



RESEARCH ARTICLE

# Effects of crop-rotation system on soil fertility, colloidal particles and irrigation erosion

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## Abstract

This study aimed to evaluate the effects of crop rotation on soil fertility, colloidal particle composition, soil particle content and the loss of humus and nutrients in typical sierozem soils affected by irrigation erosion. The research focused on comparing 3-year-old alfalfa-plowed land with long-plowed soil. Soil samples from the 0–30 cm layer were analysed to determine humus content, colloidal particle group composition and nutrient losses. Results showed that humus content in the plowed layer of 3-year alfalfa fields was 0.38 % in unwashed soil, 0.31 % in heavily washed soil and 0.24 % in areas where particles accumulated from the slope. The proportion of easily decomposable colloid particles (zero group) decreased, while stable first- and second-group particles increased. Soil particle washing was 3.6 times higher in eroded areas. Losses of humus, nitrogen, phosphorus and potassium were reduced by 2.7-, 2.2-, 2.8- and 3.1-fold, respectively. These findings indicate that crop rotation with alfalfa improves soil fertility, enhances colloidal particle stability and reduces nutrient loss in irrigated sierozem soils.

**Keywords:** colloid particles; crop rotation; decomposition coefficient; fertility; irrigation erosion; macro and microstructures; porosity; typical sierozem soil

## Introduction

Sustainable and high-yielding agricultural crops require moderate and favorable climatic conditions, fertile soils, proper land reclamation and productive plant varieties that are resistant to extreme conditions, diseases and pests. Crop performance also depends on appropriate placement and seeding according to the natural soil and climate conditions of each region (1). Additionally, implementing optimal crop rotation, protecting soils from erosion and degradation and using innovative water and resource-saving agro-technologies are essential for maintaining sustainability and productivity (2).

In fact, all soils on which plants can grow crops are fertile, which is how they differ from barren soil, but the fertility of soils varies. Structured, fine-grained, poorly drained soils are usually the most productive. Only such soils can satisfy the plant's demand for water, nutrients and oxygen in large quantities (3). This should not give rise to the idea that it is impossible to grow a high yield on soils with low fertility and structure, because many years of advanced experience in the cultivation of agricultural crops have shown that, on the basis of high agro-technology, it has been proven that it is possible to grow a bountiful crop of cotton and other crops even on

soils that are rapidly decomposing under the influence of irrigation water of our Republic (4). In addition, if proper and rational use of the soil, rotation of agricultural crops, application of local fertilisers, organo-mineral composts and mineral fertilisers to them in scientifically based standards, proportions and periods, its productivity and structure will increase continuously.

A large number of studies show that the structure of the soil, its properties and characteristics, as well as the processes taking place in it, largely depend on the group composition and number of colloidal particles.

When agricultural crops are grown in the system of crop rotation, the water, physical, agro-physical and agrochemical properties of the soil are improved, the amount of colloidal particles and -groups that are difficult to decompose in water increases, the coefficients of soil decomposition under the influence of water are lower than one, the washing of soil particles as a result of irrigation erosion is reduced (5). Therefore, it is important to study colloidal particles in order to determine the level of susceptibility to soil culture and irrigation erosion, as well as to correctly determine the measures to combat leaching processes.

## Materials and Methods

Long-term studies were conducted on the typical sierozem soils subjected to irrigation erosion of the Central Experimental Farm of the former Cotton Research Institute of Uzbekistan (now the Research Institute of Cotton Breeding, Seeding and Cultivation).

Field and laboratory experiments were carried out on the basis of methodological manuals (6). Group compositions of colloidal particles of soil and their quantities were determined in laboratory conditions by the method of batch decomposition (7). Soil analyses were conducted using standard and widely accepted methods (8). Nitrate nitrogen was determined using the Grandval-Lajoux method (9). Available phosphorus was analysed following the Machigin method, while exchangeable potassium was determined using the Protasov method (10). The content of water-resistant macro- and microaggregates was assessed. Soil porosity was calculated based on bulk density measurements obtained using the volumetric cylinder method.

## Results and Discussion

In order to characterise the soil of the experimental field, it was found that the agro-irrigation layer with a thickness of 50–90 cm of typical sierozem soils, which have been irrigated since ancient times, was dug and morphological records were made in the lower parts of the slope where the particles were not washed, strongly washed and washed from the slope. This layer was light sierozem in colour and was observed to change to a mauve or light brown towards the lower layers (3).

When the granulometric composition of the soil was studied, the amount of sand in the plow layer of strongly washed soils (slope 4.50) was 37.3 % and in the lower part of the field, the values were 23.8 % in washed soil and 18.8 % in accumulated soil (4). There were no significant changes in the amount of dust fractions according to the levels of soil leaching. The greatest loss of particles was recorded in strongly washed soil. In strongly washed soil, the amount of physical clay in the 0–30 cm layer was 28.9 % and in unwashed and slope-washed soils, the value was 37.3 % in both cases (1).

The value was 47.4 %. Due to the fact that leaching and accumulation mainly occur in particles smaller than 0.01 mm, the mechanical composition of the soil in the sloping part of the field is lightened and in the skirt part (plume) it is heavy.

When studying the agrochemical properties of the soil before the experiment, it was found that irrigation erosion had a significant effect on the distribution of humus, total nitrogen and total phosphorus along the slope. The highest amount of humus 1.11 %, total nitrogen 0.086 % and total phosphorus 0.162 % was recorded in the tillage layer of the soil where the particles washed from the slope were sitting (accumulated). It was found that these

elements are slightly less in unwashed soil (0.96; 0.075; 0.151 %) and the lowest in heavily washed soil (0.62; 0.051; 0.133 %). It was found that unwashed soils are low in phosphorus, strongly washed soils are very low and soils with washed particles are moderately supplied, while unwashed soils are sufficiently supplied with potassium, strongly washed soils are average and the lower part of the field with washed particles is among the most supplied soils.

The susceptibility of soils to irrigation erosion largely depends on the amount of water-resistant macro- and microaggregates in their content. The data obtained in our research show that after 3-years of plowing alfalfa, the amount of macro and micro aggregates increased in unwashed, strongly washed and washed (accumulated) soils compared to the same type of soil that has been irrigated for a long time. For example, the amount of macroaggregates (> 0.25 mm) in the 0-30 cm layer of unwashed soil that has been irrigated for a long time was 6.9 % in the control option, but after 3 years of plowing with alfalfa, it reached 13.3 %, or almost 2 times, in strongly washed soil. and this indicator increased from 4.2 % to 11.5 %, i.e. increased by 2.5 times (Table 1).

Relatively large amount of water-resistant macroaggregates in soils where washed soil particles are sitting (accumulated) is explained by the settling of humus and nutrient-rich particles washed from the slope during cotton care over the years and 3-year alfalfa plowing.

Volumetric mass of soil is one of the main and most important physical properties of soil. Soil water permeability, moisture capacity, heat and air exchange mode and microbiological activity depend on it.

It is known that the increase in volume mass leads to a decrease in air and moisture in the soil, as a result of which the water and nutrient regime is disturbed and finally, productivity decreases.

In the experiment, the volumetric mass of the soil in the areas subjected to irrigation erosion was 1.37 and 1.46 g/cm<sup>3</sup> in the plowed (0–30 cm) and under-plowed (30–50 cm) layers of unwashed soils that have been irrigated for a long time after plowing annual alfalfa was 1.28 and 1.38 g/cm<sup>3</sup> respectively.

Bulk density was found to be decreased by 0.08 g/cm<sup>3</sup> (Table 2). The same pattern was observed in other types of the studied soil, but the volume mass was slightly higher in the soil where the particles washed down from the slope were sitting (accumulated) and on the contrary, it was lower in the strongly washed soil.

This situation can be explained by the fact that the mechanical composition of the soil on which the particles washed down from the slope are sitting is heavier than that of unwashed and strongly washed soils, as well as the decrease in volume mass of strongly washed soils and the reduction of the physical clay fraction in its composition.

The specific mass of the soil mainly depends on the

**Table 1.** The effect of crop-rotation on the amount of water-resistant macro- and microaggregates of the soil

Level of soil leaching	Layer (cm)	Particle size (mm) and quantity (%)			
		> 0.25		0.25–0.01	
		Formerly plowed soil	3-years alfalfa plowed soil	Formerly plowed soil	3-years alfalfa plowed soil
Not washed	0–30	6.9	13.3	11.1	16.9
	30–50	5.9	11.3	12.2	18.5
Strongly washed	0–30	5.3	12.8	9.7	16.0
	30–50	4.4	11.8	10.9	17.4
The washed particles are sitting	0–30	8.1	17.4	12.2	20.6
	30–50	7.2	15.6	15.5	18.1

**Table 2.** Effect of crop rotation on bulk density, particle density and porosity of soils subjected to irrigation erosion

Level of soil leaching	Layer (cm)	Former arable land			3-years alfalfa plowed soil		
		Volume mass (g/cm <sup>3</sup> )	Relative mass (g/cm <sup>3</sup> )	Porosity (%)	Volume mass (g/cm <sup>3</sup> )	Relative mass (g/cm <sup>3</sup> )	Porosity (%)
Not washed	0–30	1.37	2.71	49.4	1.28	2.69	52.4
	30–50	1.46	2.71	46.1	1.38	2.69	48.9
Strongly washed	0–30	1.33	2.73	51.9	1.26	2.69	53.2
	30–50	1.46	2.73	46.5	1.37	2.70	49.2
The washed particles are sitting	0–30	1.39	2.69	48.3	1.32	2.67	50.6
	30–50	1.48	2.69	45.0	1.40	2.67	47.6

mineralogical composition of the soil. When the solid phase specific masses of irrigation-eroded soil were studied, the highest of 2.73 g/cm<sup>3</sup> was observed in heavily leached soils from old tillage. This indicator was 2.71 g/cm<sup>3</sup> in unwashed soil and 2.69 g/cm<sup>3</sup> in the lower part of the field where soil particles washed down from the slope were sitting. After 3-years of plowing alfalfa, the specific mass decreased compared to the long-irrigated soils and by 2.69 g/cm<sup>3</sup> in the unwashed soil, 2.70 g/cm<sup>3</sup> in the strongly washed soil and in the soil with soil particles washed down from the slope (accumulated) was found to be equal to 2.67 g/cm<sup>3</sup>.

According to the results of the study, it was found that after 3-years of plowing alfalfa, regardless of the levels of irrigation erosion, the porosity of the soil is higher compared to the old, plowed land. In long-tilled soils, porosity in the plow layer (0–30 cm) was 49.3 % in unwashed soil, 51.9 % in heavily washed soil and 48.0 % in slope-accumulated soil. After 3-years of alfalfa cultivation, porosity increased to 52.4, 53.5 and 49.8 %, representing increases of 3.1, 1.6 and 1.8 % respectively. This improvement is attributed to higher humus content, enhanced macro- and microaggregate formation and reduced bulk and particle density.

It is known that the amount of water in the soil affects the rate of humification of plant residues, mineralisation of humus and its transformation into simple salts. All microbiological processes slowdown in dry soil. Only if there is a certain amount of water in the soil, there are favorable conditions for the processes of decay and mineralisation. The supply of nutrients to the plant and all the physiological and microbiological processes taking place in it are carried out through water. Therefore, it is important to have high soil moisture and especially high field moisture capacity in agriculture.

In the old-tilled plots, field moisture capacity in the 1 m soil layer was 20.6 % across unwashed, heavily washed and slope-accumulated typical sierozem soils. After 3 years of alfalfa cultivation, field moisture capacity increased to 22.0 %, representing a 1.6 % increase. The highest field moisture content of 22.9 % was observed in the lower (plume) part of the field where the particles washed from the slope were sitting in the 3-year alfalfa field and it was 1.2 % higher than in the old plowed land.

A typical sierozem soil from a heavily leached old tillage has a minimum field moisture capacity. In their 1 m layer, the moisture capacity of the field was 18.7 % and it was equal to 19.9 % in the 3-years alfalfa plowed version and it was noted that it was 1.2 % higher than the old cultivated land.

Soil fertility refers to its ability to fully and continuously provide the plant with water and nutrients and depends on a number of water-physical, agro-physical, agro-chemical and biochemical properties. In the experiment, it was found that when 3-years alfalfa was planted on typical sierozem soils subjected to irrigation erosion, their productivity increased due to the accumulation of large amounts of organic matter in the soil and the improvement of physical properties (Table 3). It can also be seen from the data in Table 3 that there is a large difference in the amount of humus according to the degree of leaching of the soil.

The content of humus in the plowed (0–30 cm) and under-plowed (30–50 cm) layers of the old unwashed soil was 0.90 and 0.71 %, respectively, in the heavily washed and washed from the slope, it was 0, 80 and 0.63; it was found to be equal to 1.08 and 0.80 %. These indicators were 1.28 and 0.98 % in the unwashed soil where 3-year-old alfalfa was planted and 1.11 and 0.98 % in the heavily washed soil.

At a slope of 0.93 %, the amount of particles washed from the slope increased by 1.32 % and 1.01 % in the settled soil (Table 3).

According to Table 3, the humus reserve in long-plowed, unwashed soil is 58.41 t/ha in the 0–50 cm layer. In strongly washed soil, it is 50.32 t/ha and in soil where particles accumulated from the slope, it is 69.20 t/ha. After planting 3-years-old alfalfa, these values increased to 76.20 t/ha, 67.10 t/ha and 81.56 t/ha, respectively. Compared to the long-plowed soils, this represents an increase of 17.79, 16.78 and 12.36 t/ha, resulting in improved soil fertility.

To assess soil fertility, cultivation level and susceptibility to irrigation erosion, as well as to develop measures against leaching processes based on slope, exposure and local conditions, it is necessary to separate soil colloidal particles into distinct group compositions. In this study, we examined the group composition of colloidal particles in soils affected by irrigation erosion and observed

**Table 3.** Effect of crop-rotation on humus content of soils subjected to irrigation erosion

Layer (cm)	The amount of humus in the soil (%)			Humus reserve in the soil (t/ha)		
	Not washed	Strongly washed	The washed particles are sitting	Not washed	Strongly washed	The washed particles are sitting
Soil that has been cultivated since ancient times						
0–30	0.90	0.80	1.08	37,26	31.92	45,36
30–50	0.71	0.63	0.80	21.15	18.40	23.84
0–50	0.81	0.72	0.94	58,41	50.32	69.20
Three-year alfalfa plowed soil						
0–30	1.28	1.11	1.32	49.15	41,62	52.67
30–50	0.98	0.93	1.01	27.05	25.48	28.89
0–50	1.13	1.02	1.17	76.20	67.10	81.56

significant differences between old plowed soil and 3-years-old alfalfa plowed soil.

The highest amount of colloidal particles, easily degradable by water, was found in the 0–30 cm and 30–40 cm layers of heavily washed soils from ancient times and were 10.32 and 10.55 respectively, or 61.0 and 67 in relation to the total colloid concentration made up 1 %. These indicators are relatively lower in soils with unwashed and washed-down particles, namely 9.25 and 8.85 respectively; 7.10 and 5.81 % or 55.8 and 58.3 in total; it was equal to 38.9 and 39.0% (Table 4).

As a result of the accumulation of organic residues and the aggregation of small elementary particles in the 3-years alfalfa plowed soil, the share of the zero group, which is easily decomposed by water, decreased due to the increase in the amounts of the first and second groups that do not decompose under the influence of water in the total sum of the group composition of colloidal particles.

The lowest content of colloidal particles in the zero group was recorded in plowed and sub-plowed soil layers where the particles washed down from the 3-years-old alfalfa plowed slope (6.45 and 5.30 % or 27.0 and 26.9 % of the total). These indicators

ranged from 7.80–6.78 % in unwashed soil and from 8.05–8.11 % in heavily washed soil, corresponding to 45.9–42.5 % and 44.1–51.5 % of the total respectively.

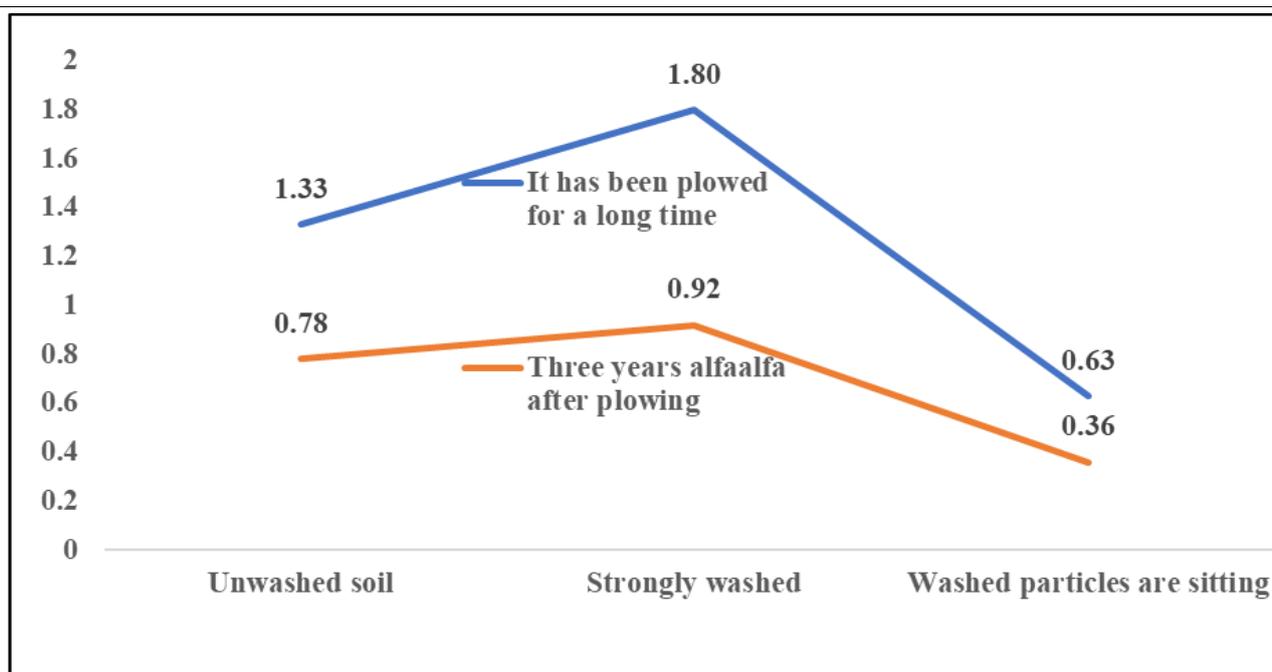
The amount of the first and second groups of colloidal particles was 4.09 and 13.38 % in 3-years-old alfalfa plowed soil and 3.21 and 7.95 % in old plowed land respectively. In unwashed and heavily washed soils, these indicators are low, that is, 3.13 in the 3 years alfalfa plowed version; 6.08 and 2.69; by 7.52 %, 2.31 in old-fashioned versions; 5.09 and 1.67; it was found to be equal to 4.92 %.

When dividing the amount of colloidal particles of the zero group by the sum of the amount of the first and second groups, that is, the coefficient of dispersion (coefficient of dispersion), it can be seen that it is on average 1.3 in washed soils that have been plowed for a long time, 1.8 in strongly washed soils and 0 in soils with particles washed down from the slope was equal to 0.6, the decomposition coefficients decreased and 0.8, respectively, due to increased resistance to leaching processes of 3-years-old alfalfa plowed soils; these values, 0.9 and 0.4, correspond to the strongly eroded soil and the slope-bottom accumulated soil respectively (Fig. 1).

Based on the above data, it can be said that the greater the

**Table 4.** Effect of crop rotation on colloidal particle group composition in irrigation-eroded soils

Background	Layer (cm)	Group (%)			Total	Percentage compared to total			KD ( $\frac{0}{I + II}$ )
		0	I	II		0	I	II	
Unwashed soil									
It has been driven for a long time	0-80	9.25	2.31	5.08	16.59	55.8	13.9	30.3	1.26
	30-40	8.85	2.48	3.86	15,19	58.3	16.3	25.4	1.39
Alfalfa is driven	0-30	7.80	3.13	6.08	17.01	45.9	16.4	35.7	0.84
	3040	6.78	3.23	5.95	15.96	42.5	20.2	37.3	0.73
Strong washed soil									
It has been driven for a long time	0-80	10.32	1.67	4.92	16.91	61.0	9.9	29.1	1.56
	30-40	10.55	1.87	3.30	15.72	67.1	11.9	21.0	2.04
Alfalfa is driven	0-30	8.05	2.69	7.52	18,26	44.1	14.7	41.2	0.78
	3040	8,11	2.48	5.15	15.74	51.5	15.8	32.7	1.06
Soil where washed particles sit (bottom of field)									
It has been driven for a long time	0-80	7,10	3.21	7.95	18,26	38.9	17.6	43.5	0.63
	30-40	5.81	3.06	6.02	14.89	39.0	20.6	40.4	0.63
Alfalfa is driven	0-30	6.45	4.09	13.38	23.92	27.0	17.1	55.9	0.36
	3040	5.30	3.83	10.58	19.71	26.9	19.4	53.7	0.36



**Fig. 1.** Degradation coefficients by farming background in typical sierozem soils subjected to irrigation erosion.

amount of the zero group of colloidal particles and the higher the decomposition coefficient, the more the soil is prone to irrigation erosion.

The data showed, when the same amount of water was applied to cotton fields, it was observed that the leaching of soil particles was different depending on the agricultural background and the degree of leaching of the soil (Table 5).

With strong irrigation erosion (slope 4.5°), soil leaching was 43.7 t/ha during the vegetation period, while in the 3-years alfalfa plowed variant, it was 12.1 t/ha, indicating a 3.6-fold reduction in soil leaching 4.1 t/ha of particles were leached in the previously plowed unwashed soil, but 2.5 t/ha of soil particles were leached after alfalfa plowing, representing a 1.6-fold reduction. The lowest amount of leaching (1.0 t/ha) was recorded in the 3-years alfalfa field on soils where particles washed down from the slope had settled.

In the research, when the humus and nutrients washed away by sewage and sludge were determined, in the old plowed soils with strong irrigation erosion, 404.5 kg/ha of humus, 60.8 kg/ha of nitrogen, 44.8 kg/ha of phosphorus, 372.1 kg/ha of potassium was lost. In the 3-years alfalfa field, humus and nutrient losses were 160.7, 27.6, 15.9 and 119.3 kg/ha respectively, with corresponding reductions of 2.7, 2.2 and 2.8, representing a 2.2–3.1-fold decrease.

The loss of humus and nutrients was also noted in the soils where the particles were washed and washed down from the slope (accumulated), but in 3-years-alfalfa plowed variants, the loss of humus and nutrients decreased by 1.8–2.3 times compared to the variants on the old plowed lands.

## Conclusion

Due to irrigation erosion, soil particles were washed down the slope, redistributing humus and nutrients. The upper slope became depleted, while the lower areas where the particles accumulated became enriched. In 3-years alfalfa plowed fields, compared to older plowed land, humus content in the arable layer is 0.38 % in unwashed soil, 0.31 % in strongly eroded soil and 0.24 % in areas where particles have accumulated at the slope bottom. The humus reserves are 11.89 t/ha, increasing by 9.70 t/ha and 7.31 t/ha, respectively. Consequently, soil fertility improves, along with water-physical and agro-physical properties. In soils affected by irrigation erosion, plowing 3-years-old alfalfa increases the amount of stable colloidal particles (first and second groups), while disintegration coefficients decrease from 1.8 to 0.9. Alfalfa not only increases the productivity of leached soils but also increases the leaching of soil particles by 3.6 times, the loss of humus and nitrogen, phosphorus and potassium substances by 2.7, 2.2; 2.8 respectively. It reduces by 3.1 times. Therefore, in order to obtain a high and high-quality harvest from agricultural crops in the soils affected by irrigation

erosion, it is necessary to apply mineral fertilisers and local fertilisers according to the level of leaching of the soil and to introduce alternating planting.

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## Authors' contributions

NSN conceived the study, supervised the experimental design and revised the manuscript. SDK and RRU carried out field experiments, soil sampling and laboratory analyses. BYY performed data processing and statistical analysis. AKK and RAK contributed to result interpretation and discussion. All authors read and approved the final manuscript.

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interests to declare.

**Ethical issues:** None

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**Table 5.** Effect of crop rotation on soil leaching (t/ha), loss of humus and nutrients (kg/ha)

Level of soil leaching	Background	Soil leaching (kg/ha)	Loss of humus and nutrients, kg/ha			
			Hummus	Nitrogen	Phosphorus	Potassium
Not washed	It has been driven for a long time	4.1	40.5	14.7	4.5	43.5
	Alfalfa is driven	2.5	24.3	12.8	2.9	26.1
Strongly washed	It has been driven for a long time	43.7	404.5	60.8	44.8	372.1
	Alfalfa is driven	12.1	160.7	27.6	15.9	119.3
The washed particles are sitting	It has been driven for a long time	2.3	28.5	12.0	3.0	30.3
	Alfalfa is driven	1.0	15.9	10.8	1.9	18.0

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