Protection against risks of losing a harvest of agricultural crops by means of applying the data obtained from the space monitoring systems of plant cover

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Abstract. Recently, in the domestic practice of agricultural insurance, interest in index insurance products has increased from both insurers and insurants. This is due to the high efficiency demonstrated by them as a tool to protect against the risk of yield loss, with a low level of associated moral hazard, low maintenance costs of the insurance contract. Index insurance implies the conclusion of a contract providing for the payment of insurance compensation when the base indicator reaches a specified threshold, the base indicator being an indirect sign of the occurrence of actual damage. When insuring crops, such a baseline can be high temperatures, lack of precipitation during the growing season. However, a more accurate indicator of the magnitude of the crop, and hence its shortage, is the normalized differential vegetation index (NDVI), obtained using space monitoring of vegetation. This fact is a reliable prerequisite for the use of this indicator in the index insurance of agricultural crops. Mathematical modeling of the dependence of the yield of spring barley in certain districts of the Rostov region on NDVI indicators made it possible to determine the main parameters of the corresponding index insurance products and to prove the effectiveness of their use to reduce the risks of yield loss. In particular, efficiency is expressed in stabilizing the income of agricultural producers by years, which is confirmed by a decrease in the coefficients of variation of this indicator in some cases to 27%.

1. Introduction
The use of insurance as a tool for minimizing the effects of adverse weather and climate phenomena is becoming increasingly important, especially in foreign agribusiness practices, as the primary task for agricultural producers is to effectively stabilize their income. Agricultural insurance is actively developed by all countries from the top five world leaders in the production of agricultural products. Among the leading countries actively supporting the agricultural insurance system are China, the USA, India, Spain [14-17].
Recently, overseas crop insurance is gaining increasing recognition based on monitoring the state of a relatively physical parameter that is independent of the insurance object, the value of which is an indicator of the occurrence of the insured event [1].

Index insurance is carried out in case of deviation of a specially developed parameter (index) from its agreed threshold value. The calculation of the amount of damage caused to a specific farm is also not made according to individual indicators of the insured, but is based on the magnitude of the change in the index. If the critical index threshold is exceeded, the insurer pays the policyholder a certain amount according to the contractual terms [2].

The use of index insurance simplifies the process of concluding a contract and settling losses, since it does not provide for mandatory inspection of crops and assessment of losses incurred by the enterprise, which significantly saves the cost of insurance. Therefore, such insurance is attractive not only for the insured, but also for the insurers themselves. In general, this creates favorable prerequisites for reducing the risks of the agrarian sector. The two main index products that are widely used are insurance based on a yield index and insurance based on weather indices.

Index insurance products are expedient and effective in the case when the index has a high correlation with the performance indicators of the insured object and, accordingly, the policyholder’s financial loss scenario. Such a correlation is possible if the risk is homogeneous over a wide area. From this point of view, the indicators of vegetation indices, which quite accurately reflect the expected yield of agricultural crops, including with reference to weather data, are of interest.

Remote sensing systems are now becoming more common in the production of agricultural products. Their use contributes to an increase in agricultural production, effective forecasting of crop yields, cost reduction, and increased profitability of agricultural enterprises [3].

Modern data of remote sensing of the earth, obtained with the help of imaging equipment installed on various spacecraft, have technical characteristics that allow to solve a whole range of tasks in the field of agricultural production, from mapping field boundaries to analyzing the degree of land utilization and condition of agricultural crops on large areas. The use of multi-temporal data also allows one to track the dynamics of changes in vegetation cover, the dynamics of agrotechnical work, identify areas affected by natural disasters, and solve many other problems.

So, S. I. Mikhailov notes the following benefits from the use of remote sensing data for solving problems in the field of agricultural production:

- Relevance of the information received;
- High accuracy of the information received;
- High frequency of obtaining information;
- Wide coverage of the study area;
- Data acquisition in a single standardized form;
- Possibility of accumulating statistical information and using it for yield forecasts and damage estimates [4].

The last of the listed advantages of using remote sensing data creates prerequisites for their use both in estimating crop loss when insuring crops and as a basic indicator of an index insurance product characterized by a very high predictive accuracy and, accordingly, low base-line risk. Baseline risk in the context of index insurance is an inaccuracy in determining the occurrence of an insured event based on a fixed index value, under which the occurrence of obligations to pay insurance compensation in the actual absence of damage may occur and, conversely, the absence of such obligations in case of crop loss.

The hypothesis discussed in the present work is that an index insurance of crops with the use of field space monitoring has the properties of an effective tool to protect agricultural producers from risks and high attractiveness potential for insurers.

This paper is a continuation of the authors’ publications, which present the results of research on the problems of the development, implementation, and application of index insurance products in the practice of agricultural insurance.
2. Methods

An index-based insurance is a type of insurance whereby the insured is compensated for crop loss caused by adverse weather conditions (e.g., high temperatures, insufficient moisture, etc.) that occurred during a certain crop vegetation period (as well as during the pre-vegetation period). The degree of manifestation of these adverse conditions is expressed in certain indicators (for example, insufficient moisture can be expressed by deviating the amount of precipitation from their multiyear average or from the optimum values for a particular culture, etc.). Such indicators serve as the basis for the development of the insurance product and are called the index. They determine the occurrence of the insurance event, and the insurance indemnities are calculated according to their size.

When insuring on the basis of indexes, the relationship between crop yields and the base indicator should be fairly close, and the connection should be formalized in a certain way.

To determine the parameters of index insurance contracts, random yields \( \tilde{y}_t \) can be decomposed into a component \( \tilde{y}_t^w \), that depends on the actual implementation of weather or other conditions in a year \( t \), and a component \( \tilde{e}_t \), that is determined by other random factors:

\[
\tilde{y}_t = \tilde{y}_t^w + \tilde{e}_t,
\]

where

\[
\tilde{y}_t^w = \text{const} + \alpha \cdot I_t,
\]

\[
E(\tilde{e}_t) = 0; \quad \text{cov}(\tilde{e}_t, \tilde{y}_t^w) = 0,
\]

\[
E(\tilde{y}_t^w) = \mu^w.
\]

The value \( \tilde{y}_t^w \) is determined by solving the regression equation of the dependence of the farm’s productivity on the \( I_t \) index. Thus, the formalization of the dependence of yield on weather and other conditions is achieved through the construction of regression models. The regression equation allows us to estimate the effect of the index unit (millimeter, degree, etc.) on the yield value, and thereby estimate the size of the loss from the impact of factors and the amount of insurance compensation.

As stated above, the basis of the index insurance product in general is the regression equation for the dependence of crop yield on a set of weather and other indicators (indices), which can be represented as follows:

\[
\tilde{y}_t^w = a_0 + a_1 x_{1t} + a_2 x_{2t} + \ldots + a_n x_{nt},
\]

where \( \tilde{y}_t^w \) – the value of the effective trait (crop yield) in the year \( t \) at certain values of factor signs (indexes) \( x_{1t}, x_{2t}, \ldots, x_{nt} \) over the same period, c/ha; \( a_0 \) – free term of the equation; \( a_1, a_2, a_n \) – regression coefficients.

In this case, the expectation of the predicted crop yield is determined by the formula:

\[
E(\tilde{y}_t^w) = a_0 + a_1 E(x_{1t}) + a_2 E(x_{2t}) + \ldots + a_n E(x_{nt}).
\]

Provided that the insured’s losses are considered to be negative deviations of the value predicted by the yield regression equation in the year \( t \) (\( \tilde{y}_t^w \)) from its expected value, we obtain if \( E(\tilde{y}_t^w) - \tilde{y}_t^w > 0 \):

\[
L_t = E(\tilde{y}_t^w) - \tilde{y}_t^w = a_1 (E(x_{1t}) - x_{1t}) + a_2 (E(x_{2t}) - x_{2t}) + \ldots + a_n (E(x_{nt}) - x_{nt}),
\]
where $L_t$ – loss of crop in a year $t$, c / ha; $E(x_1), E(x_2), E(x_n)$ – average index values, $x_1, x_2, ..., x_n$ – index values per year $t$.

Or:

$$
L_t = \begin{cases} 
E(\hat{y}^w) - \hat{y}^w_{t}, & \text{if } E(\hat{y}^w) - \hat{y}^w_{t} > 0 \\
0, & \text{if } E(\hat{y}^w) - \hat{y}^w_{t} \leq 0 
\end{cases}
$$

Thus, using the expression (8), the loss in kind is determined and the insurance event is fixed. To determine the amount of insurance compensation for crop loss multiplied by the valuation of a unit of production ($c$):

$$
P_t = L_t \cdot c,
$$

where $P_t$ – insurance indemnity per year $t$.

With the help of the presented methodology, an insurance product based on indices is being developed. Without the introduction of additional parameters, the policyholder can expect to recover the entire amount of the crop shortfall, predicted in accordance with the model obtained (it should be noted that there may be a discrepancy between the actually obtained crop shortfall and the predicted basic risk). Studies have shown that the reasonable (or fair) insurance net tariffs (and accordingly gross tariffs) for areas of high risk farming and an increased risk of growing crops are high enough, which affects their attractiveness to the insured.

3. Results

3.1. The possibilities of applying the results of space monitoring to forecast crop yields and assess crop loss

Modern scientific works on the application of space monitoring in agricultural production can be divided into two areas: yield forecasting and assessment of the state of the land, including for the agricultural census. The first of these areas is closely related to the possibilities of estimating crop loss, which is necessary when dealing with losses under crop insurance contracts.

For example, V. M. Bryksin, A. V. Evtushkin and N. V. Rychkova [5] suggest using the EPIC modified bioproductivity model for predicting the yield of grain crops. The EPIC model is a continuous simulation model of plant development of the block type. It allows one to calculate the main culture parameters (biomass, leaf index, plant height, etc.) for each day and compare them with the data of ground-based measurements and remote sensing of the earth and, if necessary, make adjustments. The six main meteorological characteristics of the model are the maximum and minimum air temperatures, incoming solar radiation, precipitation, relative humidity, and wind speed, which are fully or partially measured at a number of Russian meteorological stations.

The issues of forecasting the yield of grain and leguminous crops in the Central Black Earth Regions based on the integration of ground and satellite data were done by A. I. Strashnaya, L. L. Tarasova, N. A. Bogomolova, T. A. Maksimenkova, O. V. Bereza [6]. In their work, the authors studied the statistical series of yields of these crops from a sown area for the period 1993–2013 to solve the problem of predicting the average yield of cereals in regions. In their studies on the development of methods for predicting the yield of grain crops, they used correlation and graphical analysis methods that revealed the closeness of the relationship between crop yields and meteorological factors (temperature, lack of air humidity, hydrothermal moisture coefficient, moisture reserves) and normalized difference vegetation index (NDVI) for decades and months of spring-summer vegetation (altogether 18 factors were studied).

The practical possibility of using geographic information systems in assessing and predicting crop yields was considered in the work of V. V. Novokhatin, I. S. Chubareva [7]. The authors revealed the
dependence of the yield on the value of phytomass, calculated formulas for predicting the yield, assessed the dynamics of accumulation of phytomass during the vegetative period for the main types of crops. The constructed model shows that there is an objective relationship between the magnitude of the phytomass of a cultivated plant during the period of maximum maturity and the values of the actual yield.

An example of foreign scientific research in this area is the work of A.V. Kolotiya [8], in which the concept of agromonitoring is given, which includes two main components: the estimation of acreage and yield forecasting. The paper proposes a generalized regression model for predicting the yield of winter wheat. This model provides a forecast of winter wheat harvest in Ukraine with an accuracy of 10% relative to official statistics.

Nichiporovich, Z. A. and Radevich, E. A. analyzed the experience of using NDVI for monitoring agricultural lands of woodlands according to the IKONOS spectrozonal space imagery [9]. The authors discuss the experience of using NDVI, on the basis of which they proposed methods for automated recognition, classification and assessment of the state of lands under various agricultural uses (agricultural crops, pastures, peat soils, water bodies, etc.).

Of great interest is also the work of I. Yu. Savin, E. R. Tanov, and S. Kharzinov [10], which develops a new approach to assessing the quality of arable land, based on the use of MODIS satellite data. The essence of the approach consists in expert analysis of the vegetation index NDVI for the last 10-12 years separately for different groups of crops, as well as the interannual variability of the seasonal maximum of the vegetation index NDVI, the value of which is used as an indicator of the state of crops and crop yields on individual fields.

Thus, it is necessary to recognize that space monitoring technologies and remote sensing of the earth provide an extensive information base and practical possibilities for predicting the crop and estimating its possible loss.

3.2. Prerequisites for the use of a normalized differential vegetation index (NDVI) as a baseline index insurance index

The key issues of using remote sensing data for index insurance of crops are the definition of a baseline for the insurance product and the method of its calculation.

One of the most effective indicators for predicting crop yields can be the normalized differential vegetation index (NDVI). It is an indicator of the amount of light close to the infrared spectrum reflected by the plant, in comparison with the visible light absorbed by plants during photosynthesis. The association of NDVI with plant growth is based on the fact that healthy plants very well reflect the rays in the infrared spectrum. The NDVI value is calculated on the basis of satellite images, reflects the characteristics of vegetation (biomass and chlorophyll activity), and indicates a possible yield [3]. The expected yield is greater when the peak of biomass (the maximum value of the curve) is larger and the photosynthesis period is longer. The value of NDVI may indicate a possible decrease in yield, for example, due to a sudden hurricane or frost.

The analysis of NDVI indicators together with agrometeorological indicators and in comparison with previous years allows to determine the tendency of cultural development in the coming period. Analysis of NDVI indicators for the region over a long previous period (10 years or more) helps to assess the frequency of adverse (dangerous) conditions for the development of crops.

Comparing crop yields with NDVI, it is possible to identify the degree of compliance with NDVI and crop yields (higher NDVI corresponds to higher yields). In addition, for more reliable results, the analysis can be supplemented by a comparison of yields and agrometeorological indicators of previous years.

The reviewed scientific papers contain a number of variations on the combination and use of NDVI data that equally reliably predict crop yields. Therefore, NDVI has the potential to use it as a basis for index insurance products and insurance programs. In addition, the required platform is currently being used by insurance organizations in practice.
3.3. Evaluation of the closeness of the relationship of crop yields and normalized differential vegetation index (NDVI)

Evaluation of the possibility of applying crop insurance product based on the NDVI index was carried out using the example of spring barley cultivated in different parts of the Rostov region (Rostov region ranks first in gross barley collections in Russia as of November 1, 2016 (1,155.7 thousand tons, or 6.1% of the total gross collection [11]). The study period was limited to the period of 2001-2016 and due to the availability of data on the NDVI values provided by the satellite vegetation analysis service “VEGA-Science” of the Space Research Institute of the Russian Academy of Sciences [12].

The Rostov region includes forty three municipal districts, data on the dynamics of average NDVI spring crops of which are presented in Figure 1 (by weeks of the vegetation period). Note that the NDVI spread interval in early April is rather small, while by it increases significantly the middle of July, testifying to the influence of many local factors on the development of plants.

![Figure 1](image-url). Perennial average NDVI values of spring crops for 2001–2016 the districts of the Rostov region.

The summary statistical characteristics of the NDVI changes of spring crops by region are shown in Table 1. Indicators of the magnitude of data heterogeneity — the standard deviation and coefficient of variation — confirm the conclusion that there is an increase in differences in plant conditions by region.

Analysis of the connection of spring barley yields and NDVI values showed a close statistically significant relationship (the correlation coefficients of these two values, calculated in the context of the regions, were 0.70–0.80), which creates good prerequisites for building the model. Thus, in the present work in expression (5), the NDVI indicator will be used as the sole factor sign. However, as noted above, the information on this index covers a rather limited time period, which leads to certain difficulties and limitations when building a model. To increase the reliability of the results, we propose to extend the study period by simulating conditional NDVI values for earlier periods based on the prevailing actual weather conditions of a particular year. At the same time, using the regression model, it is necessary to formalize the dependence of the NDVI indicator on the observed temperature and precipitation, and then, using the resulting model, find the expected values of NDVI.
Table 1. Indicators of variation of NDVI spring crops in the Rostov region (calculated on the basis of multiyear average data for the regions of the region for 2001–2016)

| Indicator                      | May 7-13 | May 14-20 | May 21-27 | May 28 - June 3 | June 4-10 | June 11-17 | June 18-24 | June 25 - July 1 | July 2-8 |
|--------------------------------|----------|-----------|-----------|----------------|-----------|------------|------------|-----------------|---------|
| Minimum value                 | 0.4378   | 0.4665    | 0.4863    | 0.4980         | 0.4719    | 0.4341     | 0.3880     | 0.3535          | 0.3340  |
| Average value                 | 0.5102   | 0.5418    | 0.5610    | 0.5667         | 0.5616    | 0.5475     | 0.5224     | 0.5042          | 0.4899  |
| Maximum value                 | 0.5932   | 0.6160    | 0.6353    | 0.6414         | 0.6307    | 0.6178     | 0.5916     | 0.5782          | 0.5764  |
| Standard deviation            | 0.0450   | 0.0433    | 0.0439    | 0.0444         | 0.0452    | 0.0475     | 0.0519     | 0.0586          | 0.0646  |
| The coefficient of variation  | 0.0882   | 0.0800    | 0.0783    | 0.0784         | 0.0805    | 0.0867     | 0.0993     | 0.1162          | 0.1318  |

In connection with this fact, we used weather data from meteorological stations located in the Rostov region, namely the Gigant (WMO 34740 index) and Tsimlyansk (WMO 34646 index). At the same time, for the purposes of this study, it was assumed that the data from these stations fairly accurately reflect the weather conditions in a territory within a radius of one hundred kilometers, which is schematically reflected in Figure 2. Taking this into account, the following areas of the Rostov region were selected for research: Veselovsky, Martynovsky, Peschanokopsky, Salsky, Tselinsky districts (the territory of the station Gigant); Volgodonsky, Morozovsky, Semikarakorsky, Tatsinsky, Ust-Donetsky, Tsimlyansk districts (the territory of Tsimlyansk station).

At the first stage, we analyzed the dependence of the yields of spring barley on NDVI values. In accordance with the results of the logical and correlation analysis, we found that the mathematical formalization most accurately and reliably influences the yield on the value of NDVI, recorded in the period of June 11-17, about 3-4 weeks before harvest.

The correlation coefficients between NDVI and barley yield in selected areas are in the range of 0.70-0.80 (Table 2), which indicates a close relationship between the values. Thus, this indicator may form the basis for further work on the formation of an insurance product based on the NDVI index.

The marked closeness of the connection between NDVI and the yield of spring barley is confirmed by a visual study of the joint dynamics of the two analyzed indicators (in Figure 3, an example is given of the dynamics in the Tselinsky district). The synchronicity of the variability of the vegetative index and the yield volatility is clearly traced. An assessment of the type of dependence of the yield of spring barley on the observed NDVI value led to the conclusion that the relationship was linear, which was the prerequisite for creating a linear regression model and formed the basis for further calculations.
Figure 2. Positions of the Gigant (WMO 34740) and the Tsimlyansk (WMO 34646) weather stations on the map of the Rostov region.

Table 2. Statistical characteristics of NDVI values and spring barley yields (calculated on the basis of data for the regions of the region for 2001-2016).

| District of Rostov region | NDVI from June 11-17 | Spring Barley Yield | NDVI and Yield Correlation Coefficient |
|---------------------------|----------------------|---------------------|--------------------------------------|
|                           | Average value | Standard deviation | The coefficient of variation | Average value, c/ha | Standard deviation | The coefficient of variation |                           |
| Veselovsky                | 0.5758        | 0.0691              | 0.12                      | 23.85              | 6.90              | 0.29                      | 0.74                     |
| Martynovsky               | 0.5621        | 0.0724              | 0.13                      | 16.69              | 5.80              | 0.35                      | 0.74                     |
| Peschanokopsky            | 0.6040        | 0.0839              | 0.14                      | 28.69              | 9.91              | 0.35                      | 0.79                     |
| Salsky                    | 0.5497        | 0.0823              | 0.15                      | 21.34              | 6.53              | 0.31                      | 0.70                     |
| Tselinsky                 | 0.5602        | 0.0716              | 0.12                      | 26.79              | 6.61              | 0.25                      | 0.80                     |
| Volgodonsky               | 0.5633        | 0.0613              | 0.11                      | 15.89              | 5.45              | 0.34                      | 0.74                     |
| Morozovsky                | 0.5294        | 0.0613              | 0.12                      | 14.59              | 6.29              | 0.43                      | 0.74                     |
| Semikarakorsky            | 0.5892        | 0.0749              | 0.13                      | 20.69              | 7.25              | 0.35                      | 0.78                     |
| Tatsinsky                 | 0.5211        | 0.0599              | 0.11                      | 13.29              | 5.49              | 0.41                      | 0.78                     |
| Ust-Donetsky              | 0.5888        | 0.0612              | 0.10                      | 15.68              | 5.38              | 0.34                      | 0.72                     |
Figure 3. The relationship between the yield of spring barley and NDVI values in the period of 11-17 June for 2001–2016 in the Tselinsky district (Rostov region.)

3.4. Modeling the relationship of crop yields and normalized differential vegetation index (NDVI) as the basis for the development of an index insurance product

In order to overcome the short duration of the dynamics and the associated low reliability of the simulation results, we built models of the NDVI dependence of each region in the period from June 11-17 on the sum of average daily temperatures for the period from May 1 to June 11 and the amount of precipitation for the period from April 1 to June 11 (the indicated periods were chosen experimentally). For calculations by area, the weather data of Gigant and Tsimlyansk meteorological stations were used in accordance with their remoteness. Based on the models, the expected NDVI values for the earlier period, 1983-2000, were determined. Thus, for each study area, elongated series of NDVI dynamics were obtained.

Later, the authors carried out a mathematical modeling of the dependence of the yield of spring barley in 1983–2016 from the NDVI value in certain areas of the Rostov region in accordance with (5), and, using the least squares method, the parameters of the regression equations were found, the information on which is presented in Table 3:

Table 3. Estimation of model parameters of dependence of spring barley yield on NDVI value.

| Districts of Rostov region | Constant \((a_0)\) | Variable coefficient \((a_1)\) | Coefficient of determination \((R^2)\) |
|---------------------------|--------------------|-------------------------------|----------------------------------|
| Veselovsky                | -19.33**           | 73.42***                      | 0.72                             |
| Martynovsky               | -13.08*            | 51.46***                      | 0.60                             |
| Peschanokopsky            | -14.87*            | 65.78***                      | 0.60                             |
| Salsky                    | -12.08*            | 59.41***                      | 0.69                             |
| Tselinsky                 | -14.30*            | 63.53***                      | 0.61                             |
| Volgodonsk                | -22.88**           | 71.85***                      | 0.56                             |
| Morozovskiy               | -15.78**           | 55.92***                      | 0.63                             |
| Semikarakorsky            | -12.26*            | 57.10***                      | 0.52                             |
The statistical characteristics of the models indicate a good approximation of the values: all the coefficients of determination are above 0.60, the values of the F-statistics indicate that the found relationship is not random, all the regression coefficients are significant.

3.5. Determination of parameters of index insurance products based on the normalized differential vegetation index (NDVI)

Using the obtained dependencies, projected yield values and yield losses were calculated in accordance with (8), which, by correlating the yield loss and average yield values, made it possible to determine insurance net tariffs and gross tariffs with a fifteen percent load for different options of unconditional franchises (Table 4).

Table 4. Estimated gross tariffs of spring barley index insurance for certain districts of the Rostov region.

| District           | No franchise, | With a franchise | With a franchise | With a franchise |
|-------------------|---------------|------------------|------------------|------------------|
|                   | %             | 5%, %            | 10%, %           | 15%, %           |
| Veselovsky        | 7,78          | 7,43             | 6,61             | 5,40             |
| Martynovsky       | 8,80          | 8,66             | 8,00             | 7,12             |
| Peschanokopsky    | 8,29          | 8,24             | 6,77             | 6,77             |
| Salsky            | 9,07          | 8,92             | 7,75             | 5,92             |
| Tselinsky         | 6,87          | 6,79             | 5,52             | 4,77             |
| Volgodonsky       | 9,51          | 9,22             | 8,48             | 6,76             |
| Morozovsky        | 13,16         | 13,16            | 12,53            | 11,70            |
| Semikarakorsky    | 7,64          | 7,39             | 6,54             | 5,17             |
| Tatsinsky         | 11,71         | 11,54            | 10,50            | 10,03            |
| Ust-Donteshkoy    | 8,90          | 8,90             | 8,09             | 5,17             |
| Tsimlyansky       | 13,42         | 13,22            | 12,82            | 12,07            |

As noted earlier, reasonable index insurance tariffs can take quite high values, such as tariffs received for the Morozovsky, Tatsinsky, and Tsimlyansky districts.

Such conditions of the insurance contract as insurance rates, the size and terms of payment of insurance compensation depend on the amount of risk accepted for insurance. Therefore, it is possible to reduce tariffs to increase the attractiveness of the product by varying the amount taken for risk insurance by setting limits on the recoverable yield shortfall (corresponding to the minimum and maximum liability amounts of the insurance company) and taking risks for insurance of varying degrees of occurrence and the likelihood. In order to regulate the magnitude of the insured risk to maximally take into account the needs of policyholders, basic products can be modified in these areas. In particular, Table 4 shows the matrix of insurance tariffs at different levels of unconditional franchises.

3.6. Evaluation of the effectiveness of using index insurance products based on the normalized differential vegetation index (NDVI)

Any risk protection tool has as its ultimate goal the stabilization of income or another indicator important to the decision maker. To prove the existence of this property in the NDVI-based index
insurance, we conducted additional studies related to modeling the expected income from growing
spring barley in the territories under study for 1983–2016 in two situations:

− Without insurance;
− Using the NDVI-based index insurance to protect against the risk of crop loss.

It was assumed that the price per unit of output remained fixed (to ensure comparability of results),
the franchise was not applied, insurance premiums were paid at insurance rates presented in Table 4,
insurance indemnities were paid unconditionally, when the NDVI indicator fell below the multi-year
average and depending on magnitude of such a decrease. Statistical characteristics of the expected
values of income under these conditions are presented in Table 5.

Table 5. Comparison of the variation of the actual yield of spring barley cultivation and the
predicted yield of spring barley, taking into account crop insurance operations.

| District            | Characteristics of the income from the cultivation of spring barley | Characteristics of the income from the cultivation of spring barley, taking into account crop insurance operations |
|---------------------|---------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
|                     | Standard deviation | The coefficient of variation | Standard deviation | The coefficient of variation |
| Veselovskiy         | 6,31               | 0,26                         | 4,81               | 0,19                         |
| Martynovsky         | 5,74               | 0,34                         | 5,01               | 0,29                         |
| Peschanokopsky      | 8,22               | 0,31                         | 6,99               | 0,26                         |
| Salsky              | 6,42               | 0,29                         | 5,17               | 0,23                         |
| Tselinsky           | 6,57               | 0,26                         | 5,66               | 0,22                         |
| Volgodonsky         | 6,65               | 0,37                         | 5,84               | 0,33                         |
| Morozovsky          | 6,17               | 0,43                         | 5,43               | 0,38                         |
| Semikarakorsky      | 7,17               | 0,32                         | 6,11               | 0,28                         |
| Tatsinsky           | 5,53               | 0,38                         | 4,50               | 0,31                         |
| Ust-Donetsky        | 5,51               | 0,34                         | 4,86               | 0,30                         |
| Tsimlyansky         | 6,10               | 0,42                         | 5,04               | 0,35                         |

Reduction of standard deviations and coefficients of variation indicates a significant de-rease in
the variability of income from spring barley cultivation (reduction of variation coefficients in some
cases reaches 27%), thereby confirming the effectiveness of using index insurance products based on
the normalized difference vegetation index (NDVI) to protect against crop loss risks.

4. Conclusion
These results suggest the effectiveness of crop insurance based on the NDVI index: the close
connection between crop yields and NDVI, and, accordingly, the possibility of predicting crop loss
creates serious prerequisites for the emergence of this type of insurance in our country.

However, at present, the use of index-based insurance products must be tied to damage. This
circumstance is due to the legal aspect of regulating the conclusion and execution of insurance
contracts. Thus, according to paragraph 2 of Art. 9 of the Federal Law “On the Organization of
Insurance Business in the Russian Federation” of 11.27.1992, No. 4015-1 [13], an insured event is an event provided for by an insurance contract or a law, with the occurrence of which an insurer is obliged to make an insurance wage for the insured person, beneficiary or other third parties. That is, the event must necessarily occur, and insurance products based on the index provide for the absence of such a fact and on a calculated index, in which insurance indemnity is paid out if the conditional factor
indicated by the insurance contract has reached the agreed calculated value, which in some cases enables the insured to receive compensation if one does not have a real loss on the farm.

Thus, one of the important aspects of the development and implementation of index insurance products is to minimize the baseline risk through the use of additional procedures, for example, related to proof of damage, in particular, according to the data of the insurer’s federal statistical observation forms (No. 29-CX or No. 2- farmer), which, however, is in conflict with the classical principles of index insurance. The second direction is the improvement of the development of index products and the creation of a model for the implementation of insurance payments as closely as possible corresponding to the actual loss of the insured. The solution of this problem is a promising direction of research in the field of increasing the efficiency of instruments for minimizing risks in agriculture.

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