 t ha^{-1} and more. Average crops productivity in fifth rotation varied from 2831 to 3859 FU as influenced by fertilization systems. The maximum yields, but minimum crop returns were obtained from combination of manure total rate 160 t ha^{-1} within rotation and equivalent mineral fertilizer' application. The highest crop returns were gained after mineral fertilizers application.

Long-term application of organic and mineral fertilizers has not caused soil pollution by heavy metals above MPC and MPL.

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Received October, 23, 2015; accepted for printing April, 14, 2016