The impact of transport infrastructure on ecological status of arable land in Western Siberia

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Abstract. The use of deicing compounds and car exhaust have a negative impact on the main indicators of arable fertility. The purpose of the research was to study the physical properties of arable land and crop yields at different distances from the roads. Four soils were studied: sod-podzolic, gray forest, leached chernozem and meadow saline. Soil sampling was carried out along the Tyumen - Omsk and Tyumen - Khanty-Mansiysk highways. It was found that at a distance of 10 meters from the highway structural and aggregate composition of high-humus soils differs from the control, located 200 meters. At a distance of 50 meters or more from the road, physical indicators of arable land come back to normal. The sections adjacent to the roads up to 10 meters wide are overfilled to 1.57 g/cm³, which in the conditions of Western Siberia can cause surface waterlogging. The annual loss of grain from the negative impact of transport infrastructure on the site length of 1 kilometer and a width of 20 meters on leached chernozem is 5.0 tons. At market grain prices in the amount of \$140, the annual loss of farmers corresponds to \$1400 for each kilometer of the road passing through the chernozem fields.

1 Introduction

Western Siberia is a unique region that occupies 15% of the Russian Federation territory. Its area is 2.451 million square kilometers [1]. On the Western Siberia territory is a huge amount of minerals, natural and land resources, which are actively developed in recent decades. Long distances between cities and other settlements and the extremely difficult soil cover of Western Siberia require well-designed transport infrastructure. Historically, people tried to lay a highway on upland sites. At present, the driest sections are also selected for road construction. At long distances, this approach is economically justified.

Non-wetland areas and the most fertile land are also needed for agriculture. These territories are located in Western Siberia, mainly on the hills. As a result, a significant part of the fields is adjacent to the roads. Until the 1980s, this was not a big problem, as the traffic flow was not as intense as it is now. On separate highways intensive round-the-clock movement of cars throughout all year is noted. Especially the flow of heavy-load

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equipment working both on gasoline and on diesel fuel increased. It is demanded from organizations serving roads, active use of deicing compounds and liquids. Ultimately, these substances get on the field. It should also be noted the emergence of a large number of heavy metals, soot, exhaust gases that settle on the soil and crops. This leads to deterioration in the ecological status of agrophytocenoses, fertility reduction and shortage of agricultural products [2, 3].

Significant damage to the soil is caused by deicing mixtures made on the basis of sodium chloride [4, 5]. The cheapest is a mixture of sand and halite or sylvinite. These mixtures, despite their aggressiveness to the metal of cars, are considered to be the most effective and cheapest. It is impossible to abandon them without finding a worthy replacement. Therefore, farmers have to take into account their impact on fertility and crop yields [6, 7].

The purpose of researches. The study the ecological state of arable soils at different distances from major highways Tyumen-Omsk and Tyumen-Khanty-Mansiysk.

2 Materials and methods

Studies were conducted along the highways Tyumen-Omsk and Tyumen-Khanty-Mansiysk. Employees of the Department of soil science and Agrochemistry of the State Agrarian University of Northern Trans-Urals have studied in detail the fields adjacent to the roads in order to establish the classification of soil plots. For 100 kilometers of each highway the following soils were defined: Tyumen-Khanty-Mansiysk – sod-podzolic and gray forest soils; Tyumen-Omsk – leached chernozems and meadow saline soils [8, 9]. The similarity of soil types in areas with different distance from the roads was determined by the structure of the soil profile and properties of parent rocks. The field section, 200 meters away from the highway, was used as a control.

Structural and aggregate composition was determined by dry sowing of soil samples through a sieve column with a hole diameter of 10, 7, 5, 3, 2, 1, 0.5 and 0.25 mm, interconnected from larger diameter to smaller. Coefficient of structure (K_{str}) was calculated by the applicable formula 1:

$$K_{str} = \frac{\sum (10 - 0.25 \text{ mm})}{\sum (> 10 \text{ mm}, < 0.25 \text{ mm})} \quad (1)$$

Water tightness of aggregates was determined by soil sieving in the same column placed in water. The coefficient of water tightness was calculated as the sum of stable water aggregates ranging in size from 10 to 0.25 mm. The density of the composition was determined in field conditions, the volume-weight method using a metal hollow cylinder with a known volume. The measurements were carried out in the layer of 0-10 and 10-20 cm of arable layer in a fourfold repetition at each site. Detailed methods of carrying out these studies are given in E. V. Shein's book "Agrophysics" [10]. Selection of soil samples and determination of the addition density was carried out in the period from 2011 to 2014 at the end of August, just before harvesting crops. In the phase of full ripeness of spring wheat from 1 square meter, all plants were cut and determined the mass of grain, which was converted to biological yield of 1 hectare. Statistical processing of results was performed using Microsoft Excel.

3 Results and discussion

As our studies have shown on the site that is adjacent to the base of the highway, the structural factor corresponds to 1.9 units. It is almost 2 times lower than the values of the

control plot, located 200 meters from the highway. At a distance of up to 20 meters, the structural state of arable chernozem does not improve-the coefficient of structure is not more than 2.0 units (table.1). Taking into account the fact that the only difference between the sites is the distance, we can assume the negative impact of transport infrastructure on the fertility of leached chernozem. At a distance of 50 meters, the structural and aggregate composition of the arable land is improved, this is evidenced by the coefficient of structure (3.2 units.).

Table 1. Changes in the structural factor of the arable layer depending on the distance from the highway, %.

Soil	n*	Distance from the highway, m					
		5	10	20	50	100	200 (control)
Sod-podzolic soil	20	1.8	1.8	2.0	2.0	2.1	2.1
Grey forest soil	14	1.6	1.8	2.4	2.8	3.0	3.0
Leached chernozem	35	1.9	1.8	2.0	3.2	3.2	3.4
Meadow saline soil	12	1.2	1.2	2.3	2.7	2.6	2.7
* n - Number of soil sampling points							

Meadow saline soil in its fertility is slightly inferior to the chernozem. Its structural factor is initially 20% lower than the value of chernozem and in the control area it is 2.7 units. At a distance of 50-100 meters, the influence of transport infrastructure on the structural and aggregate composition was not found-the coefficient of structure did not differ from the control. In the immediate vicinity of the highway, this figure was minimal - 1,2 units. This is more than twice less than the coefficient of structure at a distance of 200 meters from the highway. It should be noted that the meadow saline soil and leached chernozem were located along the same highway, so the intensity of traffic was about the same. Consequently, different types of soils react differently to the proximity of transport infrastructure.

In contrast to chernozems, grey forest soils are characterized by a lower content of humus. This is reflected in their structural-aggregate condition. In the control area of arable gray forest soil, the structural coefficient does not exceed 3.0 units. At a distance of 5 meters from the slope of the road, this figure is much smaller-1.6 units. This proves the negative impact of cars. As in the previous cases, this influence is apparent in areas of fields with a width of not more than 50 meters on both sides of the road.

The minimum negative impact of transport infrastructure on the ecological state was noted on arable sod-podzolic soils. At a distance of 200 meters, the structural factor of the arable layer was 2.1 units, that among the studied soils was the minimum value. This fact is explained by the low humus content and depletion of the upper layer by silty particles as a result of the elluvial-illuvial process. In the section of the field adjacent to the highway, the structural factor was slightly lower than the control values. The lack of a strong negative effect is not a result of the low intensity of traffic on the road, as the grey forest soil is along the same highway. The absence of a decrease in the structural coefficient in the sections of different distances from the road is caused initially by a low structural coefficient. Also on sod-podzolic soil there is a process of leaching of harmful substances from the arable horizon during heavy rains and snowmelt [11].

A qualitative indicator of the ecological status of arable soils is their water resistance to water erosion. Water resistance of soil aggregates depends on humus content and availability of cations of different metals [12, 13]. The best soil for water resistance is considered chernozem. In our case, in the control plot, located 200 meters from the

highway, the water stability of soil aggregates was equal to 54.5 per cent. This was consistent with excellent water resistance (table.2). In the immediate vicinity of the highway, this figure was significantly lower – 45.6%, indicating a man-made violation of the ecological state. At a distance of 10 meters, the water resistance of arable chernozem is not restored. Only at the twenty-meter mark the negative impact of the road weakens and the water resistance of soil aggregates increases to 47.5%. At a distance of 50 meters or more from the road, this indicator reaches the target figures. Causes deterioration in water resistance of soil units adjacent to the road areas are exposure to deicing compounds. These compounds represent sodium chloride or sylvinit, which also contains a sodium ion. Humic substances interacting with ions of monovalent metals lose the ability to glue soil particles into structural units waterproof. During rain or snowmelt, the soil quickly loses its structure and impairs their fertility parameters. A similar process can be observed under natural conditions on saline or saline soils.

Table 2. Water resistance of soil aggregates of arable layer at different distances from the highway, %.

Soil	n*	Distance from the highway, m					
		5	10	20	50	100	200 (control)
Sod-podzolic soil	20	33.0	33.0	35.8	40.5	42.3	42.6
Grey forest soil	14	35.9	36.8	42.0	46.3	47.5	47.2
Leached chernozem	35	45.6	44.2	47.5	52.7	54.2	54.5
Meadow saline soil	12	33.1	34.1	35.0	43.4	43.6	44.3
* n - Number of soil sampling points							

In our study, the water resistance of the control area of meadow saline soil was lower than the values of leached chernozem. The appearance of an additional amount of sodium ions exacerbated the ecological state of the arable land adjacent to the highway. Water resistance of soil aggregates at a distance of 5 meters from the road slope was 33.1%. This indicates that the expression a stronger negative impact compared to the chernozem. This influence can be traced up to 20 meters on both sides of the road. From the mark of 50 meters water resistance of soil aggregates is restored to the value corresponding to the control. It should be noted that the negative impact of transport infrastructure on saline soils is greater than on the rest.

The water resistance of aggregates of the arable gray forest soil in the control area was equal to 47.2%, which corresponds to the average water resistance. The smaller, in comparison with chernozem, water resistance of aggregates of gray forest soil, is explained by its humus condition. As you approach the highway from a distance of 20 meters, the water resistance of gray forest soil decreases. Water resistance of aggregates on the site located 5 meters from the slope is reduced to 35.9%. As the gradient analysis shows, the zone of negative impact of the road on gray forest soils is less, since at the level of 20 meters the water quality of the units is slightly inferior to the control value (42%). The reason for this is the relatively high water permeability of gray forest soils in comparison with chernozems and meadow saline soils.

Sod-podzolic soils are considered to be low humus content and low water resistance. In the control section, the water resistance of the aggregates did not exceed 43%, which is significantly lower than the values of chernozem. On the site, located in close proximity to the highway, the water resistance of soil aggregates was 33.0%, which corresponds to a very low water resistance. The negative effect of the transport infrastructure is manifested at a distance of up to 20 meters. At this point, the water resistance of soil aggregates

increased to 35.8%. At a distance of 50 meters the impact of the highway on water resistance has not been noted.

Changes in the structural and aggregate composition entail deterioration in the density of the addition. This indicator is considered to be one of the fundamental ecological conditions of soils. Due to the annual mechanical processing of fields, the density of the plowing horizon is maintained at an optimal level-1.10-1.20 g/cm³.In the control area of leached Chernozem this indicator corresponds to the optimum (table.3). The remaining soils were compacted. This is characteristic of arable analogues and is not the result of the systemic impact of the transport infrastructure, since the control areas are 200 meters away from the road.

Table 3. Density of the arable horizon, depending on the distance from the road, g/cm³.

Soil	n*	Distance from the highway, m					
		5	10	20	50	100	200 (control)
Sod-podzolic soil	20	1.38	1.35	1.27	1.22	1.25	1.25
Grey forest soil	14	1.51	1.55	1.40	1.25	1.31	1.27
Leached chernozem	35	1.42	1.45	1.33	1.18	1.18	1.21
Meadow saline soil	12	1.57	1.53	1.54	1.41	1.31	1.32
* n - Number of soil sampling points							

The density of plowing chernozem in the immediate vicinity of the highway was 17% higher than the control area and was 1.42 g/cm³. The reason for such a strong seal is smaller water resistance of soil aggregates. They are dispersed during rains, thereby reducing the pore space in the arable horizon. We do not exclude the possibility of mechanical compaction, since the five-meter zone along the highways often serves as a turning point for agricultural machinery. The main cause of overfilling is still considered to be the loss of agronomically valuable structure. As earlier studies showed, the change in the addition density against the background of deteriorating structural-aggregate composition becomes the reason of sharp decline in filtration capacity of the adjacent road sections fields [14, 15]. Also one of the reasons for the deterioration of the addition density at a distance of up to 5 meters from the highway is the washout of clay particles from the surface of road slopes. The reasons for the mechanical nature (wash and compaction by agricultural machinery) cannot explain the overfilling of the arable horizon of chernozem at a distance of 10 meters. At this point, the addition density is 1.45 g/cm³. As you get closer to the mark of 20 meters, the density of the composition is gradually reduced, reaching to 1.33 g/cm³. At a distance of 50 meters and further from the highway, this figure does not differ from the control.

The plot of the field, located on the meadow saline soil was characterized by high density of addition-1.32 g/cm³, due to less favorable structural and aggregate composition. On the most common agricultural crops, the increased density of the plowing horizon does not have a negative impact.

In the immediate vicinity of the road (5 metres) this figure was too high - 1.57 g/cm³. Under natural conditions, such a high density is characteristic of layers with very low permeability. Part of the territory adjacent to the roads is overmoistened, and in the rainy period – flooded, at a distance of more than 5 meters. At 20 metres, the addition density remains critically high 1.54 g/cm³, and at 50 metres - 1.41 g/cm³. The reason for such a strong compaction can only be a strong dispersion of structural units caused by secondary salinity [16].

The density of plowing gray forest soil at a distance of 5 meters from the highway is also higher than the values of chernozem. It reaches 1.51 g/cm^3 , which is 19% more control. The impact of the road can be traced up to 20 meters deep into the fields. At the 50 metres the density of the composition is reduced to control values and is 1.25 g/cm^3 . The reasons for re-compaction of gray forest soil are low humus reserves, initially forming a weak structure. The appearance of sodium ions in the gray forest soil violates the structure formation, thereby further worsening the physical properties of the arable layer.

In arable sod-podzolic soils the density of addition does not differ from the values of gray forest soil and is 1.25 g/cm^3 . However, at a distance of 5 meters from the highway, the addition density is less (1.38 g/cm^3). The negative impact of transport infrastructure is already unnoticeable at a distance of 20 meters. At this point, the density of addition is 1.27 g/cm^3 and no longer increases as the distance from the road. The reason for the minimal impact of the highway on the addition density of sod-podzolic soil is a lighter granulometric composition in relation to gray forest soil and chernozem. Therefore, dispersion of initially unstable to water soil aggregates can not significantly affect the processes of compaction of the arable horizon of sod-podzolic soil [17].

A clear example of changing the ecological state of the territory adjacent to highways is the productivity of arable land in different remote areas. Crops are sharply responsive both to changing soil conditions and the presence of harmful substances and dust in the air.

On leached chernozem in Western Siberia, the farmers get relatively high yields of grain crops. In the control area of arable Chernozem, the average yield for 2011-2014 was 4.21 t/ha (Fig.1). In some years it can reach higher values. Therefore, it is extremely important for farmers that the existing road infrastructure does not have a negative impact on crops. In our studies, the average yield of spring wheat on plots located at a distance of 5 meters from the slope of the highway Tyumen-Omsk, was 1.76 t/ha. It is 2.4 times less than the values of control plot. At a distance of 10 metres from the highway, the yield of spring wheat remains at the same low level. The reason for this, as we have already noted, is the unfavorable ecological situation caused by a set of negative effects on the soil and on growing plants. This proves that a plot width of 10 metres along the highways unsuitable for cultivation for this crop.

At the level of 20 meters, the yield on leached chernozem increases to 2.87 t/ha – grain shortage is 1.32 t/ha or 32% of the control area. Grain loss from the negative influence of transport infrastructure on a stretch of 1 km and a width of 20 meters on leached chernozem is in the amount of 5.0 tons.

At market grain prices in the amount of 140 \$, the annual loss of farmers corresponds to 1,400\$ for every kilometer of the highway passing through the black earth of the field.

A similar situation is observed in the areas of meadow saline soils. The maximum yield, in spite of the alkaline reaction of the soil on average for years of research amounted to 4.15 t/ha. This shows that in conditions of Western Siberia meadow soils are not inferior in fertility to the chernozem and should be classified as the most valuable soils. However, under the influence of the transport infrastructure, the yield of spring wheat at 5 and 10 meters was minimal-1.51-1.56 t/ha. Oppression of crops is also found at a distance of 20 meters from the road – the yield of spring wheat at this level was equal to 2.42 t/ha, which is 42% lower than the values of the control area. The losses in monetary terms were the same as those in the chernozem.

Fig. 1. Changes in the yield of spring wheat depending on the distance from the highway, t/ha (2011-2014).

Low-fertile soil (gray forest and sod-podzolic) form the crop yields significantly lower. In our studies, the yield of spring wheat on these soils was 2.88 and 2.14 t/ha, which is almost 1.5-2.0 times less than the values of leached chernozem. Since the gray forest and sod-podzolic soil initially contains factors that inhibit the growth and development of plants, the negative effect of the road infrastructure is less pronounced. At a distance of 5 meters from the road, the yields in the gray forest soil amounted to 2.05 t/ha, and at a distance of 20 metres - 2.53 t/ha. On sod-podzolic soil, the difference in yield between the control and the marks 5 and 10 are still statistically provable, but at 20 meters and beyond – it is within the measurement error.

4 Conclusion

As a result of studies it was found that the road transport infrastructure of Western Siberia has a negative impact on the fields of width up to 20 meters, adjacent to the roads on both sides. The most severe deterioration is manifested in high-humus chernozems and meadow soils. The coefficient of structureand water resistance of soil aggregates at a distance of up to 20 meters from the road is almost 2 times lower than the control values located 200 meters away. The minimum negative effect of transport infrastructure is manifested on sod-podzolic soils, which initially have adverse agrophysical properties. At a distance of 50 meters or more deterioration of physical properties of arable land was not found. Proximity to roads leads to the appearance of over-compacted areas of fields. On meadow salty soil, the density of the composition reaches 1.57 g/cm3. In Siberia, this can lead to surface waterlogging of the territories adjacent to the roads. Compaction is evident at all sites, 20 meters wide, with the exception of sod-podzolic soils, where this distance is not more than 10 meters.

Yield losses of cereal crops from the effects of transport infrastructure arise as a result of the deterioration of the physical properties of arable land and the negative impact of the cars exhausts. In chernozem, the harvest of spring wheat 10 meters from the road is 1.75 t / ha, which is 2.4 times lower than control. At a distance of 20 meters from the road, yield up to 2.87 t/ha. Minimal loss of harvest is marked on sod-podzolic soil.

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