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# Influence of irrigation methods on agrophysical properties and productivity of dark chestnut soils of dry steppe on the left bank of the Volga river

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**Abstract**

The article presents the results of the studies concerning the influence of irrigation methods on agrophysical properties and productivity of irrigated medium loamy dark chestnut soil of dry steppe on the left bank of the Volga river. It is proved that the use of surface irrigation by strip flooding leads to the most unfavorable changes in the agrophysical state of the upper layers of the studied soil difference in comparison with the use of surface irrigation along furrows and sprinkling via wide-grip sprinklers. With strip irrigation the total porosity of the arable and subsurface soil horizons decreases to the greatest extent in comparison with furrows and sprinkling, the proportion of the most agronomically valuable meso-aggregates in the soil structure decreases, while the proportion of small silty micro-aggregates and large macro-aggregates increases to the maximum. All this determines the lowest productivity of irrigated dark chestnut soil after irrigation in strips, as compared to sprinkling and furrow irrigation (spring wheat yield decrease makes 0.55 t/ha and 0.77 t/ha, respectively).

## 1 INTRODUCTION

During the past century, irrigation of agricultural land, along with the chemicalization of agriculture and the introduction of modern methods of breeding new varieties and hybrids of cultivated plants, was one of the main ways to save a significant part of humanity from the problem of hunger. During the period of 1900 - 2010 the increase of irrigated lands was more intensive than the world population increase. Thus, despite almost complete exhaustion of unused and available for cultivation land plots, the transfer of millions of hectares of arable land to urban, transport and industrial territories, the irrigated area per person increased from 296 $m^2$ in 1900 to 405 $m^2$ on our planet (2010), that is, by 36.8% [1].

However, along with a significant increase of agricultural land productivity, irrigation reclamation leads to the deterioration of soil chemical and physical properties almost everywhere, which is caused by radical changes of the water regime and the water balance of territories, a change in soil-forming processes from automorphic to hydromorphic, mechanical action of irrigation water, which washes away the top fertile layer with irrational watering or destroys its structural aggregates with too large drops of artificial rain. At the same time, in hot and arid regions, such as the countries of Central Asia and Pakistan, the main reason for the degradation of irrigated lands, which manifests itself in more than half of their area, is their secondary salinization caused by the soil water regime change or irrigation with saline water. Agrophysical degradation plays a more important role in a temperate climate, for example, in the north of the Lower, south and southeast of the Middle Volga region [2, 3].

The significant influence of irrigation on the soil structure state, its porosity, granulometric, micro- and macro-aggregate composition is noted by many domestic and foreign scientists [4, 5, 6], while the great importance of soil structure in the formation of rainfed and irrigated arable land productivity was also noted by the classic of Russian agricultural science V.R. Williams [7] and modern Western researchers [8].

According to the modern international classification of FAO ON and the World Reference Base for Soil Resources (WRB) [9], quite long-term (more than 50 years) irrigation of dark chestnut soils of the Saratov Trans-Volga region or chestnut soils (kastanozem), occupying the bulk of the irrigated massifs of the region led to significant negative changes in the soil structure.

The proportion of the smallest silty particles increases significantly in the granulometric composition of these irrigated soils as compared with rainfed ones due to coarse-silty and silty particle decrease (0.25-0.05 and 0.05-0.01 $m^{-3}$, respectively). This is due to the crushing of dusty particles - illites (hydromicas), as well as smectites into the particles less than 0.001 mm, which is confirmed by the mineralogical analysis, according to which the content of illites in the silty particles of irrigated soil is 13.8% higher than in rainfed [6, 10].

Besides, as compared to rainfed dark chestnut soil, the content of large aggregates (more than 10-2 m) or lumpiness increases significantly by irrigation, which also adversely affects soil productivity. In the arable horizon, the content increase makes 95.5%, in the subsoil horizon - 35.4%. The increase of the upper horizon density (0 - 0.4 m) of this soil is also negative: by 13.6 - 29.9% as compared to the non-irrigated one [6].

It should be noted that extensive studies concerning the general effect of irrigation on the agrophysical properties of zonal dark chestnut soils have already been carried out by the scientists from the Saratov State Agrarian University and the Volga Research Institute of Hydraulic Engineering and Melioration, but the effect of specific irrigation methods on these indicators has not been studied yet. This article is devoted to the solution of this issue.

## 2 MATERIALS AND METHODS

Field experiments to study the effect of irrigation methods on the agrophysical state and productivity of irrigated dark chestnut soils were carried out (2017-2019) on the fields of LLC "Berezovskoe" in the dry steppe zone of the Saratov Trans-Volga region (Engels district of the Saratov region - Figure 1).

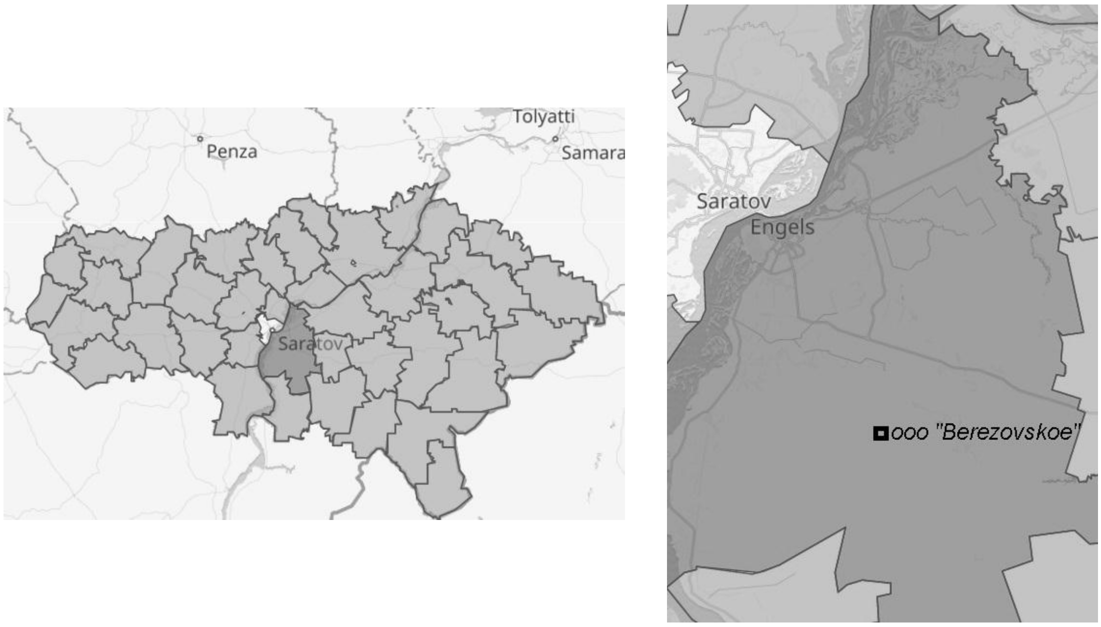



**Fig. 1** – Study area

The soil differences of the field experiment area are typical for these dark chestnut medium loamy zones. Their meter layer is characterized by a bulk density of 1.45 g/cm3, a solid phase density of 2.6 g/cm3, the porosity of 48.5%, and the moisture content with the lowest moisture capacity (LMC) of 23.5% of absolutely dry soil weight.

According to the content of water-soluble salt ions in the soil solution, the soils are classified as non-saline (Figure 2), and to non-alkalinized ones according to the share of exchangeable sodium in the cation exchange capacity (2.6%).

The climate of the research site is sharply continental and arid. The average long-term amount of precipitation in the warm period (from April to October) is 228 mm, active temperatures - 33-10 °C, air humidity deficits - 1875 mbar. The distribution of average annual precipitation, average daily temperatures and air humidity deficits over the decades of the warm season are shown on Figures 3-5.

The experiments were carried out on the field with the slope of 0.006 without a pronounced microrelief. Each variant was performed in triplicate with 3 counting strips (3.6 m wide) and the furrows with the distance between the furrow axes of 0.7 m and 4 protective stripes, 2 on each side. The distance between the experimental plots makes 12 m.

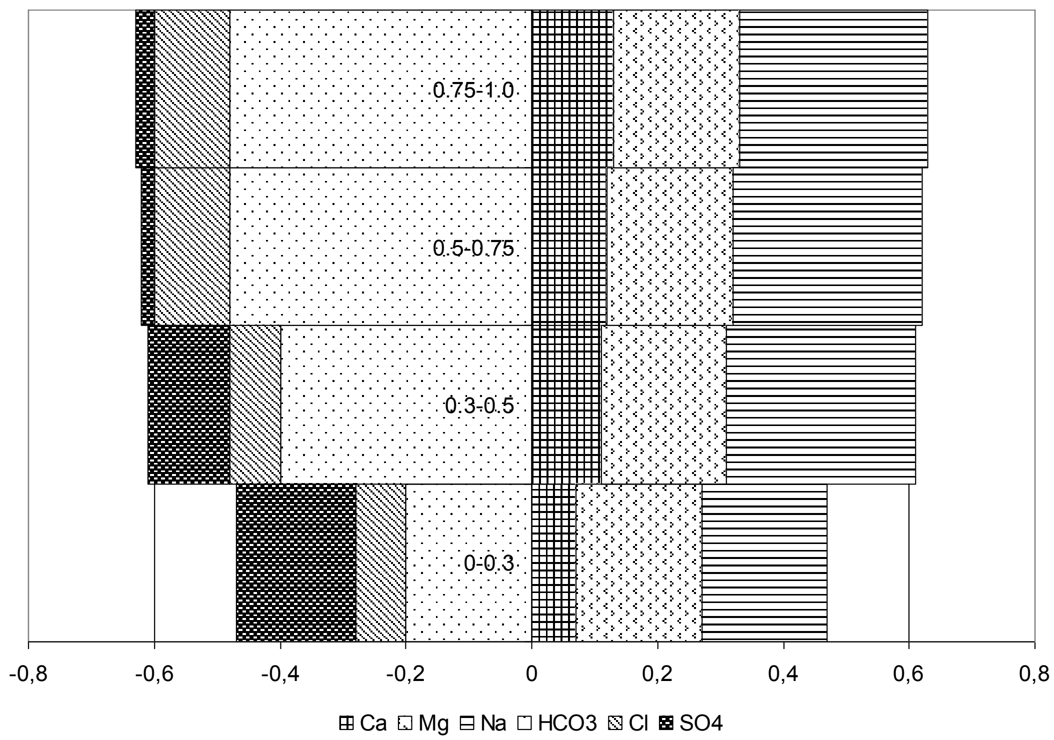



**Fig. 2** – Salt profile of the experimental site soil

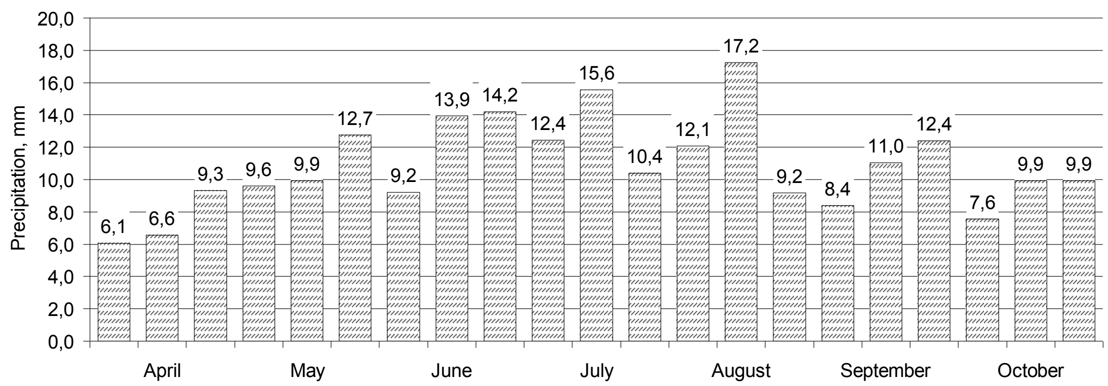



**Fig. 3** – Distribution of average annual precipitation over the warm season decades

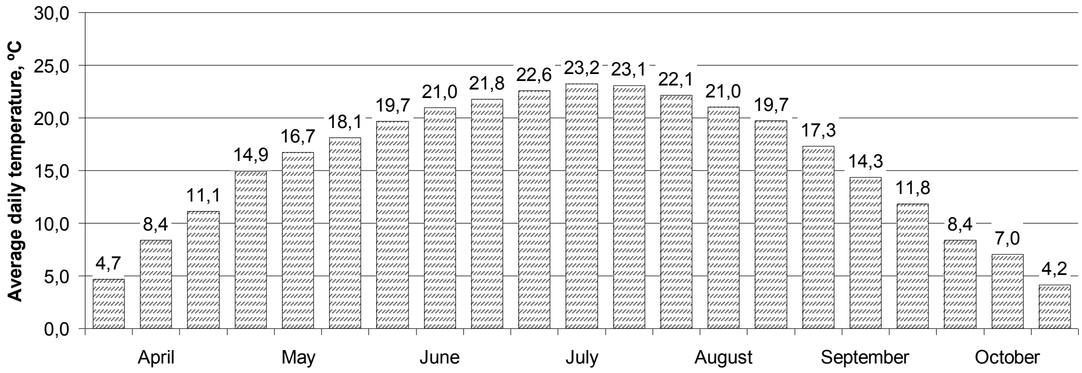



**Fig. 4** – Distribution of long-term average daily temperatures over the warm season decades

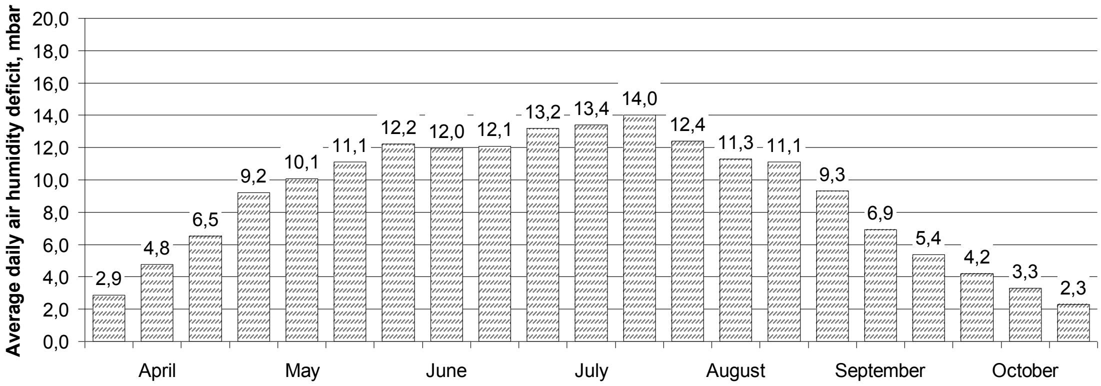



**Fig. 5** – Distribution of long-term average daily air humidity deficits over the warm season decades

The assessment of the effect of different irrigation methods on the productivity of the studied soil variety was carried out by sowing spring wheat on experimental plots, under which mineral fertilizers were applied to all variants with the rate N120P90K60.

Also, in all variants, wheat was irrigated by sprinkling via the Fregat wide-coverage sprinklers. Watering was carried out when the moisture content of the calculated soil layer (0 - 0.8 m) reached 0.7 - 0.75 of the moisture content with the lowest moisture capacity (16.5 - 17.6% of absolutely dry soil weight). This required 3 - 5 waterings, the irrigation rate was 150 - 250 mm.

## 3 RESULTS AND DISCUSSION

When the studies were carried out, it was found that the method of irrigation (surface irrigation by strips and furrows, sprinkling) has a significant effect on the main indicators of the agrophysical state of the upper horizons of the irrigated soil: on its air, water, thermal regimes, the growth and development of plants grown on it, therefore, on its productivity.

So, with irrigation in strips, a stronger soil compaction is observed as compared to irrigation by furrows and sprinkling, the porosity of the soil upper horizons - arable and sub-arable (Figure 6) is significantly reduced. On average, the total soil porosity (with the layer of 0 - 0.3 m) on this option was 2.2% lower as compared to sprinkling, and 1.6% less than furrow irrigation.


| | 0.2-0.3 | 0.1-0.2 | 0.05-0.1 | 0-0.05 |
|---|---|---|---|---|
| control | 47,4 | 51,3 | 51,6 | 51,5 |
| by stripes | 45,5 | 45,4 | 46,6 | 46,1 |
| along furrows | 46,6 | 46,7 | 49 | 46,5 |
| sprinkling | 47,3 | 47,7 | 50,9 | 46,6 |

**Fig. 6** – The total porosity of dark chestnut medium loamy soil with different irrigation methods, %

Significant variability in decrease of dark chestnut medium loamy soil porosity with different methods of irrigation compared to the control one (without irrigation) was observed for different layers of the arable and subsoil horizons (Table 1, Figure 7).

**Table 1.** Reduction of the total porosity of dark chestnut medium loamy soil layers with different irrigation methods as compared to the control one (without irrigation),%

| Layer, m | Total porosity reduction, % | | |
|---|---|---|---|
| | Irrigation by stripes | Irrigation along furrows | Sprinkling |
| 0-0.05 | 5,4 | 5,0 | 4,9 |
| 0.05-0.1 | 5,0 | 2,6 | 0,7 |
| 0.1-0.2 | 5,9 | 4,6 | 3,6 |
| 0.2-0.3 | 1,9 | 0,8 | 0,1 |
| Average | 4,5 | 2,9 | 2,1 |

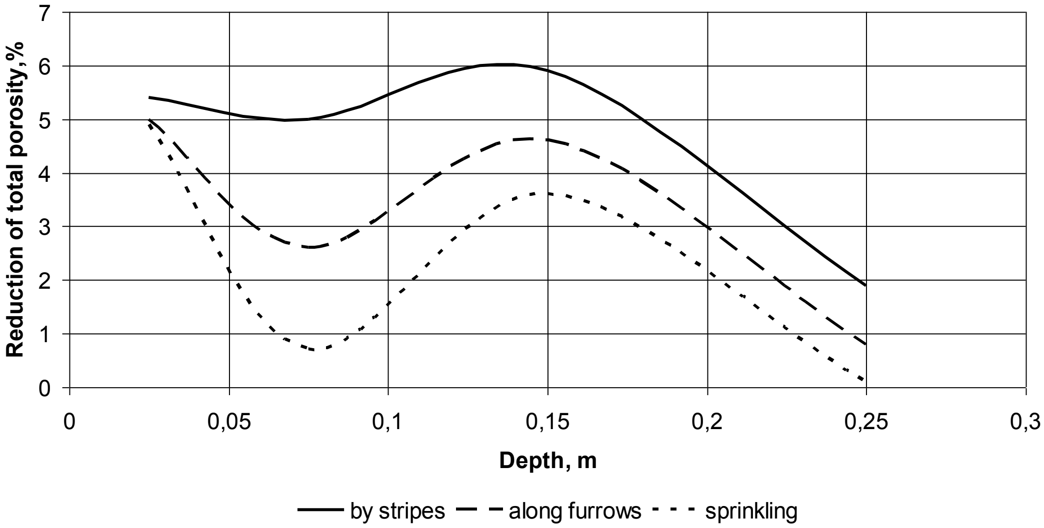



**Fig. 7** – Influence of various irrigation methods on dark chestnut medium loamy soil porosity reduction, %

Differences in the total porosity of dark chestnut medium loamy soil reduction during sprinkling, along the stripes and furrows in the upper layer (0-0.05 m): almost absent (4.9%, 5.4% and 5.0%, respectively). However, such differences are very significant in the underlying layers of the arable horizon. So, the decrease in the total porosity during sprinkling (the layer of 0.05-0.1 m) is much less than the decrease of this indicator of the agrophysical soil state than during irrigation along furrows and, especially, along stripes: 0.7% versus 2.6% and 5.0 %. In the lower part of the arable horizon (the layer of 0.1-0.2 m), such differences in porosity decrease are less pronounced, but remain significant: 3.6% - irrigation by sprinkling, 4.6% - irrigation by furrows, 5.9% (maximum decrease) - irrigation by stripes ...

In the subsurface horizon (the layer of 0.2-0.3 m), the influence of the irrigation method on soil porosity becomes much less significant, but surface irrigation methods (along furrows and, especially, along stripes) in it have a much more negative effect on the duty cycle as compared to sprinkling (decrease makes 0.8, 1.9 and 0.1%, respectively).

On average, the use of irrigation by stripes in the layer of 0-0.3 m of dark chestnut medium loamy soil led to the total porosity reduction by 4.5%, the use of furrow irrigation - by 2.9%, the use of sprinkling - by 2.1%.

Also, various irrigation methods also influenced the meso-aggregate composition (structure) of the upper layer (0-0.1 m) of irrigated dark chestnut medium loamy soil mainly negatively, but with significant differences (Table 2).

Thus, almost in all variants, except for the layer of 0.05-0.1 m, when sprinkling and irrigation was applied along the stripes, the content of large (more than 5 mm) macroaggregates increased. This growth was most pronounced during furrow irrigation: 33.51% in the upper layer (0-0.05 m) and 24.61% in the 0.05- 0.1 layer.

The content of the smallest (< 0.25 mm) dusty micro-aggregates with sprinkling and irrigation by stripes also increased: by 8.12 - 8.42% for stripe irrigation and by 6.8 - 7.12% for sprinkling. On the contrary, when they used furrow irrigation, a significant reduction of this fraction was observed: by 10.15% for the upper layer of 0 - 0.05 m and by 8.84% for the layer of 0.05 - 0.1 m.

**Table 2**. Change in the fraction content of the upper layer (0-0.1 m) of dark chestnut medium loamy soil meso-aggregate composition with various irrigation method as compared to control one (without irrigation), %

| Irrigation method | Soil layer, m | Change in fraction content of macro-aggregate composition, % | | | | | |
|---|---|---|---|---|---|---|---|
| | | > 5 mm | 5 – 3 mm | 3 – 1 mm | 1 – 0,5 mm | 0,5 – 0,25 mm | < 0,25 mm |
| By stripes | 0-0.05 | 3,85 | -6,46 | -47,61 | 2,78 | 9,01 | 8,42 |
| | 0.05-0.1 | -4,29 | -5,86 | -9,23 | 2,53 | 8,73 | 8,12 |
| Along furrows | 0-0.05 | 33,51 | -1,98 | -9,98 | -3,43 | -7,97 | -10,15 |
| | 0.05-0.1 | 24,61 | -2,81 | -4,61 | -0,82 | -7,53 | -8,84 |
| Sprinkling | 0-0.05 | 1,73 | -4,45 | -17,60 | 1,95 | 8,95 | 6,80 |
| | 0.05-0.1 | -6,13 | -5,85 | -7,19 | 0,95 | 7,60 | 7,12 |

The most significant negative change in the meso-aggregate composition (structure) of the upper layers of dark chestnut medium loamy soil was the reduction of agronomically most valuable aggregates (the fraction of 3-1 mm), shown on Figure 8.

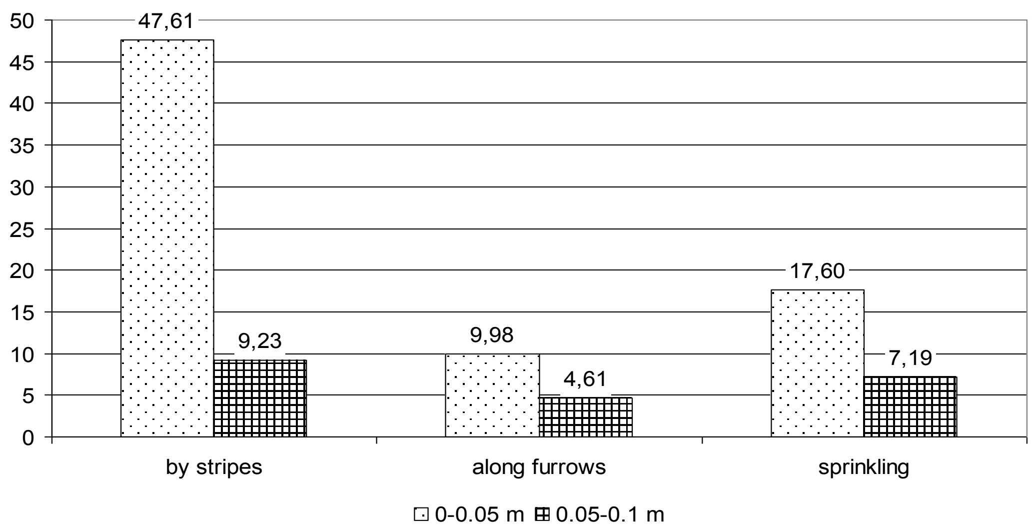
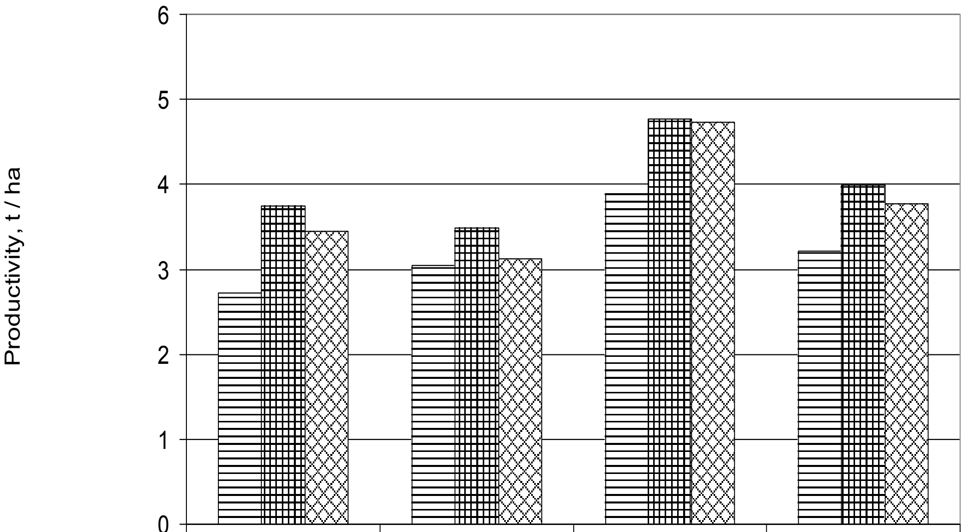



**Рис. 8** – Reduction of agronomically valuable aggregate content in the upper layers of dark chestnut medium loamy soil with different irrigation methods, %

The most significant decrease of mesoaggregates (1-3 mm) was observed during furrow irrigation: by 47.61% in the upper soil layer (0 - 0.05 m) and by 9.23% in the layer (0.05 - 0.1 m). With furrow irrigation, a minimal decrease in the content of these aggregates was noted: by 9.98% and 4.61% in the layers of 0 - 0.05 m and 0.05 - 0.1 m, respectively. The use of sprinkling irrigation was characterized by average rates of such a decrease, namely, by 17.60% in the layer of 0 - 0.05 m and by 7.19% in the layer of 0.05 - 0.1 m.

The changes in the agrophysical properties of the irrigated medium loamy dark chestnut soils of the dry steppe Trans-Volga region resulting from the use of various irrigation methods have led to a significant differentiation of its productivity. The influence of irrigation methods on productivity during field experiments was assessed by the yield of spring wheat cultivated during irrigation.

The research results are presented on the Figure 9 and 10.




| | 2017 | 2018 | 2019 | Average |
|---|---|---|---|---|
| by stripes | 2,72 | 3,04 | 3,89 | 3,22 |
| along furrows | 3,74 | 3,48 | 4,77 | 3,99 |
| sprinkling | 3,45 | 3,12 | 4,73 | 3,77 |

**Fig. 9** – Productivity of irrigated dark chestnut medium loamy soil with different irrigation methods, t/ha

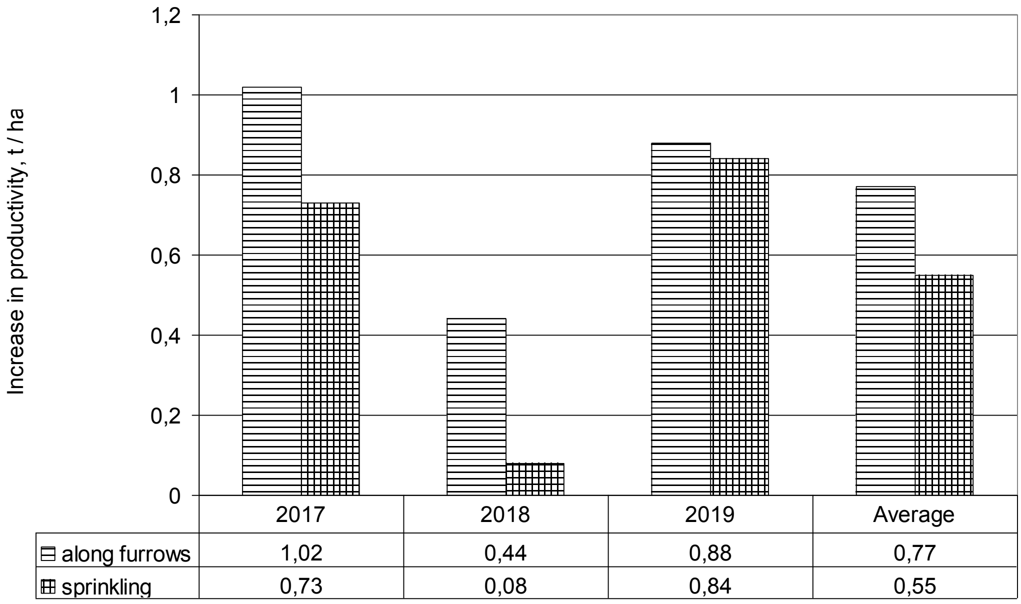



**Fig. 10** – Increase of irrigated dark chestnut medium loamy soil productivity with furrow and sprinkler irrigation as compared to strip irrigation, t/ha

The highest productivity was observed during furrow irrigation: from 3.48 to 4.77 t/ha (3.99 t/ha on average), the lowest productivity - during strip irrigation: from 2.72 to 3.89 t/ha (3.22 t/ha on average). Sprinkling demonstrated medium productivity: the average value was 3.77 t/ha with fluctuations from 3.12 to 4.72 t/ha per year.

## 4 CONCLUSION

In the natural and climatic conditions of the dry steppe of the left-bank areas of the Saratov region, the irrigation methods significantly affect the main indicators of agrophysical well-being and the productivity of zonal irrigated dark chestnut soils.

Under the influence of different methods of irrigation, the total porosity of the arable and sub-arable horizons of the studied soil changed differently, with a general tendency to reduction. The largest drop of this indicator was observed with strip irrigation: in the layer of 0 - 0.3 m by 4.5% on average; the smallest drop was during sprinkling: by 2.1% on average in the layer of 0 - 0.3 m. At the same time, irrigation had a much less effect on the porosity of the subsurface horizon than that of the arable one with all methods of irrigation: its decrease was 1.9%, 0.8% and 0.1% for irrigation by stripes, along furrows and sprinkling, respectively. In the arable horizon (the layer of 0 - 0.2 m), the corresponding indicator was 5.6% for irrigation by stripes, 4.2% for furrows and 3.2% for sprinkling.

Also, under the influence of different irrigation methods, the structure of the upper layers of the irrigated medium loamy dark chestnut soil changed in different ways. For example, when they used strip irrigation and sprinkling in the structure of the upper soil layer (0.1 m), the content of small silty microaggregates increased significantly by 8.27% and 6.96%, respectively, which changed negatively the difference of agrophysical state of the studied soil. On the contrary, when they used irrigation in stripes, the content of such microaggregates decreased by 9.5%.

At the same time, the content of the most valuable agronomic meso-aggregates (1 - 3 mm) decreased in the upper (0 - 0.1 m) layer for all irrigation methods: by 28.42% with strip irrigation, by 12.4% with sprinkling and by 7.3% for furrow irrigation. The loss of valuable agronomic mesoaggregates in the layer of 0 - 0.05 m of irrigated medium loamy dark chestnut soil was especially significant when it was irrigated in strips: 47.61%.

Such unfavorable changes, but different with different irrigation methods, in the agrophysical state of the upper horizons of the main zonal irrigated soil also led to its differentiation in productivity, which was assessed by the yield of spring wheat cultivated on the experimental plot for irrigation using the Fregat sprinkler.

Experimental plots with strip irrigation were characterized by minimal productivity. The yield of spring wheat was higher on average both with sprinkling (by 0.55 t/ha) and with furrow irrigation (by 0.77 t/ha) (2017-2019), which is explained by the following facts: when you use strip irrigation, the greatest decrease is observed in the total porosity of the arable and sub-arable soil horizons, and the greatest decrease in the content of the most agronomically valuable meso-aggregates, as well as a maximum increase of silty micro-aggregates and large macro-aggregates (more than 5 mm) in the seeding layer (0 - 0.1 m).

Increase of spring wheat yield with furrow irrigation was 0.22 t/ha on average (2017-2019) as compared to sprinkling.

Thus, the agrophysical properties of the irrigated medium loamy dark chestnut soil are most adversely affected by flood irrigation in strips. To a lesser extent, such a negative impact is produced by furrow irrigation and sprinkling, and with irrigation in strips, the decrease in total porosity occurs immediately after the first irrigations. When irrigating along furrows and sprinkling, water-resistant meso-aggregates become sprayed micro-aggregates only at the end of the growing season.

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