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The effectiveness of methods and algorithms for detecting and isolating factors that negatively affect the growth of crops

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ABSTRACT

This article discusses a large number of textural features and integral transformations for the analysis of texture-type images. It also discusses the description and analysis of the features of applying existing methods for segmenting texture areas in images and determining the advantages and disadvantages of these methods and the problems that arise in the segmentation of texture areas in images. The purpose of the ongoing research is to use methods and determine the effectiveness of methods for the analysis of aerospace images, which are a combination of textural regions of natural origin and artificial objects. Currently, the automation of the processing of aerospace information, in particular images of the earth's surface, remains an urgent task. The main goal is to develop models and methods for more efficient use of information technologies for the analysis of multispectral texture-type images in the developed algorithms. The article proposes a comprehensive approach to these issues, that is, the consideration of a large number of textural features by integral transformation to eventually create algorithms and programs applicable to solving a wide class of problems in agriculture.

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1. INTRODUCTION

The basis for this study is the features of the growth of agricultural crops during the growing season and factors that negatively affect their growth in the conditions of the Research and Production Center for Grain Farming named after A.I. Barayev. The study is aimed at identifying and highlighting homogeneous areas that are identified with crops. Currently, the study of this issue is relevant among scientists of various specialties-agronomists, chemists, biologists, and technologists. In this work, the main attention is paid to the processing of aerospace information, in particular, images of the earth's surface, namely, images of the normalized difference vegetation index (NDVI) texture type. At the same time, the main way to extract information is to decipher images, which are the main carrier of information about the area, which is identified with plant species, humidity, crop damage on aerospace images. This article discusses spectral transformations based on orthogonal matrices and informative textural features. In total, 6 types of transformations and 4 structural, and 10 statistical textural features are considered. It is assumed that the characteristics of textural features, such as the order/disorder ratio, the proportion of zones with an "anomalous" textural, obtained for different images, as well as various spectral coefficients, can be additionally correlated with values characterizing weeds, seedlings, and crops. Software products that allow you to perform detailed textural analysis can be successfully used in various fields of science and industry. First of all, these are research institutes in the field of agriculture and agroindustry.

The study of agricultural crops in Kazakhstan and the automatic review of their condition is one of the topical issues. Information on determining the growing season, methods for determining the quantitative characteristics of the development of crops using the spectral coefficient of brightness, as well as the development of a texture-type image processing model are determined using aerospace image processing. It becomes possible to determine whether it is a coniferous or deciduous forest and whether the fields are sown with cereals or legumes, which becomes possible only by textural features. And you can also determine whether forests are infested with pests or areas are abandoned. Another area of research where these methods can be effectively used is the diagnosis of internal human pathologies, including malignant ones, using images obtained with a thermal imager. The fundamental difference between the ideas of our study and existing analogs lies in the correct application of mathematical methods and their deeper study. For example, we know of over two hundred textural features, but scientific reviews typically use about fifty types. At the same time, only 3-4 features are usually used in practice, for example, when processing satellite images. This means that the original images are fully verified. The same can be said about the application of integral transformations. For example, the Haar transform is used in the study of the stress strength of metals to characterize cracking.

Ortiz-Toro *et al.* [1] compare three different textural features extraction methods, radiomics, fractal dimensionality, and superpixel-based novel histone for pneumonia detection on chest x-ray images, and evaluate classification models generated from two different image datasets. All methods implemented in this work gave positive results, especially methods obtained using both superpixel-based histones and those with fractal dimension.

Abdikerimova *et al.* [2] dealt with methods for analyzing textural images. Microphotographs of plant raw materials obtained by transmission electron microscopy are considered. The implemented algorithms allowed detecting and highlighting areas in the image that are identified with porosity, microelements, and cell walls of plants obtained after mechanochemical treatment. To solve the problem, textural features, clustering, R/S analysis, orthogonal transformations, and wavelet analysis were used. Much attention has been paid to the development of software tools that allow the selection of the features that describe textural differences to segment textural regions into subregions. Researchers from the chemical industry have shown the applicability of textural features to identify characteristic areas in photomicrographs.

In [3], the generalized Haar wavelet functions are applied to the problem of ecological monitoring by the earth remote sensing method. The authors have studied generalized Haar wavelet series and suggest using the Tikhonov regularization method to check their correctness. The article also considers the problem of using orthogonal transformations in earth remote sensing technologies for environmental monitoring. Remote sensing of the earth makes it possible to obtain information from space vehicles of the medium, high spatial resolution, to carry out hyperspectral measurements. Spacecraft have dozens or hundreds of spectral channels. For image processing, a device of discrete orthogonal transformations, namely, wavelet transforms, was used. This work aims to apply the regularization method to one of the problems associated with remote sensing of the earth, and the subsequent processing of satellite images using discrete orthogonal transforms, in particular, generalized Haar wavelet transforms.

Feodor and Natalya [4] studied variations of the strip method. Namely, we considered opt_1ions based on the use of various matrices: Hadamard, Haar, Frobenius, and matrices. These variants of the strip method have been implemented. The main goal is to study the quality of reconstruction of one-dimensional signals (images are not considered) for various matrices in the case of impulse noise. Various types of matrices and signals were tested. A theoretical estimate in terms of spectral coefficients is a decomposition of the error rate for the bandpass transform based on the Hadamard matrix in the case of impulsive noise.

Adjed *et al.* [5] introduce a fusion of structural and textural features of two descriptors, i.e., benign and malignant cancers. For accurate detection and classification, they used a support vector machine (SVM) classifier with a cross-validation random sampling method between the three skin lesions listed in the urn:x-wiley:17519640: media:cvi2bf00422:cvi2bf00422-math-0001 database. The researchers confirmed the applicability of structural features from wavelet and curvelet transforms in medical images.

Aziz *et al*. [6] presented using informative feature extraction to detect a cancer node from three levels in medical images. To improve the interpretation of information in an image for a human audience, authors use an image enhancement step. In the stage of image processing, namely in the segmentation includes the segmentation of the desired area into a plurality of sub-areas. Cancer at this stage is detected on the basis of abstract features.

Sidorova [7] considers a histogram for an automatic hierarchical multidimensional clustering algorithm. In this study, a method is proposed for choosing the clustering detail in different areas of the vector space of spectral features, depending on the average separability of clusters. The algorithm is used for the automatic classification of multispectral satellite data during land cover recognition. In this article, the researcher does not consider methods based on integral transformations, that is, the applicability of these methods. A feature of this work is the recognition of objects in aerospace by textural features. In particular, the effectiveness of orthogonal transformation methods and the joint use of structural and statistical features were demonstrated.

2. METHOD

The adjacency matrix contains information characterizing the texture. After constructing the adjacency matrix, we can obtain quantitative estimates in the form of a vector of textural features [8], [9]. According to the matrix of joint occurrence, about twenty features are calculated, the most commonly used of them are (1) to (16).

- Energy:

$$T_1 = \sum_{i=1}^{S}\sum_{j=1}^{S}[p(i,j)]^2 \quad (1)$$

- Entropy:

$$T_2 = \sum_{i=1}^{S}\sum_{i=1}^{S} p(i,j)\cdot \log_2(p(i,j)) \quad (2)$$

- Homogeneity:

$$T_3 = \sum_{i=1}^{S}\sum_{j=1}^{S}\frac{p(i,j)}{1+|i-j|} \quad (3)$$

- Contrast:

$$T_4 = (i-j)^2\cdot p(i,j) \quad (4)$$

- Differential entropy:

$$T_5 = \sum_{i=2}^{S} p_{x+y}(i)\log(p_{x+y}(\mathrm{i})) \quad (5)$$

Here,

$$p_{x+y}(k) = \sum_{i=1}^{S}\sum_{j=1}^{S}\delta_{i+j,k}p(i,j), \quad k = 2,3,\ldots,2S, \quad \delta_{m,n} = \begin{cases}1, & if \quad m=n\\ 0, & if \quad m\neq n.\end{cases} \quad (6)$$

- The sum of the variance:

$$T6 = \sum_{i=2}^{2S}(i-T5)^2 p_{x+y}(i); \quad (7)$$

- Correlation:

$$T7 = \sum_{i=1}^{N}\sum_{j=1}^{N}\frac{(i-\mu_i)(j-\mu_j)\cdot p(i,j)}{\sigma_i\sigma_j}; \quad (8)$$

mean values and standard deviations for $\mu_i, \mu_j, \sigma_i,\ \sigma_j - p(i,j)$.

– Dispersion:

$$T_8 = \sum_{i=1}^{S} \sum_{j=1}^{S} (i-\mu)^2 p(i,j) \; ; \tag{9}$$

– The overall average value:

$$T_9 = \sum_{i=2}^{2S} i \cdot p_{x+y}(i); \tag{10}$$

Here, $p_{x+y}(k) = \sum_{i=1}^{S} \sum_{j=1}^{S} {}_{i+j=k} p(i,j)$, $k = 2,3,\ldots,2N$ - tangent diagonal distribution.

– The inverse difference moment:

$$T_{10} = \sum_{i=1}^{S} \sum_{j=1}^{S} [1+(i-j)^2]^{-1} p(i,j) \tag{11}$$

– The total (total) entropy:

$$T_{11} = -\sum_{i=0}^{S-1} p_{x-y}(i) \log(p_{x-y}(i)); \tag{12}$$

here $p_{x-y}(k) = \sum_{i=1}^{S} \sum_{j=1}^{S} {}_{|i-j|=k} p(i,j)$, $k = 0,1,2,3,\ldots,N-1$ - main diagonal distribution.

– 1-an informative measure of correlation:

$$T_{12} = \frac{T_2 - HXY_1}{\max(HX, HY)}; \tag{13}$$

Here,

$$HX = -\sum_i p_x(i) \log(p_x(i)), \; HY = -\sum_j p_y(j) \log(p_y(j)),$$
$$HXY_1 = -\sum_i \sum_j p(i,j) \log(p_x(i) p_y(j)), p_x(i) = \sum_{j=1}^{S} p(i.j); p_y(j) = \sum_{i=1}^{S} p(i.j). \tag{14}$$

– Information measurement of correlation 2:

$$T_{13} = [1 - \exp(-2(HXY_2 - T_2))]^{1/2}; \tag{15}$$

Here,

$$HXY_2 = -\sum_i \sum_j p_x(i) p_y(j) \log(p_x(i) p_y(j)) \tag{16}$$

Information measures are determined by statistical symbols of the 2nd order, brightness values at the point (i, j) based on the elements of the adjacency matrix. Recently, a structured method for describing textures have been developed, based on the shape and size of the elements that make up the textural, the calculation of local features, and the analysis of the distribution of textural elements in the image. In structural approaches to textural analysis, textural are expected to be built from simple textural primitives according to certain layout rules, and these primitives are regularly or frequently repeated. Designations are given based on the length of the series [10], [11]. The textural run length is the number of constant brightness elements in the bitmap path.

A series is the maximum connected collection of pixels of the same brightness elongated in a straight line [12], [13]. The series is characterized by brightness, length, and direction. On coarse-grained textures, these series are longer than on fine-grained ones. S_g- the existence of values that brightness takes, S_r– of the possible lengths of the series, but $p(i,j)$-i we denote the number of series length j with brightness. Haralik [10] proposed five statistical values $p(i,j)$ for textural analysis.

– Inverse torque:

$$T_{14} = \frac{\sum_{i=1}^{S_g} \sum_{j=1}^{S_r} \frac{p(i,j)}{j^2}}{\sum_{i=1}^{S_g} \sum_{j=1}^{S_r} p(i,j)}; \tag{17}$$

– Moments:

$$T_{15} = \frac{\sum_{i=1}^{S_g} \sum_{j=1}^{S_r} j^2 p(i,j)}{\sum_{i=1}^{S_g} \sum_{j=1}^{S_r} p(i,j)}; \tag{18}$$

– Variation of brightness:

$$T_{16} = \frac{\sum_{i=1}^{S_g} \sum_{j=1}^{S_r} (p(i,j))^2}{\sum_{i=1}^{S_g} \sum_{j=1}^{S_r} p(i,j)} \tag{19}$$

– Series length heterogeneity:

$$T_{17} = \frac{\sum_{i=1}^{S_g} (\sum_{j=1}^{S_r} (p(i,j)))^2}{\sum_{i=1}^{S_g} \sum_{j=1}^{S_r} p(i,j)} \tag{20}$$

– Share images in the series:

$$T_{18} = \frac{\sum_{i=1}^{S_g} \sum_{j=1}^{S_r} p(i,j)}{\sum_{i=1}^{S_g} \sum_{j=1}^{S_r} jp(i,j)} \tag{21}$$

In [14], methods of orthogonal transformation are shown for distinguishing agricultural cereals and their weeds. The six methods of orthogonal transformation presented in this work are Cosine [15], [16], Hadamard order 2^n [17], [18], Hadamard order $n = p + 1$, $p \equiv 3(mod\, 4)$ a prime number, i.e. based on the Legendre symbol [19], Haar [20], [21], Slant [22], [23], and Dobeshi-4 [24], [25].

3. RESULTS AND DISCUSSION

3.1. Analysis of informative texture features and methods of orthogonal transformations

The experiment was carried out in the MATLAB environment using the image processing toolbox. The initial data was taken from the open-access Planet.com [26] to solve this problem, written functions were used to calculate texture features. The considered areas were taken randomly, as shown in Figure 1. All textural features were calculated for each selected area and were considered in the studies as a vector of textural features. To solve the problem related to the recognition of homogeneous areas, the choice of informative textural features was calculated in the Statistics Soft environment. Therefore, for each selected area, informative was calculated, and from the selected 18 features, informative 3 textural features were determined: T15, T9, and T18.

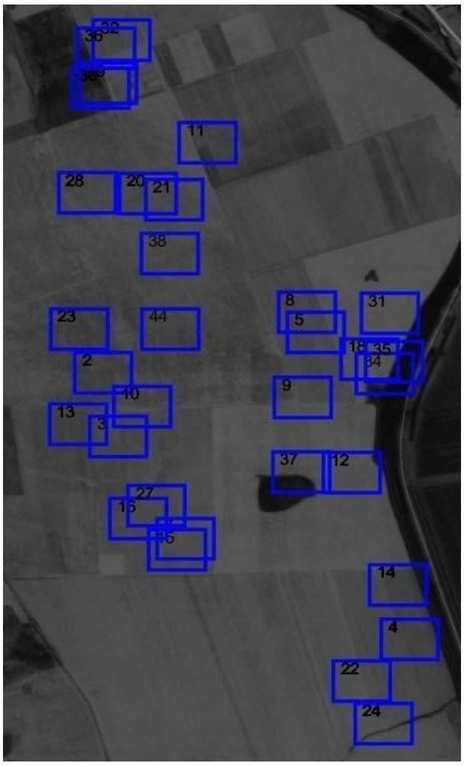

Figure 1. Considered areas for experiment

The distance between points, between the centers of clusters, is calculated according to different metrics, for example, the distance between points is calculated in the Euclidean metric. In this report, the Euclidean metric and the nearest neighbor method were used. As a result of the study of the selected areas, areas belonging to 3 classes and their Euclidean distance were determined as shown in Table 1.

Table 1. Classes to which observations belong, Euclidean distance

Plot numbers on images	Cluster Membership (data_textura_1) Linkage distance=790,385 Ward`s method Euclidean distances			
	Cluster Membership	opt_1	sum_avg	dolya
3	3	537.767881	46.3228477	0.04316888
10	3	599.195298	48.8674503	0.04092507
13	3	477.923775	43.6245695	0.04583355
15	3	611.920199	49.4226159	0.04046012
16	3	564.385795	47.4724834	0.04212517
27	3	630.910331	50.179702	0.0398501

The agglomerative method, in contrast to the methods of analysis of variance, determines the distance between clusters. More precisely, the distance between clusters increases by the sum of the squared distances of objects to the centers of clusters. In general, this method tends to create small clusters, although it seems to be very efficient as shown in Figure 2. Table 2 shows values between and within groups. The belonging of an object to a cluster is described by symbols. An important measure is the percentage of variance values within a cluster and the variance values between clusters. We can see the quality of clustering by the F-test value (average 52%). The result of the analysis of variance in Table 2 for three clusters shows a good quality of clustering: the significance of the p-level is less than 3% everywhere. As shown in Table 2, an analysis of the variance of textural features was performed in Statista Soft.

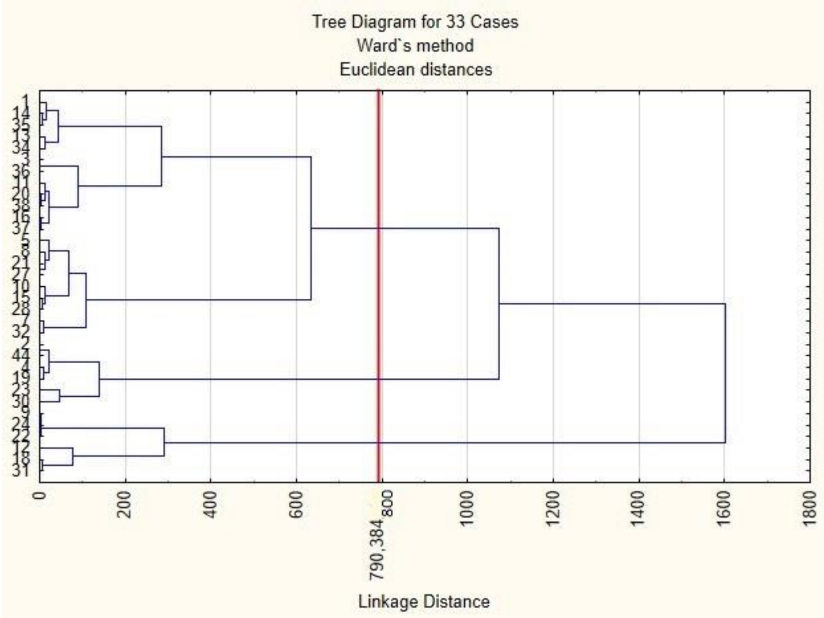

Figure 2. Dendrogram of clusters obtained with 18 textural features

Table 2. Analysis of variance of textural features

Variable	Analysis of Variance (experiment_1)					
	Between clusters	df	Inside clusters	df	F	signify (p)
opt_1	474345.4	4	41581.50	28	79.85324	0.000000
sum_avg	961.3	4	156.01	28	43.13366	0.000000
dolya	0.0	4	0.00	28	34.61647	0.000000

3.2. Comparative analysis of methods of textural features for recognition of crops on aerial images

In this work, we examined the areas where crops are grown at the Research Centre Experiments were carried out on sites belonging to this research center, as shown in Figure 3. We used aerospace images, in different growing seasons, obtained from the site [26].

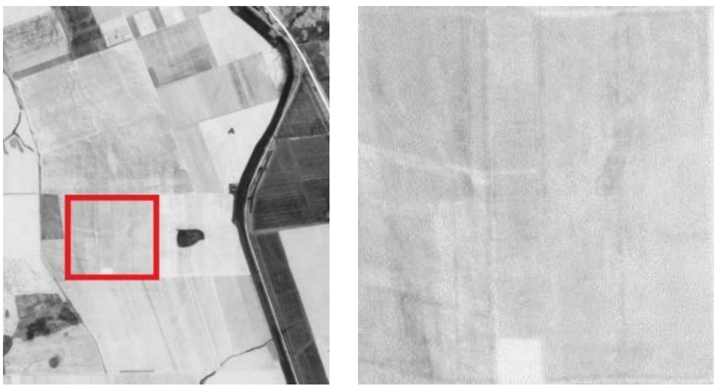

Figure 3. Original image of the area under consideration

In this work, out of 18 combined textural features, 3 informative textural features were identified; T15, T9, and T18 identifying wheat and weed foci. In Figure 4, the final stage of the algorithm, that is, clustering is implemented with a running window with a size of 3×3. An experiment was carried out by a non-standard method using an orthogonal transformation to the considered aerospace image. As a result, clustering by low-frequency coefficients was obtained. The result of image processing by this method is presented in Figure 5.

According to experts from the Scientific Center, wheat was sown from 05/12/2021 to 05/25/2021. Weed foci have been hybridized since 06/17/2021. Table 3 shows the result of experiments carried out using texture features and orthogonal transformation methods.

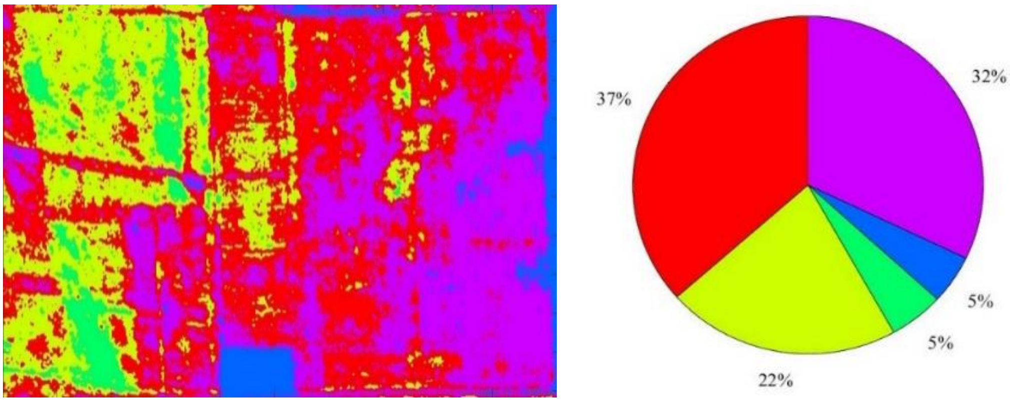

Figure 4. The result of clustering by textural features T15, T9, T18

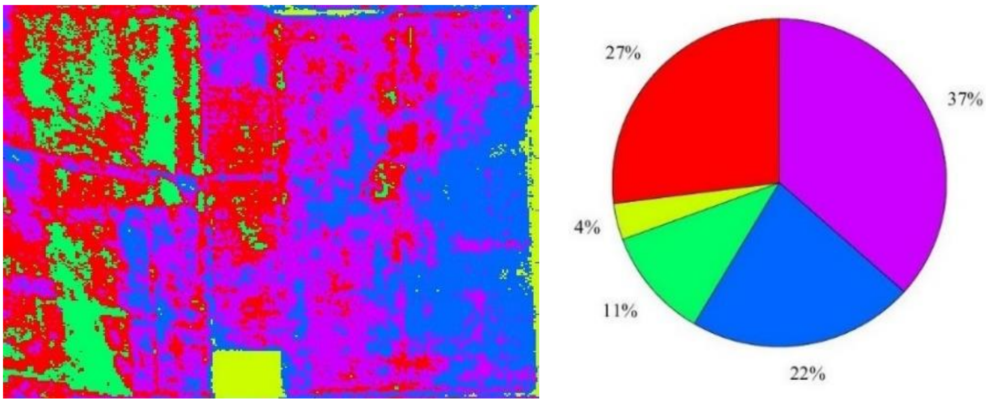

Figure 5. The result of clustering by the Haar method of orthogonal transformation

Table 3. The results of the value of clustering by textural features and the average value of the methods of orthogonal transformation

Data / Methods	9.06.2021	01.07.2021	21.07.2021	06.08.2021	14.09.2021
Orthogonal transformations (average value)	37%	9 %	5.5%	6.7 %	2.8 %
Textural features (T7, T10, T11)	37 %	7%	3%	2%	1%

After processing a multispectral grayscale image NDVI, orthogonal transformation methods and the efficiency of using informative textural features are determined. In the course of the research work, reference values of the land plot were created using spectral brightness coefficients. Based on the reference values created in each growing season, we see the effectiveness of the methods used.

After using the methods of orthogonal transformation and informative textural features, homogeneous areas were identified on aerospace images, compared with the exact data provided by the agronomists of the Scientific Center, and the percentage of weeds was calculated. In the course of the study, the following drawback of these methods was revealed, the high resolution of aerospace images does not make it possible to recognize plant pests and diseases on them. The mathematical description of these research methods requires the accuracy and processing time of one used image. According to experts, as a result of applying orthogonal transformation methods to aerospace images, the accuracy and percentage of weeds were effectively determined. After applying informative textural features, weed plant foci were found in the resulting images, and the percentage gave a difference of about 2% compared to their data.

4. CONCLUSION

For the selected area of aerospace images, orthogonal transformation methods and the use of informative textural features were carried out. Informative textural features were calculated by a non-standard method in the MATLAB programming environment, and informative textural features (T15, T9, T18) were determined in the Statistica Soft environment. The results of calculations of previous studies using orthogonal transformation methods are shown. These methods have revealed homogeneous areas in aerospace images. As shown in Table 3, the percentage of growth dynamics of the weed focus is determined. The growth dynamics of weeds for the considered 5 growing seasons corresponding to the accurate information of the experts. Based on the data obtained after hybridization, the percentage of weeds has decreased since 06/17/2021, that is, the effectiveness of these methods has been determined. The results of the study allow the user to take recommended measures to eliminate negative factors affecting the growth of crops. In addition, it offers information no less than knowledge of additional specialists for farmers in the future.

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