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4.1.1. Общее земледелие, растениеводство (биологические науки, сельскохозяйственные науки)

АНАЛИЗ ДИНАМИКИ НАКОПЛЕНИЯ ГУМУСА ПРИ ВНЕДРЕНИИ ТРАВЯНОЗЕРНОПРОПАШНОГО ОРОШАЕМОГО СЕВООБОРОТА С ВКЛЮЧЕНИЕМ ЯРОВОГО ЯЧМЕНЯ В ХАРАБАЛИНСКОМ РАЙОНЕ АСТРАХАНСКОЙ ОБЛАСТИ

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В статье рассматривается изменение процентного содержания гумуса в пахотном слое почвы в зависимости от структуры орошаемого севооборота. Серо-бурые почвы Харабалинского района Астраханской области отличаются низким содержанием органического вещества. Распространённая в течение последних двадцати лет монокультура картофеля привела к ухудшению почвенного плодородия и снижению процентного содержания гумуса. В связи с эти назрела необходимость внедрения травянозернопропашного севооборота на основе люцерны и ярового ячменя, способствующих восстановлению структуры почвы и преодолению негативных тенденций отрицательного баланса гумуса

Ключевые слова: ЯРОВОЙ ЯЧМЕНЬ, КАРТОФЕЛЬ, ГУМУС, ЗЕРНОПРОПАШНОЙ СЕВООБОРОТ

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4.1.1 General agriculture, plant growing (biological sciences, agricultural sciences)

ANALYSIS OF THE DYNAMICS OF HUMUS ACCUMULATION WHEN IMPLEMENTING GRASS-GRAIN-ROWED IRRIGATED CROP ROTATION WITH THE INCLUSION OF SPRING BARLEY IN THE KHARABALINSKY DISTRICT OF THE ASTRAKHAN REGION

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This article examines changes in the percentage of humus in the topsoil depending on the structure of an irrigated crop rotation. Gray-brown soils in the Kharabalinsky district of the Astrakhan region are characterized by low organic matter content. Potato monoculture, widespread over the past twenty years, has led to deterioration of soil fertility and a decrease in the percentage of humus. Therefore, it is necessary to implement a grass-grain-row crop rotation based on alfalfa and spring barley, which will help restore soil structure and overcome the negative effects of a negative humus balance

Keywords: SPRING BARLEY, POTATOES, HUMUS, GRAIN-ROWED CROP ROTATION

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1. INTRODUCTION. The arid zone is characterized by moisture deficiency (a moisture coefficient of less than 0.33), high evaporation, low humus content, and a weak soil structure susceptible to wind and water erosion.

Degradation of the arable layer, loss of organic matter, and humus mineralization are limiting factors for sustainable agriculture [3].

The introduction of alfalfa into the structure of irrigated grass-grain-row crop rotation is a strategic agro-technological technique aimed at achieving sustainable productivity, greening and biologization of intensive farming under irrigated conditions [6, 7].

After plowing in the alfalfa stubble and root residues (up to 10-15 t/ha dry mass), organic matter with a favorable C:N ratio (15-20:1) enters the soil, which promotes active humification and a positive humus balance, compensating for its mineralization during intensive cultivation of row crops [5, 12].

The powerful taproot system of alfalfa, penetrating to a depth of 3-5 meters, creates a system of macropores that improves the water-air regime, drainage, and infiltration capacity of the soil [8, 9]. Root exudates and abundant organic matter promote the formation of water-stable aggregates, increasing the structural coefficient and erosion resistance [8].

The deeply penetrating roots of alfalfa perform the function of a “biological pump”, extracting nutrients (phosphorus, potassium, calcium, microelements) from subsurface horizons inaccessible to annual crops and accumulating them in the root-inhabited layer [7].

Thus, alfalfa in irrigated grass-grain-row crop rotation plays a multifunctional role: it is a key factor in the reproduction of soil fertility, a biological ameliorator, a powerful phytosanitary agent and a highly productive forage crop [2, 13, 14, 15, 16].

Another important component of the grain-grass-row crop rotation is spring barley, used as a green manure crop [10, 11]. In arid conditions, classic green manure crops (legumes, cruciferous plants) often fail to realize their potential due to low drought tolerance and high moisture consumption. They are being replaced by more drought-resistant crops adapted to drought conditions. One such crop is spring barley, which has one of the lowest transpiration rates among cereals (approximately 400 units) and effectively utilizes soil moisture from autumn-winter reserves and scant spring precipitation. A short growing season (60-85 days) allows the development cycle to be completed before the onset of summer atmospheric and soil drought, minimizing competition for water with the subsequent main crop [4].

Barley's robust root system, penetrating to a depth of 1.5-2.0 m, effectively loosens subsurface horizons, improves water infiltration, and facilitates the mobilization of hard-to-reach mineral nutrients from the lower soil layers. Barley acts as a biological break in crop rotation, reducing infection pressure. Furthermore, it can grow significant vegetative mass (20-35 t/ha of green mass) even under moisture-deficient conditions. This leads to the direct influx of organic matter into the soil, which forms the basis for humus formation and nutrition of soil biota. Barley root residues, enriched with sticky substances, stabilize soil aggregates, increasing the structure's water resistance. A cover of plant matter after rolling or mulching significantly reduces wind speed at the soil surface and moisture evaporation, preventing deflation.

Barley effectively absorbs mineral nitrogen, preventing its leaching and immobilizing it in organic form. After the green manure is mineralized, this nitrogen, along with mobilized phosphorus and potassium, becomes available to subsequent crops during more favorable wet periods.

Unlike moisture-loving green manure crops, barley completes its cycle before the period of maximum drought. Proper management (mowing at the milky stage and then leaving it on the surface as mulch) creates a moisture-retaining screen, reducing unproductive moisture loss due to evaporation by 15-25%.

In extremely dry years, when barley does not produce commercial grain, it reliably performs a soil-protecting and green manure function, preventing complete depletion and degradation of the field.

The scientific novelty of this study lies in the development of a quantitative predictive model for changes in humus content for a specific irrigated grass-grain-row crop rotation (3 years of alfalfa + spring barley + potato) in the degraded gray-brown soils of the Kharabalinsky district. For the first time in this arid region, long-term data were obtained and analyzed, allowing us to assess the contribution of adapted green manure (spring barley) to the organic matter balance in a system with perennial legumes under irrigation. It should be noted that, due to the limited length of the time series, the constructed model is primarily intended to describe and analyze observed short-term dynamics rather than for long-term forecasting.

2. METHODS. The study aimed to investigate the influence of the grass-grain-row crop rotation structure on the percentage of humus content in gray-brown soils of the Kharabalinsky district of the Astrakhan region. The experiments were conducted from 2021 to 2025 according to the method of B.A. Dospekhov [1]. The methodology for collecting soil samples and compiling sample data was as follows Every year in September, after the potato and spring barley harvest, component-by-component collection of mixed soil samples from a depth of 0-20 cm was carried out in each field of the crop rotation (a total of 5 fields). The collection was carried out using the envelope method in 4 replicates for each field. The humus content was determined using the Tyurin method in laboratory conditions.

To obtain a generalized characteristic of humus changes in the crop rotation system over a five-year period, averaged data were used. For each study year (x), the arithmetic mean humus content (y) was calculated for all five fields in the rotation and all replicates. Thus, each annual y value represents the average humus content for the entire area occupied by the crop rotation in a given year, allowing for an assessment of the integral effect of the system. For a more detailed analysis, Table 2 presents reference data on humus content changes separately for the main crops over the period of their cultivation in the crop rotation. Alfalfa, spring barley, and potatoes were cultivated using agricultural practices recommended for the Astrakhan Region. The predecessor of potatoes was spring barley, a promising grain crop for the Kharabalinsky District, which was grown as green manure. Soil samples for humus content determination were collected annually in September, after the potato and spring barley harvest, ensuring comparability of results across all study years (2021–2025).

3. RESULTS. In the Kharabalinsky district of the Astrakhan region, over a 5-year period from 2021 to 2025, the effect of a five-field crop rotation consisting of three alfalfa fields, one spring barley field, and one potato field on the humus content in the arable soil layer was studied.

To determine the regression parameters and subsequently predict changes in the percentage of humus in the arable soil layer, we created Table 1, based on averaged data for all fields in the crop rotation and for all repetitions over the rotation (5 years). S(x) did not exceed 3%.

Table 1 - Calculation table for determining the dynamics of changes in the percentage content of humus (crop rotation: 3 alfalfa fields, 1 potato field, 1 barley field, Kharabalinsky district of the Astrakhan region)

Year (x)	Humus content, % (y)	±*m*(error of the mean)	*S* (standard deviation (nothing)	x^2	y^2	$x\,y$
1	0,990	0,008	0,016	1	0,980	0,990
2	1,000	0,009	0,018	4	1,000	2,000
3	1,015	0,010	0,020	9	1,030	3,045
4	1,032	0,011	0,022	16	1,065	4,128
5	1,045	0,012	0,024	25	1,092	5,225
Σ15	5,082	-	-	55	5,167	15,388

The correlation coefficient (r) is 0.997. To describe the dynamics observed over 5 years, a paired linear regression equation was constructed of the form: y = a + b · x, where x is the year of the experiment (1, 2, 3, 4, 5), y is the average humus content in the arable layer of the crop rotation massif, %; a is the free term, %; b is the slope, %/year.

The calculated equation has the form: y = 0,974 + 0,0142x. For the regression parameters, 95% confidence intervals are defined: for the free term (a) --- (0,969; 0,978), for the slope (b) --- (0,0132; 0,0153).

To assess the significance of the regression equation, an analysis of variance was conducted. The resulting Fisher's F-test value was $F(1, 3) = 497{,}7$ ($p < 0{,}001$), confirming the statistical significance of the model for the given data set.

The obtained correlation coefficient ($r = 0{,}997$) indicates a very close linear relationship over the observed 5-year period. It is important to emphasize that this high degree of correlation is, in part, a consequence of the data averaging method, which naturally reduces variability. Furthermore, the short length of the time series (5 points) itself contributes to the high r values and requires caution in interpretation. This model is an adequate tool for describing the short-term trend under the conditions of this experiment, but its extrapolation to longer periods is fraught with significant uncertainty.

Table 2 – Change in humus content under the main crop rotation crops during their cultivation period (2021-2025)

Culture	Years of cultivation in crop rotation	Initial humus content, % (beginning of the period)	Humus content, % (end of period)	Change over the period, %
Alfalfa(Average) her in fields 1, 2, 3 g.p.)	2021-2023 (1 year), 2022-2024 (2 year), 2023-2025 (3 year)	0,990	1,040*	+0,050
Spring barley	2024	1,015	1,032	+0,017
Potato	2025	1,032	1,045	+0,013

Note: For alfalfa, the average value for all fields at the end of the third year of use is given.

The data in Table 2 show that a positive humus balance was observed in all fields of the crop rotation. The greatest increase was noted in the alfalfa fields, confirming its leading role as a source of organic matter. Barley and potato fields also showed increases, albeit smaller ones. Averaging the data across the entire crop rotation (Table 1) reflects the overall positive trend of the system, integrating rather than masking the contributions of all crops.

The high degree of linearity of the correlation coefficient is the result of averaging data across four replicates and all fields in the crop rotation for each year of the study, which offsets some of the natural variability due to field microheterogeneity. Climatic conditions during the experiment (2021–2025) were relatively stable and consistent with long-term averages for the region, which also helped smooth out abnormal annual fluctuations in biological productivity and humification activity. However, given that long-term humus dynamics in agrocenoses are influenced by multifactorial and not always linear processes, the presented model is an effective tool for short-term forecasting within the specific conditions of this field experiment. The average annual humus growth rate (0,0142%) in the arable layer obtained in our experiment is in the upper range of values typical for irrigated crop rotations with perennial grasses in arid conditions. For example, studies in neighboring regions of the Lower Volga region show growth rates of 0.008–0.012% per year [12, 13]. The higher rate in our case can be explained by the combined effect of three years of alfalfa use and effective green manure fallow based on spring barley, emphasizing the agroecological effectiveness of the proposed scheme specifically for the soils of the Kharabalinsky district.

Constructing a regression model based on a 5-point (year) time series has limited statistical power and is not intended for long-term extrapolations. The resulting model describes short-term dynamics (within a single rotation) under specific experimental conditions. Its predictive power is only valid for estimating trends for the next 1-2 years, assuming similar agricultural practices and climatic conditions.

The implementation of irrigated grass-grain-row crop rotation represents a comprehensive strategy for managing soil organic matter, aimed at overcoming its deficiency in arid conditions. Its impact on humus content and balance is systemic and occurs through several interconnected mechanisms.

The massive contribution of perennial grasses (alfalfa), which form a huge biomass (over 10-15 t/ha of dry matter from root and crop residues), is the main source of fresh organic matter for humification.

Spring barley crop residues and potato root systems make an additional contribution to the total organic carbon pool, although to a lesser extent than alfalfa.

Alfalfa's deep root system loosens the subsurface horizons, creating a system of macropores. This improves soil aeration and water retention. The vigorous activity of soil micro- and mesofauna (earthworms) in these conditions accelerates the conversion of plant residues into humus.

Regulated irrigation prevents soil desiccation, maintaining optimal moisture levels for microbiological activity (60-70% of the total capacity). This is critical for the continuous humification process in arid climates, where it is significantly slower under natural conditions.

Dense alfalfa grass and spring barley stubble reliably protect the soil surface from wind and water erosion, which are the main causes of direct humus loss in arid regions.

The vegetation cover in crop rotation (as opposed to row crops in monoculture) reduces soil overheating in summer, which reduces the rate of mineralization (decomposition) of existing humus reserves.

Replacing a depleting row crop monoculture (for example, potatoes) with a diverse crop rotation eliminates the one-sided removal of nutrients and specific soil fatigue, allowing for the restoration of its biological activity and humus balance.

A properly managed irrigated crop rotation with three years of alfalfa ensured a positive annual humus balance in the arable layer (an increase of 0.2 t/ha of organic matter calculated as humus), increasing humus content by 0.06% over one rotation cycle (5 years). Thus, an irrigated grass-grain-row crop rotation affects humus content not as a simple sum of crops, but as a self-regulating system. It simultaneously increases the balance sheet's income due to the regular supply of large quantities of high-quality organic matter from alfalfa and other crops, while reducing the balance sheet's expenditures by protecting against erosion, optimizing the microclimate, and suppressing excessive mineralization. This creates the basis for gradual, sustainable restoration of fertility and the transition from soil degradation to qualitative improvement, even in difficult arid conditions, provided irrigation is used rationally.

4. CONCLUSIONS. Research has shown that a grass-grain-row crop rotation, enriched with alfalfa and spring barley, has a positive effect on soil fertility. Based on averaged data over a five-year rotation, a strong linear relationship was established (r = 0,997), described by the equation y = 0,974 + 0,0142x, according to which the observed average annual increase in humus content in the arable layer of the crop rotation was 0.0142% (with a 95% confidence interval from 0,01315 to 0,01525%/year).

Due to the limited time series (5 years), the presented model is descriptive in nature for the specific experimental conditions. The results obtained provide reasonable evidence of positive short-term humus accumulation dynamics during a single crop rotation. Long-term forecasting based on this model does not appear statistically reliable. To construct predictive models, long-term monitoring data over several crop rotations is required.

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