International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-4, April 2019

Phytomelioration as a Factor of Increasing Fertility, Productivity of Crop Rotation and Improving Soil Moisture Dynamics of Southern Black Soil

Anatoliy Petrovich Solodovnikov, Dmitriy Aleksandrovich Upolovnikov, Fedor Petrovich Chetverikov, Batyr Zainullinovich Shagiev, Konstantin Igorevich Pimonov

Abstract*: *A new farming system has been proposed, which combines phytomelioration and minimization of primary tillage for saving the water-physical factors of southern black soil fertility and productivity of spring crops of early grain crops cultivated in field crop rotation. During the research, it has been found that minimization of tillage during a crop rotation that includes 3 years of using the alfalfa phytomeliorant contributed to longer preservation of soil fertility.

It has been experimentally found that plowing on a layer of alfalfa increased air permeability by 53 %, and disk plowing by 171 %. The greatest permeability in the variant with minimal tillage was noted in case of soil overturning, which amounted to 112 mm/hour. During the first year after plowing into the phytomeliorant, the moisture content in the one meter thick soil layer increased by 0.8 % after plowing, and by 1.3 % after disk plowing. The highest increase in the soil moisture was noted in the third year – 1.3 – 1.5 %, which amounted to 18.2 – 21.0 mm of moisture.

The yield of grain crops in case of minimal tillage in a crop rotation with the phytomeliorant exceeded the reference by 6.0 – 73.2 % in the first year, by 16.9 – 60.9 % in the second year, by 24.6 – 56.7 % in the third year after harrowing the soil after alfalfa, by 11.0 – 57.5 % in the fourth year, and by 10.9 – 44.0 % in the fifth year. In the plowed variants in field crop rotation, the after-effect of phytomelioration ended by the fifth year. The yield data for barley and oats were within the error of the experiment, compared to the reference variant (with the use of lentil instead of alfalfa). In the variants with minimal tillage, the productivity of barley increased by 16.3 %, and that of oats increased by 10.9 % in the fifth field of crop rotation, compared to the reference.

In the sixth field, after tillage of an alfalfa field in the variant with the use of conventional dump tillage in crop rotation, the productivity of spring cereals was lower by 7.1 – 16.1 %, compared to the reference. The combination of phytomelioration and minimum tillage, the grain yield was the same as in the reference.

Index Terms*: *phytomelioration, dump, and minimum tillage, soil moisture, permeability, spring wheat, oats, barley, lentil.

Manuscript published on 30 April 2019.
***** Correspondence Author (s)
Anatoliy Petrovich Solodovnikov*, Saratov State Vavilov Agrarian University, Saratov, Russia.
Dmitriy Aleksandrovich Upolovnikov, Saratov State Vavilov Agrarian University, Saratov, Russia.
Fedor Petrovich Chetverikov, Saratov State Vavilov Agrarian University, Saratov, Russia.
Batyr Zainullinovich Shagiev, Saratov State Vavilov Agrarian University, Saratov, Russia.
Pimonov Konstantin Igorevich, Don State Agrarian University, Rostov region, Russia.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/4.0/

I. INTRODUCTION

Insufficient use of organic fertilizers and phytomelioration on the basis of classical soil treatment with the overturning of the soils with low humus content results in deterioration of soil physical and hydrophysical properties, and, consequently, lower productivity of crop rotation. Therefore, the development of a new system of agriculture that combines phytomelioration and minimizing main tillage is relevant.

Restoring soil fertility by perennial and biennial herbs has been discussed in many works, but without regard to the after-effect and minimization of main tillage after phytomelioration [1-12].

In the experiments, the authors used alfalfa, which has several botanical and biological features, as the phytomeliorant. An important advantage of alfalfa is its ability, in the symbiosis with rhizobia, to assimilate molecular nitrogen from the atmosphere, and to accumulate it in the roots and crop residues [13, 14]. It has a deeply located powerful root system which improves soil structure, increases its water and air permeability, and prevents water and wind erosion [15]. Alfalfa leaves up to 10 tons of organic matter with the roots and stubbles; this organic matter contains up to 120 – 150 kg/ha of nitrogen. In this regard, the formation of perennial legumes is one of the best precursors for the vast majority of field crops. This also stabilizes and restores soil fertility [16].

The process of water infiltration in the soils is of great importance for creating good moisture reserves in the soil. The flow of moisture in the soil at full water-bearing capacity is divided into two stages: the stage of absorption, which is dominated by the process of filling large and free pores with water (water permeability); and the stage of filtration, when the water passes through the pores (capillaries) filled with water [17].

The research was aimed at studying the combined effects of phytomelioration and methods of main tillage (dump and minimum tillage) on the water regime of southern black soil and the yield of spring wheat, oats, barley and lentil in the conditions of the Saratov region.

© Copyright: All rights reserved.

II. METHODS

The experiments were performed at the experimental field of the Saratov State Agricultural University n.a. N. I. Vavilov in 2009 – 2015. The soil at the experimental plot was represented by southern black soil containing 3.1 – 3.2 % of humus. Main soil tillage after alfalfa of the third year of use was performed during 2009 – 2012. By the many years' average data, in the area of the experiments, there were 132 mm of rainfall during the vegetation period of spring early crops (May to July). In 2010, from May to July, there were 72.3 mm of rainfall, in 2011 – 79.6 mm, in 2012 – 80.2 mm, in 2014 – 110.1 mm, respectively, by 59.7; 52.4; 51.8, and 21.9 mm less than the many years' average norm, in 2013, the total rainfall for the period was 222.2 mm, in 2015 – 138.3 mm, which exceeded the many years' average by 90.2 and 6.3 mm.

The experiments were performed in a field crop rotation that included the following alternation (factor A):

1. lentil, spring wheat, oats, barley (reference 1);
2. meliorative field (alfalfa of 3 years of use), spring wheat, oats, barley, spring wheat, oats, barley;
3. meliorative field (alfalfa of 3 years of use), oats, barley, spring wheat, oats, barley, spring wheat; and
4. meliorative field (alfalfa of 3 years of use), barley, spring wheat, oats, barley, spring wheat, oats.

Two methods of main soil tillage were studied (factor B):

1. dump plowing with plow PLN-5-35 to the depth of 23 – 25 cm (reference 2);
2. minimal tillage with a disc harrow Catros-3001 to the depth of 10 – 12 cm.

The experiment was repeated 4 times. The area of the experimental plots was 250 m^2, that of the accounting plots – 150 m^2. The plots were placed randomly. Variety of spring wheat was Favorite, of oats – Skakun, of barley – Nutans 642, of lentil – Vekhovskaya, and of blue alfalfa – Diana.

The field experiment was accompanied by observations and studies in accordance with the generally adopted practices and guidelines [17-19].

Agrotechnics in the experiment: after harvesting of predecessors, the experimental plot was treated with herbicide Roundup at the rate of 4 l/ha. Main tillage was performed 2 weeks after spraying with the herbicide, according to the scheme of the experiment.

III. RESULTS

Improving physical and mechanical properties of the soil using the phytomeliorant promotes the higher accumulation and efficient use of moisture. Monitoring soil permeability has shown that dump tillage after alfalfa helped to increase this indicator to 161 mm/hour, i.e. by 53 %; while minimum tillage – by 171 %. The maximum permeability in the variant with minimum tillage after alfalfa (the phytomeliorant) was observed in case of soil turnover – 112 mm/hour. By the fourth year of cultivating cereals, soil permeability decreased by 18 %, compared to dump tillage, and only by 4 %, compared to minimal tillage. By the sixth year, soil treatment with soil turnover resulted in a permeability decrease down to 107 mm/h, which corresponded to the background values (105 mm/h). In the variant with minimal tillage, soil permeability was higher than in the reference by 13 mm/h, or 26 % (Table 1).

Minimal tillage with a disc harrow resulted in a decreased permeability, compared to plowing, in the first year by 34 %, in the second year – by 29 %, in the third year – by 28 %, and in the sixth year – by 42 %. The decreased permeability in the variants where disk harrow Catros-3001 was used may be attributed to increased spraying of structural aggregates to the mechanical particles that silt in (decrease the permeability of) capillary pores. In addition, decomposition of organic matter of alfalfa in the conditions of insufficient moisture in case of minimal tillage occurred to a greater extent at the expense of anaerobes, and in case of dump tillage – due to aerobic microorganisms.

Table 1. Water permeability of soil in spring crops by to variants of the experiment, mm/h

Tillage	Year of crop rotation with the phytomeliorant						Grain crop rotation with lentil (reference)
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	
dump (reference 1)	161	159	151	132	115	107	105
minimal	106	112	108	102	81	62	49

Improved soil permeability in crop rotation with an ameliorative field had an influence on the accumulation of moisture during the autumn-and-winter period (Table 2).

Table 2. Soil moisture before sowing spring crops in the 1.0 m layer, percentage from the weight of absolutely dry soil

Variant		Years of research after phytomelioration/rotation					
	method of	2010 – 2013	2011 – 2014	2012 – 2015	2013 – 2015	2014 – 2015	2015

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)
© Copyright: All rights reserved.

crop rotation (factor A)	tillage (factor B)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
crop rotation with lentil (reference)	dump (reference 1)	19.6	19.7	19.5	19.4	19.3	18.8
	minimal	17.8	18.2	17.9	18.3	18.0	17.1
crop rotation with alfalfa	dump	20.4	20.9	20.8	20.2	19.7	18.6
	minimal	19.1	19.6	19.4	19.6	19.1	17.5
Increase in soil moisture in a crop rotation with the phytomeliorant compared to the reference							
crop rotation with alfalfa	dump	0.8	1.2	1.3	0.8	0.4	-0.2
	minimal	1.3	1.4	1.5	1.3	1.1	0.4

In the first year after phytomelioration, soil moisture in the one-meter thick layer increased by 0.8 % in case of dump tillage, and by 1.3 % in case of minimal tillage. The maximum increase in soil moisture in the grass level, compared to reference 1, was noted in the third year, and amounted to 1.3 – 1.5 % of the weight of absolutely dry soil. The calculations show that during the third year, additional 18.2 – 21 mm of moisture accumulated, during the fourth year – 11.2 – 18.2 mm, and during the fifth year – 5.6 – 15.4 mm. It can be noted that minimum tillage with a disc tool after phytomelioration had greater effect on moisture accumulation in the one-meter layer of soil, compared to a crop rotation with lentil. A positive effect after such tillage remained evident for 6 years, and after plowing – for only 5 years. A final criterion of the developed agricultural system is its performance, which is characterized by product yield per unit area. Accounting for the grain yield of spring wheat and barley in a grain crop rotation with the use of the alfalfa phytomeliorant has shown that the maximum difference was observed in perennial grasses. The growth of spring wheat and barley yield in the variants with plowing amounted by crops to 0.60 and 0.33 t/ha, or 50.0 and 22.0 %, accordingly, and in the variants with minimum tillage – to 0.71, 0.36 t/ha, 73.2; 28.6 % (Tables 3, 4). Oats productivity in case of plowing increased on average over 4 years (2010 – 2013) by 0.19 t/ha, or 10.6 % (Table 5). In the variant with disk harrowing, it increased by 0.10 t/ha, or 6.0 %.

On the turnover of perennial grass (2011 – 2014), the highest yield growth was observed in spring wheat in the variant with turnover – 47.6 %, while after minimum tillage with a disc tool to the depth of 10 – 12 cm, the yield growth was 60.9 %. The smallest yield growth was observed in the case of oats cultivation and amounted to 15.3 % and 16.9 %, respectively.

Table 3. Spring wheat grain yield, t/ha

Variant		Years of research after phytomelioration/rotation					
crop rotation (factor A)	method of tillage (factor B)	2010 – 2013	2011 – 2014	2012 – 2015	2013 – 2015	2014 – 2015	2015
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
crop rotation with lentil (reference)	dump (reference 1)	1.20	1.28	0.93	0.89	0.87	0.84
	minimal	0.97	1.10	0.81	0.80	0.84	0.75
crop rotation with alfalfa	dump	1.80	1.89	1.29	1.32	1.14	0.78
	minimal	1.68	1.77	1.27	1.26	1.21	0.74
yield growth in a crop rotation with the phytomeliorant, compared to the reference							
crop rotation with alfalfa	dump	0.60	0.61	0.36	0.43	0.27	-0.06
	minimal	0.71	0.67	0.46	0.46	0.37	-0.01
LSD_{05} (for factor A)		0,12	0.13	0.11	0.14	0.11	0.15
LSD_{05} (for factor B)		0,09	0.08	0.08	0.08	0.07	0.07
LSD_{05} (for factor AB)		0,10	0.11	0.09	0.11	0.10	0.12

In the third year of dump tillage in a crop rotation with the phytomeliorant (2012 – 2015), the growth of spring wheat productivity, compared to reference, was 0.36 t/ha, for disk harrowing – 0.46 t/ha; for oats – 0.29 t/ha and 0.32 t/ha; for barley – 0.24 t/ha and 0.29 t/ha. By the fourth year (2013 – 2015) of spring grain crops cultivation, the phytomeliorative efficiency of alfalfa dropped to 9.8 – 48.3 % in case of plowing, and to 11.0 – 57.5 % for disk harrowing. The decreased efficiency of the phytomeliorant is probably due to mineralization of the organic residues delivered to the soil by alfalfa.In the plowed variants in a crop rotation with the use of the alfalfa phytomeliorant, no yield growth of barley (-0.08 t/ha) and oats (+0.04 t/ha) was observed by the fifth year, compared to the reference; these deviations were within the experimental error. Minimization of main tillage increased the productivity of barley by 16.3 %, and of oats – by 10.9 %.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)
© Copyright: All rights reserved.

Table 4. Barley grain yield, t/ha

Variant		Years of research after phytomelioration/rotation					
crop rotation (factor A)	method of tillage (factor B)	2010 – 2013	2011 – 2014	2012 – 2015	2013 – 2015	2014 – 2015	2015
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
crop rotation with lentil (reference)	dump (reference 1)	1.50	1.57	0.98	1.08	1.09	1.13
	minimal	1.26	1.36	0.79	0.86	0.86	0.93
crop rotation with alfalfa	dump	1.83	1.81	1.22	1.19	1.01	1.03
	minimal	1.62	1.64	1.08	1.14	1.00	0.91
yield growth in a crop rotation with the phytomeliorant, compared to the reference							
crop rotation with alfalfa	dump	0.33	0.24	0.24	0.11	-0.08	-0.10
	minimal	0.36	0.28	0.29	0.28	0.14	-0.02
LSD_{05} (for factor A)		0,10	0.09	0.09	0.10	0.09	0.10
LSD_{05} (for factor B)		0,08	0.06	0.06	0.07	0.05	0.06
LSD_{05} (for factor AB)		0,08	0.10	0.09	0.11	0.08	0.08

In 2015, 6 years after dump tillage of an alfalfa field, the productivity of spring grain crops was lower than in a crop rotation with lentil by 7.1 – 16.1 %. With minimal tillage, the yield was at the level with reference 1.

Analysis of the results obtained has shown that spring cereals in a crop rotation with alfalfa are more responsive to minimum tillage, compared to a crop rotation without the phytomeliorant. On average over the 5 years, spring wheat yield growth in case of disk harrowing to the depth of 10 – 12 cm was 0.53 t/ha, or 58.8 %, and in case of plowing – 0.45 t/ha, or 43.0 %. Oats and barley productivity growth in case of minimal tillage was observed for 5 years, and was 14.1 % and 26.2 %, respectively, while in case of dump plowing, it was observed for only 4 years, and amounted to 13.8 % and 18.0 %.

Table 5. Oats grain yield, t/ha

Variant		Years of research after phytomelioration/rotation					
crop rotation (factor A)	method of tillage (factor B)	2010 – 2013	2011 – 2014	2012 – 2015	2013 – 2015	2014 – 2015	2015
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
crop rotation with lentil (reference)	dump (reference 1)	1.79	1.89	1.48	1.53	1.32	1.24
	minimal	1.66	1.71	1.30	1.36	1.10	1.19
crop rotation with alfalfa	dump	1.98	2.18	1.77	1.68	1.36	1.04
	minimal	1.76	2.00	1.62	1.51	1.22	1.19
yield growth in a crop rotation with the phytomeliorant, compared to the reference							
crop rotation with alfalfa	dump	0.19	0.29	0.29	0.15	0.04	-0.20
	minimal	0.10	0.29	0.32	0.15	0.12	0.01
LSD_{05} (for factor A)		0,09	0.09	0.07	0.10	0.09	0.10
LSD_{05} (for factor B)		0,08	0.06	0.06	0.07	0.05	0.06
LSD_{05} (for factor AB)		0,08	0.10	0.09	0.11	0.08	0.08

IV. CONCLUSION

Minimization of main tillage in a crop rotation with the use of the phytomeliorant allowed preserving soil fertility for a longer period. During the first year of alfalfa, dump plowing increased permeability by 53 %, and minimal treatment – by 171 %. By the sixth year of plowing with soil turnover, permeability was the same as in the reference, and in case of minimal tillage, it was higher by 26 %.

In the first year tillage after perennial grass, soil moisture increased by 0.8 % in the case of plowing, and by 1.3 % in case of minimal tillage. The highest growth of soil moisture was observed in the third year – 1.3 – 1.5 %, which amounted to 18.2 – 21.0 mm of moisture. Spring cereal crops in field crop rotations with the use of phytomeliorant are more responsive to minimal tillage, compared to a field crop rotation that includes a field of lentil.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)
© Copyright: All rights reserved.

The increased productivity was observed for 5 years: for spring wheat – 58.8 %, for oats – 14.1 %, for barley – 26.2 %; while in case of dump plowing, it was observed for only 4 years for oats and barley, 13.8 % and 18.0 %, respectively. Spring wheat is the most responsive to phytomelioration, and oats are the least responsive to it.

ETHICAL PERMISSION

Ethical permission has been obtained from the Commission of the Department of Agriculture, Land Reclamation, and Agricultural Chemistry of the Federal State Budgetary Educational Institution of Higher Professional Education Saratov State Agrarian University named after N. I. Vavilov of the Ministry of Agriculture of the Russian Federation.

RESEARCH FUNDING SOURCE

Federal State Budgetary Educational Institution of Higher Professional Education Saratov State Agrarian University named after N. I. Vavilov of the Ministry of Agriculture of the Russian Federation.

CONFLICT OF INTERESTS

The authors confirm the absence of conflict of interests in the article sent for publishing.

REFERENCES

1. V. A. Gankin, E. P. Denisov, A. P. Solodovnikov, G. I. Shesterkin, “Vliianie mnogoletnikh trav na agrokhimicheskie svoistva pochvy i urozhainost posleduiushchikh kultur” [The influence of perennial herbs on the agrochemical properties of soil and the yield of subsequently sown crops], Bulletin of the Saratov State Agrarian University n.a. N. I. Vavilov, 2, 2005, pp. 5 – 6.
2. E. P. Denisov, A. P. Solodovnikov, K. E. Denisov, “Netraditsionnye mnogoletnie kultury v kachestve fitomeliorantov” [Nontraditional perennial crops used as phytomeliorants], Niva Povolzhya, 2(7), 2008, pp. 14 – 18.
3. E. P. Denisov, A. P. Solodovnikov, K. E. Denisov, Effektivnost kompleksnykh fitomelioratsii v Povolzhye [Efficiency of complex phytomelioration in the Volga region]. Saratov: FSBEI HPE "Saratov State Agrarian University", 2007.
4. E. P. Denisov, A. P. Solodovnikov, A. S. Mokin, “Uluchshenie agrofizicheskikh svoistv iuzhnykh chernozemov pod vliianiem mnogoletnikh trav” [Improving agrophysical properties of southern black soils under the influence of perennial herbs], Forage Production, 3, 2006, pp. 19 – 21.
5. I. V. Kirichkova, Priemy povysheniia produktivnosti mnogoletnikh trav, i ikh vliianie na plodorodie pochv v usloviiakh Nizhnego Povolzhia [Methods of improving the productivity of perennial herbs and their influence on soil fertility in the Lower Volga region]: abstract of a diss. ...Doctor of Agricultural Sciences, Kinel, 2009.
6. E. P. Denisov, A. P. Solodovnikov, N. P. Molchanova, D. G. Shesterkin, R. Z. Tugushev, “Mnogoletnie travy kak predshestvenniki i fitomelioranty zernovykh kultur” [Perennial herbs as precursors and phytomeliorants for crops], Bulletin of the Saratov State Agrarian University n.a. N. I. Vavilov, 11, 2013, pp. 23 – 27.
7. K. I. Pimonov, S. P. Tokareva, Indigo woad: monograph, Don State Agricultural University, 2018.
8. K. I. Pimonov, A. M. Struk, G. P. Kutuzov, “Biological features and the possibility of economic use of Indigo woad”, Forage Production, 9, 2010, pp. 28 – 30.
9. K. I. Pimonov, Optimization of nutrition and cultivation of untraditional crops on ordinary black soil in the zone of unstable moistening: diss. ...Doctor of Agricultural Sciences, Rostov-on-Don, 2012.
10. A. P. Solodovnikov, E. P. Denisov, K. E. Denisov, D. V. Goverdov, “Usloviia formirovaniia urozhainosti mnogoletnikh trav i ikh fitomelioativnaia sposobnost” [The conditions of forming the yield of perennial herbs and phytomeliorative ability], Forage Production, 3, 2006, pp. 14 – 18.
11. E. V. Chernyshov, Izmenenie agromeliorativnykh svoistv chernozema vyshchelochennogo pod vliianiem fitomeliorantov i izvestkovaniia v usloviiakh lesostepnogo Povolzhia [Changes in the soil meliorative properties of leached black soil under the influence of phytomeliorants and liming in the conditions of forest-steppe of the Volga region]: abstract of a diss. cand. of Agricultural Sciences, Penza, 2006.
12. O. L. Shaitanov, R. A. Shurkhno, “Introduction of new species and varieties of perennial herbs as a factor of increasing their environment-forming role”, Forage Production, 7, 2005, pp. 9–13.
13. A. P. Kozhemiakov, Y. V. Laktionov, V. V. Eliseev, “Rol klubenkovykh bakterii v vozdelyvanii bobovykh kultur” [The role of nodule bacteria in cultivation of leguminous crops], Agro-inform, 2014, pp.34 – 36.
14. K.A. Fischbeck, D.A. Phillips, “Host plaut and Rhizobi effects on acetylene reduction in alfalfa during regrowth”, Grop Sc, 22(2), 1982, pp. 251 – 54.
15. A. U. Gazdanov, P. M. Shorin, Z. P. Dzhigkaeva, “Znachenie mnogoletnikh bobovykh i zlakovykh trav v povyshenii plodorodiia pochv i zashchite ee ot erozii” [Importance of perennial legumes and cereals in improving soil fertility and protecting it from erosion], Bulletin of the International Academy of Ecology and Life Protection Sciences, 13(3), 2008, pp. 131 – 133.
16. M. S. Tagirov, O. L. Shaitanov, G. F. Sharipova, “Assessment of organic matter accumulation by new varieties of alfalfa on gray forest soils of Tatarstan”, Agriculture, 3, 2015, pp. 17 – 20.
17. V. M. Goncharov, E. V. Shein, S. I. Zinchenko, Methods of assessing and predicting the agro-climatic and soil parameters in agricultural landscapes, Vladimir: Rost, 2010.
18. B. A. Dospekhov, Metodika polevogo opyta (s osnovami statisticheskoi obrabotki rezulьtatov issledovanii) [The methodology of field experiment (with the bases of statistical processing of research results)] 5th edition, revised and amended. Moscow: Agropromizdat, 1985.
19. B. D. Kiryushin, R. R. Usmanov, I. P. Vasilyev, Osnovy nauchnykh issledovanii v agronomii [Bases of scientific research in agronomy]. Moscow: KolosS, 2009.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)
© Copyright: All rights reserved.