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Optimization of The Soil Agrophysical Properties for Spring Rape on Leached Black Soil

Оптимизация агрофизических свойств почвы под яровой рапс на выщелоченном черноземе

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Abstract

An important agronomic task in cultivating spring rape is improving the physical properties of leached black soil, which are extremely important for increasing its productivity. A central role in the physics of these soils is played by studying its density, which helps regulate the soil processes and maintain favorable conditions for spring rape. According to the studies, the highest productivity of spring rape is observed in the case of the arable layer density of 1.00 – 1.10 g/cm^3. Moreover, in the case of soil density of 1.10 g/cm^3, productivity is better by 5.6 – 8.5 % than in the case of 1.00 g/cm^3. The number of seeds per pod has increased especially strongly (by 13.8 %). In the subsurface layer (30 – 40 cm), soil density of 1.10 – 1.20 g/cm^3 is optimal for spring rape growth and development.

Keywords. Optimal density, soil physical properties, spring rape, yield rate, biometric indicators, vegetative mass, root system, black soil.

Аннотация

Важной агрономической задачей при возделывании ярового рапса является улучшение физических свойств выщелоченного чернозема, которые имеют исключительно важное значение для повышения его продуктивности. Центральное место в физике этих почв занимает изучение ее плотности, при помощи которой можно регулировать почвенные процессы и поддерживать условия, благоприятные для ярового рапса. Согласно нашим исследованиям, наивысшие показатели продуктивности ярового рапса наблюдались при плотности пахотного слоя 1,00-1,10 г/см3. Причем при плотности почвы 1,10 г/см3 показатели продуктивности были лучшими, чем при плотности 1,00 г/см3 на 5,6-8,5 %. Особенно сильно увеличивалось количество семян в стручке (на 13,8 %). В подпахотном (30-40 см) слое для роста и развития ярового рапса оптимальной является плотность почвы 1,10-1,20 г/см3.

Ключевые слова: Оптимальная плотность, физические свойства почвы, яровой рапс, урожайность, биометрические показатели, вегетативная масса, корневая система, черноземные почвы.

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Introduction

Sunflower is the main oil crop in Russia. However, reasonable calculations show that the limiting saturation of arable land rotation with sunflower in the favorable agro-climatic zones does not allow creating the necessary raw material base for vegetable oil and feed protein in the amounts that meet the needs of the population. In solving the problem of vegetable oil and feed protein production, rape is one of the key crops (Artemov & Kiselev, 1997; Artemov & Karpachev, 2005; Shpaara, 2006, 2007; Gulidova, 2000; Gulidova et al., 2016; Gulidova, 2019; Karpachev, 2008; Narizhnii, 1991; Savenkov & Karpachev, 2017; Cramer, 1990). However, despite the favorable conditions for rape growth in many regions of Russia, the state of the rapeseed industry does not meet the modern requirements. There are many reasons for this, and one of them is the problem of creating optimal conditions in the soil for the development of the root system and rape plants in general.

An important agronomic task in cultivating rape plants is improving physical properties of black soil, which are extremely important for understanding soil as a usage object (Kachinskii, 1931). Currently, the agrophysical properties of black soil differ from the optimal values and have a steady tendency to deteriorating. The overcompaction of this soil, the loss of the coarse structure, decreased normal field capacity, and water permeability occur (Shcherbakov & Vasenev, 2000). Soil physics open broad ways for regulating soil processes and maintaining the conditions favorable for biological activity in it through mechanical treatment, irrigation, and land reclamation (Revut, 1972). A central place in soil physics is occupied by studying its density, which depends on the texture and the structural state of soil, and the arable layer – through the technology of crop cultivation (Kuznetsova, 1978; Kuznetsova, 1979).

In studying the mechanism of field crops relationship with soil with various densities, it is first necessary to study the nature of their root systems as organs that are in close contact with soil. The plants' ability to grow at the maximum rate depends on whether the soil they are growing in has the biological, chemical, and physical properties needed by the root system for fully satisfying the plants' need in nutrients and water. The growth rate of a plant depends on the processes that occur both in its shoots and the roots. The products of photosynthesis are formed in the leaf apparatus when the sunlight energy influences the carbon dioxide absorbed from the air and the water absorbed from the soil. These products interact with the minerals entering through the roots and form the compounds required for the growth and development of spring rape plants (Gulidova et al., 2017). The final yield rate may be limited by a shortage of any these substances, regardless of whether they are formed in the shoots or in the roots.

Changing the roots environment is usually easier than changing the environment in which the aboveground organs of plants are located. First of all, this concerns the problem of soil density, since the consistency of the arable layer is one of the significant indicators that can be used for judging about the effectiveness of mechanical treatment for creating the optimal soil consistency, given the biological characteristics of the cultivated crops. Different plants require different soil densities. Each plant on certain soil requires certain optimal density that creates the best conditions for many processes in the soil. With the optimal soil consistency, plants use less nutrients for generating a unit of organic mass.

The optimal soil density is the density at which the yield rate, in otherwise equal conditions, is the highest (Kuznetsova, 1978); it is not the same for various crops. Crops, due to their individual biological characteristics, require certain environmental conditions for normal growth and development, including soil density. For cereal crops, it ranges between 1.10 g/cm^3 and 1.20 g/cm^3, while for root crops, it usually does not exceed 1.0 – 1.10 g/cm^3 (Sidorov & Zezyukov, 1992). Cereal crops respond to compaction weaker than tilled crops (Maillard et al., 1984). With increasing the density of the arable layer by 0.01 g/cm^3 above the optimal value, the yield rate of grain crops decreases on average by 0.06 t/ha (Vasenev & Bukreev, 1993). If the density of leached black soil exceeds 1.20 g/cm^3, and that of ordinary and typical soil with heavy and medium texture exceeds 1.15 g/cm^3 , the growth and development of crops are inhibited, the efficiency of the used fertilizers drops sharply (Viter et al., 2011), and the air permeability decreases by 82 – 97 % (Currie, 1984). The magnitude of the negative effect of soil density on the plants depends not only on its properties but also on the prevailing weather conditions during the growing season (Vasiliev & Revut, 1965), and is more evident in unfavorable hydrothermal conditions (Gritsai, 1982).

Studying the main issues concerning the plants' root system and the mechanisms of absorbing water and nutrients from the soil is important for determining the reasons for low yields and developing the methods for obtaining the maximum yields of spring rape. Spring rape is one of the main oil crops in the Central Black Earth Region, and it is very important to know what soil density ensures its maximum productivity in this cultivation region.

Methods

The influence of the soil density on the productivity of spring rape was studied in a field experiment. The soil with the bulk density of 0.9, 1.0, 1.10, 1.20, and 1.30 g/cm^3 in the 0 – 30 cm layer was manually filled into vessels without bottoms.

An additional experiment was performed for studying the influence of the subsurface layer of 30 – 40 cm with the bulk density of 1.0, 1.20, and 1.30 g/cm^3 on spring rape growth and development. Observations and calculations were performed following the method of B.A. Dospekhov (Dospekhov, 2011).

Results

The habitat of the root system of a plant with its constantly changing temperature, humidity, and the chemical and biological environments – from the stimulating to the toxic ones – could not but contribute to the development of certain requirements to soil density in rape during plant growing. The studies showed that seedlings of rape had appeared almost simultaneously, but they had been more friendly in the variants with the bulk soil weight of 1.20 and 1.30 g/cm^3.

The analysis of the effect of the bulk weight on the biometric parameters of spring rape showed that with the soil density of 1.30 g/cm^3, the decrease in rape productivity had been the most significant in all respects: the weight of seed per plant had decreased by 56.6 %, the weight of 1,000 seeds – by 14.8 %, the plant height – by 45.8 %, the green mass of the crop – by 45.1 %, and the seeds yield – by 56.9 % (Table 1). With the soil density of 1.30 g/cm^3, spring rape showed underdeveloped above-ground part and root system. Moreover, the roots did not penetrate deep into the soil, and were spread on the surface. The topsoil drying created additional unfavorable conditions for the development of the root system and uninterrupted plants' nutrition. This reduced the yield rate.

Table 1.
The productivity of spring rape plants depending on various soil densities in the 0 – 30 cm layer (Gulidova, 2000).

Indications	Soil density in the 0 – 30 cm layer, g/cm^3				
	0.90	1.00 (reference)	1.10	1.20	1.30
Number of pods per plant, pcs	28.5	29.4	28.0	28.1	24.9
Number of seeds per pod, pcs	20.5	21.7	24.7	20.8	17.5
Weight of seeds per plant, g	1.55	1.75	1.90	1.54	0.76
Weight of 1,000 seeds, g	2.6	2.7	2.7	2.6	2.3
Plant height, cm	122.3	136.0	137.7	113.3	73.7
Green mass yield, g/vessel	494.7	530.0	559.7	486.0	291.0
Deviation, + (-) to the reference	-35.3	0.0	+29.7	-44.0	-239.0
Seeds yield, g/vessel	46.6	52.7	57.2	46.2	22.7
Deviation, + (-) to the reference	-6.1	0.0	+4.5	-6.5	-30.0

With the arable layer bulk weight of 1.20 g/cm^3, a negative effect of the density on the biometric indices of spring rape was also noted, but to a lesser extent than with the density of 1.30 g/cm^3. The number of pods per plant decreased by 4.4 %, the number of seeds per pod – by 4.2 %, the weight of seeds per plant – by 12 %, the weight of 1,000 seeds – by 3.7 %, the plant height – by 16.7 %, the green mass yield – by 8.3 %, and the seeds yield – by 12.3 %. Such soil density did not allow the rape root system to develop throughout the entire thickness of the arable layer. It was compactly spaced on the surface and only partially used the nutrients and the available moisture from the soil.

The highest indices of spring rape productivity were observed with the density of the arable layer of 1.00 – 1.10 g/cm^3. Moreover, the following parameters were high: the number of pods per plant (28.0 – 29.4 pcs.) and the number of seeds per pod (21.7 – 24.7 pcs.); also, the seeds were larger (1,000 pcs. – 2.7 g). The green mass yield was 530.0 – 559.7 g/vessel, and that of the seeds – 52.7 – 57.2 g/vessel. With the soil density of 1.10 g/cm^3, the productivity indicators were better than with the density of 1.00 g/cm^3 by 5.6 – 8.5 %. The number of seeds per pod increased especially strongly (by 13.8 %).

With the bulk density of 1.00 – 1.10 g/cm^3, rape had a well-developed vegetative mass, its root system was more evenly distributed throughout the arable layer, which allowed it to use the most of nutrients and productive moisture for growth and development. In this case, it was noted that when the tip of the root penetrated into the soil pores that were larger than it, the tip of the root thickened, compacting the surrounding soil particles so that the soil density in the vicinity of the root increased.

A decrease in the soil density from 1.00 to 0.90 g/cm^3, when the arable layer was loose, negatively affected the growth and development of rape plants. The number of pods and seeds per pod decreased by 3.1 – 5.5 %, the seeds were small, and the plants were lower (by 13.7 cm). The green mass yield was 494.7 g/vessel, which was 6.7 % less than in the reference. The seeds yield decreased by 11.6 %. However, it should be noted that rape productivity on loose soil with the density of 0.90 g/cm^3 was greater than that on dense soil (1.20 g/cm^3). Therefore, loose soil is more preferable for rape than dense soil.

The influence of the subsurface layer (30 – 40 cm) density on rape productivity was insignificant. A decrease in productivity was observed only with the bulk density of 1.30 g/cm^3. The number of pods per plant decreased by 6.8 %, the number of seeds – by 9.8 %, the weight of 1,000 seeds – by 3.8 %, the green mass yield – by 10.9 %, and the seeds yield – by 18.1 % (Table 2).

With the soil density in the range between 1.00 and 1.20 g/cm^3, many biometric indicators of rape productivity (the number of seeds per pod, the weight of 1,000 seeds, the plant height) were almost the same. However, with the density of 1.10 – 1.20 g/cm^3, there were 3.8 % more pods per plant, the weight of seeds per plant increased by 4.4 %, the green mass yield increased by 6.3 – 11.4 g/vessel, and the seeds yield increased by 2.3 g/vessel.

Table 2.
Spring rape productivity depending on various indications of the bulk weight of the subsurface (30 – 40 cm) layer (Gulidova, 2000).

Indications	Bulk weight of the subsurface layer, g/cm^3			
	1.00 (reference)	1.10	1.20	1.30
Number of pods per plant, pcs	29.3	30.4	30.4	*27.3*
Number of seeds per pod, pcs	23.5	22.4	23.8	21.2
Weight of seeds per plant, g	1.80	1.80	1.88	1.47
Weight of 1,000 seeds, g	2.6	2.7	2.6	2.5
Plant height, cm	135.7	141.0	138.0	121.3
Green mass yield, g/vessel	543.3	554.7	549.3	484.3
Deviation, + (-) to the reference	0.0	+11.4	+6.3	-59.0
Seeds yield, g/vessel	54.1	53.9	56.4	44.3
Deviation, + (-) to the reference	0.0	-0.2	+2.3	-9.8

Conclusion

1. The optimal density for spring rape on leached black soil is 1.00 – 1.10 g/cm^3. With this density, the maximum productivity of spring rape has been obtained. Rape had well-developed vegetative mass and root system; the root system was more evenly distributed throughout the arable layer, which allowed it to use most nutrients and productive moisture for growth and development.
2. A decrease in the soil density from 1.00 to 0.90 g/cm^3 has negatively affected rape plants' growth and development.
3. With the soil density of 1.30 g/cm^3, rape had underdeveloped root system and vegetative mass. The decrease in rape productivity had been the most significant in all respects: the weight of the seeds per plant had decreased by 56.6 %, the weight of 1,000 seeds – by 14.8 %, the height of the plants – by 45.8 %, the green mass yield – by 45.1 %, and the seeds yield – by 56.9 %.
4. In the subsurface (30 – 40 cm) layer, the optimal soil density for the growth and development of spring rape is 1.10 – 1.20 g/cm^3.

References

Artemov, I.V. & Karpachev, V.V. (2005). Raps – maslichnaya i kormovaya kultura [Rape is an oilseed and forage crop]. Lipetsk: 143.

Artemov, I.V. & Kiselev, A.M. (1997). Puti razvitiya proizvodstva kormov i rastitelnogo masla [Ways of development of feed and vegetable oil production]. *Feed production,* 4, 2 – 7.

Cramer, N. (1990). Raps. Züchtung, Anbau und Vermarktung von Körnerraps. Eugen Ulmer Verlag Stuttgart, 146.

Currie, J.A. (1984). Gas diffusion through soil crumbs: the effects of compaction and wetting. *Journal of Soil Science,* 6, 1 – 16.

Dospekhov, B.A. (2011). Metodika polevogo opyta (s osnovami statisticheskoi obrabotki issledovanii): uchebnik dlya studentov vysshikh selskokhozyaistvennykh uchebnykh zavedenii po agronomicheskim spetsialnostyam [The methodology of field experience (with the basics of statistical processing of research): a textbook for students of higher agricultural educational institutions in agronomic specialties]. Moscow: Alliance, 351.

Gareev, R.G. (1996). *Raps – kultura vysokogo ekonomicheskogo potentsiala* [Rape is a crop of high economic potential]. Kazan: Publishing House Dom pechati, 240.

Gritsai, A.D. (1982). *Vliyanie plotnosti slozheniya pakhotnogo sloya seroi opodzolennoi legkosuglinistoi pochvy na usloviya razvitiya i produktivnosti rastenii* [The influence of the density of consistency of the arable layer of gray podzolic light loamy soils on the conditions of development and productivity of plants]. Problems of reducing the compaction effect on the soil of tractor running systems, mobile agricultural machinery and working bodies of tillage machines: scientific works of UAA, 59 – 62.

Gulidova V.A., Zubkova, T.V., Kravchenkov, A. Dubrovina, O.A. (2017). The Dependence of Photosynthetic Indices and the Yield of Spring Rape on Foliar Fertilization with Microfertilizers. *Online journal of Biological Sciences,* 17(4), 404 – 407.

Gulidova, V.A. (2000). Teoreticheskie osnovy povysheniya urozhainosti kultur i snizheniya zatrat v sevooborote s rapsom pri raznykh sistemakh osnovnoi obrabotki pochvy v lesostepi TsChR: diss…dokt. s.-kh. nauk [The theoretical basis for increasing crop yields and reducing costs in rape crop rotation for different systems of primary tillage in the forest-steppe of the Central Black Earth Region: diss... doct. of agr.sciences]. Voronezh: 323.

Gulidova, V.A. (2019). *Raps – vysokomarzhinalnaya kultura Rossii* [Rape is a high-margin culture of Russia]. Yelets: Federal State Budgetary Educational Establishment of Higher Education "Bunin Yelets State University", 310.

Gulidova, V.A., Khryukina, E.I. & Sergeev. G.Ya. (2016). *Raps. Sovremennye tekhnologii vozdelyvaniya* [Modern cultivation technologies]. Voronezh: 45.

Kachinskii, N. A. (1931). *Izuchenie fizicheskikh svoistv pochvy i kornevykh sistem pri territorialnykh pochvennykh obsledovaniyakh. Programma i metodika rabot* [The study of the physical properties of the soil and root systems in territorial soil surveys. Program and methodology]. M.: Selkhozgiz, 109.

Karpachev, V. V. (2008). *Raps yarovoi. Osnovy selektsii* [Spring rape. Selection Basics]. Lipetsk: 236.

Kuznetsova, I. V. (1978). *Fizicheskie svoistva yuzhnykh chernozemov Rostovskoi oblasti i nekotorye voprosy ikh obrabotki* [Physical properties of southern black soils of the Rostov oblast and some issues of their tillage]. Physical conditions of the soil fertility, M.: 110 p.

Kuznetsova, I. V. (1979). O nekotorykh kriteriyakh otsenki fizicheskikh svoistv pochv

[About some criteria for assessing the physical properties of soils]. *Soil Science*, 3, 81 – 88.
Maillard, A. Neyroud, A. & Ves, A. (1984). Effect du tassement du sol avant la preparation final du lit de semence. Revue Suisse d' Agriculture, 16(5), 249 – 253.
Narizhnii, I.F. (1991). Ekonomika proizvodstva i ispolzovaniya rapsa [Economics of rape production and use]. M.: Rosagropromizdat. 190.
Revut, I. B. (1972). *Fizika pochv* [Soil physics]. L.: Kolos, 366.
Savenkov, V.P. & Karpachev, V.V. (2017). *Nauchno-prakticheskie osnovy upravleniya agrotekhnologiyami proizvodstva yarovogo rapsa* [Scientific and practical principles of managing agricultural technologies for the production of spring rape]. Lipetsk: Publishing House LSTU, 461.
Shcherbakov, A.P. & Vasenev, I.I. (2000). Antropogennaya evolyutsiya chernozemov [Anthropogenic evolution of black soils]. Voronezh: Publishing House of Voronezh State University, 412.
Shpaara, D. (2006), (2007). Vozobnovlyaemoe rastitelnoe syre (proizvodstvo i ispolzovanie, v 2-kh knigakh) [Renewable plant materials (production and use, in two books)]. St. Petersburg-Pushkin, 416, 348
Sidorov, M.I. & Zezyukov, N.I. (1992). *Zemledelie na chernozemakh* [Agriculture on black soils]. Voronezh: VSAU,184.
Vasenev, I.I. & Bukreev, D.A. (1993). Sposob otsenki kachestva pochvennogo pokrova ekosistem [Method for assessing the quality of ecosystem soil cover]. *Soil science*, 9, 82 – 86.
Vasiliev, A.M. & Revut, I.B. (1965). *Plotnost pochvy optimalnaya dlya rosta selskokhozyaistvennykh rastenii na yuzhnykh karbonatnykh chernozemakh Tselinogradskoi oblasti* [Optimal soil density for the growth of agricultural plants on southern carbonate black soils of the Tselinograd oblast]. Hydrophysics and soil structure. L.: Gidrometeoizdat, 2, 26 – 32.
Viter, A.F., Turusov, V.I., Garmashov, V.M. & Gavrilova, S. A. (2011). Obrabotka pochvy kak faktor regulirovaniya pochvennogo plodorodiya [Tillage as a factor in the regulation of soil fertility]. Voronezh: Publishing House Istoki, 208.