Water supply volumes and temperature regime influence on rice productivity in the Lower Kuban reclamation complexes

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Abstract. The statistical analysis of the irrigation water volume and air temperatures sum influence on the average rice productivity in the irrigation systems of the Lower Kuban is presented in the article. The analysis was performed by using quadratic and power regression equations; the each factor contribution to the productivity value was estimated by the statistical significance of the regression, correlation and determination coefficients. The rice culture sensitivity to the irrigation regime - to the water volume supplied to irrigation systems, and to the temperature regime according to the vegetation months, was analyzed. It was found that only during two months of the growing season - July and September, high temperatures and irrigation water scarcity lack provide a synergistic effect in relation to the high yield formation.

1. Introduction
In different vegetation periods, the plants sensitivity to environmental factors varies and, depending on the development phase and environment, the same growth factor may correspond to a multidirectional influence on the agricultural crops growth and development. In this regard, the ambiguity of the rice culture reaction to the water regime, which in turn affects the plants temperature regime and the oxygen supply to the growing organs, is described in detail in the scientific literature [1-3].

The statistical analysis of the environmental factors influence on crop productivity in rice-growing farms in the Krasnodar region is given in the article. Two factors of the external environment - the actual supplied irrigation water amount and the air temperatures sum during different periods of crop vegetation were considered in the research. The uneven demand of rice crops for irrigation water in different vegetation periods was taken into account during analysis: from sowing and seed sprouting to full ripeness.

2. Materials and methods
As the information basis for the analysis was actual data for a 10-year period (2009-2018) on water supply, crop acreage and irrigation rate at three irrigation systems that are the part of the Lower Kuban reclamation complex: Kuban, Chernoerkovskaya and Kryukovskaya (table 1), average monthly air temperature data and the sum of monthly temperatures at the Krasnodar/Kruglik meteorological station (table 2).
Table 1. Indicators of water supply to the Kuban, Chernoyerkovskaya and Kryukovskaya irrigation systems.

| Indicators                        | Kuban irrigation system | Chernoyerkovskaya irrigation system | Kryukovskaya irrigation system |
|-----------------------------------|-------------------------|------------------------------------|--------------------------------|
| Total water supply, million m³ per year | 1407                    | 536                                | 64                             |
| Water supply to rice, million m³ per year | 872                     | 418                                | 49                             |
| Rice irrigation area, thousand ha | 47                      | 23                                 | 7                              |

Table 2. The average monthly values of air temperature and the sum of monthly temperatures, °C, for 10 years (2009-2018).

| Indicators          | May  | June | July | August | September |
|---------------------|------|------|------|--------|-----------|
| Maximum temperature | 23.7 | 28.1 | 30.9 | 31.5   | 25.4      |
| Minimum temperature | 14.2 | 18.7 | 20.7 | 19.7   | 15        |
| Sum of temperatures | 586.2| 698.7| 796.9| 796.2  | 602.4     |

Table 3. Quadratic regression coefficients values.

| Irrigation system     | a₁   | a₂   | a₃   | a₄   | a₅   | c     | R²   | R²b  |
|-----------------------|------|------|------|------|------|-------|------|------|
| Cuban                 | -45.1| -501.9| 0.2 | 44.0 | 11.1 | 1317.4| 0.93 | 0.86 |
| Chernoyerkovskaya     | -105.6| -428.4| -2.5| -108.6| 60.7 | 1781.7| 0.61 | 0.37 |
| Kryukovskaya          | 65.4 | 108.6| -1.5| 0.0  | -5.7 | -642.2| 0.71 | 0.51 |

Based on these data, variational calculations of the irrigation water volume and air temperature influence on the average rice productivity in the Lower Kuban irrigation systems were performed by using the regression analysis methodology.

3. Results and discussion

Analysis of the water supply volume and temperature sums influence

The collected indicators of the average productivity and the temperatures sum of vegetation periods for 10 years are attributed to all Lower Kuban irrigation systems. At the analysis first stage, the coefficients of two-factor quadratic correspondence were calculated (table 3). As disposal variables, the water supply volume at the specific irrigation system and the sum of air temperatures for the growing season at the Krasnodar/Kruglik meteorological station were considered.

The regression equation has the form:

\[ Y = c + a_1 \times x_1 + a_2 \times x_2 + a_3 \times x_1^2 + a_4 \times x_2^2 + a_5 \times x_1 \times x_2 \]  

(1)

where \( Y \) is productivity; \( c, a_1, a_2, \ldots, a_5 \) is regression coefficients; \( x_1 \) is the water supply volume for rice irrigation, thousand m³/ha, \( x_2 \) is the sum of average daily air temperatures for 5 months (May-September), thousand °C per day.

| Irrigation system     | a₁   | a₂   | a₃   | a₄   | a₅   | c     | R²   | R²b  |
|-----------------------|------|------|------|------|------|-------|------|------|
| Cuban                 | -45.1| -501.9| 0.2 | 44.0 | 11.1 | 1317.4| 0.93 | 0.86 |
| Chernoyerkovskaya     | -105.6| -428.4| -2.5| -108.6| 60.7 | 1781.7| 0.61 | 0.37 |
| Kryukovskaya          | 65.4 | 108.6| -1.5| 0.0  | -5.7 | -642.2| 0.71 | 0.51 |

where \( R² \) is the correlation coefficient, \( R²b \) is the coefficient of determination

Graphs of the obtained correspondences are shown in the Figure 1. Within the lines of the actual studied factors values, response surface regression for the Kuban irrigation system (figure 1a) has a saddle-like shape with two points: the first one, mild to relatively cool year and low values of irrigation rate reaches the level of 68 c/ha, and the second one (showing the potentially possible productivity up to 90 c/ha) for conditions of high heat- and moisture supply. The saddle area indicates
the presence of fairly frequent distortions in agricultural technology, due to the violation of planned indicators for providing the irrigation system with water and its use, which is not fully consistent with weather conditions. For the Chernoerkovskaya irrigation system, the regression response surface has a similar form ($R=0.61; R^2=0.37$), with less delineated surface points.

The response graph of the rice productivity regression correspondences at the Kryukovskaya irrigation system areas on the temperatures sum in the growing season and the irrigation norm has a different form (figure 1-b). The surface has a delineated optimum in the range of irrigation norms of 14-15 thousand m$^3$/ha with a linear increase in productivity (from 60 to 72 c/ha) in proportion to the temperatures sum accumulated during the vegetation. Preliminary analysis shows that the organization of rice bays irrigation on the system regardless the amount of water supplied and the temperature regime is a certain set irrigation regime which is strictly observed, possibly due to the technical features of the irrigation system or as the result of many years’ experience.

**Figure 1.** The rice productivity correspondence on the irrigation norm and the air temperatures sum value for the growing period in the Lower Kuban:
a) for the Kuban irrigation system  b) for the Kryukovskaya irrigation system.

**Analysis of the water supply factor impact**

When analyzing rice crops water supply factors dynamics influence during the growing season, regression in the form of the exponential function product was used. The equation of the required dependence has the form:

$$Y = c \times x_1^{a_1} \times x_2^{a_2} \times \ldots \times x_n^{a_n}$$  \hspace{1cm} (2)

where $x_1, x_2, ..., x_n$ are factors of production and environment by month (irrigation norms and temperature sums).

After logarithmizing both parts of the equation, we get a linear function for which we find the coefficients ($c$, $a_1$, $a_2$, ..., $a_n$) by using the least squares method; we can judge the contribution of each factor to the yield value and evaluate the statistical significance by the correlation and determination coefficients. The used values of the analyzed factors in the calculations are represented by dimensionless normalized ratios of the actual (tabular) value to the minimum, average and maximum value for the selected time interval: the value for each month separately for 10 years, the value from May to September for each year and for each one for the entire period of the research. This scaling was carried out in order to identify the influence of factor variability by month for the entire research period, for vegetation or for the entire 10-year period, and, in addition, for a more visual assessment of each factor contribution to the function value.

**Table 4.** The regressions coefficients of the productivity dependence on the irrigation regime according to the growing season months.

| Factor contribution, % | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $c$  | $R$   | $R^2$ |
|------------------------|-------|-------|-------|-------|-------|------|-------|-------|
| **Kuban irrigation system** |       |       |       |       |       |      |       |       |
| 1. On average value from May to September | -0.39 | -0.63 | -1.11 | -1.26 | -1.07 | 4.36 | 0.91  | 0.84  |
| The contribution of factor in % | -0.51 | -0.81 | -1.42 | -1.61 | -1.37 |      |       |       |
| 2. On the minimum value from May to September | 0.18  | -0.02 | 0.02  | 0.004 | -0.03 | 4.12 | 0.67  | 0.45  |
| The contribution of factor in % | 0.29  | -0.03 | 0.03  | 0.007 | -0.04 |      |       |       |
| 3. On the maximum monthly value | -0.01 | 0.08  | -0.36 | -0.18 | -0.24 | 4.01 | 0.88  | 0.77  |
| The contribution of factor, % | 0.04  | -0.31 | 1.41  | 0.72  | 0.97  |      |       |       |
| **Chernoyerkovskaya irrigation system** |       |       |       |       |       |      |       |       |
| 1. On average value from May to September | -0.37 | -0.79 | -0.62 | -0.75 | -0.56 | 4.12 | 0.57  | 0.33  |
| Factor contribution, % | 0.030 | 0.065 | 0.051 | 0.062 | 0.046 |      |       |       |
| 2. On the minimum monthly value | 0.02  | 0.05  | 0.03  | 0.07  | -0.06 | 4.03 | 0.40  | 0.16  |
| The contribution of factor in % | 0.44  | 1.10  | 0.66  | 1.54  | -1.32 |      |       |       |
| 3. On the maximum monthly value | -0.11 | -0.16 | 0.06  | -0.05 | -0.06 | 3.99 | 0.49  | 0.24  |
| The contribution of factor, % | 1.16  | 1.70  | -0.63 | 0.53  | 0.63  |      |       |       |
| **Kryukovskaya irrigation system** |       |       |       |       |       |      |       |       |
| 1. On average value from May to September | 0.03  | 0.46  | 0.79  | 0.72  | 0.30  | 3.87 | 0.59  | 0.35  |
| Factor contribution, % | 0.08  | 1.26  | 2.16  | 1.97  | 0.82  |      |       |       |
| 2. On the minimum monthly value | -0.18 | 0.07  | -0.03 | 0.06  | -0.42 | 4.12 | 0.62  | 0.39  |
| The contribution of factor in % | 0.09  | -0.03 | 0.01  | -0.03 | 0.21  |      |       |       |
| 3. On the maximum monthly value | -0.01 | -0.01 | -0.01 | -0.03 | -0.11 | 4.03 | 0.44  | 0.19  |
| The contribution of factor, % | 0.10  | 0.12  | 0.03  | 0.46  | 1.70  |      |       |       |

Based on the calculations results (table 4), the most informative regressions with high values of correlation and determination coefficients ($R$ and $R^2$) were selected, among which there were calculation variants scaled by the average value of the waterfall for the period from May to September ($R=0.91$ and $R^2=0.84$). The choice of such a scaling parameter, according to our assumption, may be
closer than others to the value of the minimum planned water supply, which plays an important role in the efficiency of irrigation water use [4].

For the Kuban irrigation system, variations exceeding the average watersupply during the growing season have a positive effect with the increase from May to September. According to the minimum monthly value, exceeding the water supply level (regression 2) shows a significant positive contribution in May. Exceeding variations in the maximum monthly water supply has a negative contribution in July, as well as in August and September (regression 3).

For the Chernookovskaya irrigation system, an informative regression was not obtained, and based on the set of coefficient values, it is possible to build a priority series of months for the importance of water supply for irrigation within the limits of the practiced volumes (regression 2, 3): June, August and May. Irrigation rates higher than the minimum and lower than the maximum monthly values (closer to the average) have a significant contribution to the value of productivity during these months.

The Kryukovskaya irrigation system is most responsive to exceeding the average monthly water supply in July and August, then in June and September (regression 1). On increments of water supply at the beginning of vegetation (exceeding the maximum monthly level), the response of crop productivity is insignificant and is more clearly manifested in the last month of vegetation (regression 3).

Analysis of the influence of the temperature factor

The research of the temperature factor influence by month was carried out similarly, by using the above approach with the help of regressions. Scaling was also performed by the ratio of the current value to the average, minimum, and maximum for the selected time interval: the value by month for 10 years, the value from May to September for each year, and for the entire research period.

Based on the analysis results of the (Table 5), the most informative regressions were identified for the sample series of variations in monthly temperature totals for vegetation (scaled by the average and maximum values of temperature totals for the period from May to September of each year). The highest value of the correlation coefficient \( R=0.89 \) was obtained for regression when scaling the sample with the maximum values. The regression coefficients of the yield dependence on temperature analysis results show that for climatic conditions of Lower Kuban contribution of the temperature factor for each month when excess of the air temperature average value positively affects the productivity rate (regression 1), in July the lack of temperature leads to a decrease in productivity (regression 2), and in June it is vice versa (regression 3). Exceeding the background temperature, which has a positive influence on productivity, is observed in July and August, and a negative impact is in September and May (the months in the text are listed by the degree of temperature influence).

### Table 5. The regressions coefficients of the productivity dependence on monthly air temperature.

| Coefficient value | a1   | a2   | a3   | a4   | a5   | c     | R     | R²   |
|-------------------|------|------|------|------|------|-------|-------|------|
| 1. On average value from May to September | 7.94 | 9.12 | 10.30| 9.90 | 7.88 | 3.94  | 0.82  | 0.67 |
| The contribution of factor, % | 0.81 | 0.93 | 1.05 | 1.01 | 0.81 |
| 2. On maximum value from May to September | 0.24 | -0.32| 1.03 | -0.20| 0.08 | 4.21  | 0.89  | 0.80 |
| The contribution of factor, % | -0.55| 0.74 | -2.38| 0.46 | -0.18|
| 3. On minimum monthly value for all years | -0.19| -176 | -0.05| -0.29| -0.22| 4.31  | 0.73  | 0.53 |
| The contribution of factor, % | -0.005| -4.32| -0.001| -0.007| -0.005|
Rice crops are most sensitive to high temperatures in June that leads to a significant decrease in productivity (4.3%), and during the other months this influence is insignificant (regression 3).

Comparison of the two dynamic factors influence, natural, due to the characteristics of the regional climate, and water, depending on the water content of the source of the Kuban river and its tributaries, the technical characteristics of reservoirs, waterworks, irrigation systems and the rice crops water regime practiced in farms shows their relationship, which affects the crop productivity. Indeed, only for the two months of the growing season in July and September, high temperatures and the absence of irrigation water shortage are most often a favorable situation for the high yield formation, which provides a synergistic effect.

August is the hottest month in the Kuban and high temperatures, regardless of the availability of irrigation water, often negatively affect productivity, and in May and June, there may be distortions caused by both a lack of heat in the presence of water, and its excess, which occurs when the volume of irrigation water is slightly reduced within the average values.

It can be assumed that in the process of organizing irrigation in farms are guided by the reaction of culture and high air temperatures in June and August, as the result, large volumes of irrigation water are supplied based on the possibility of increasing the flow rate and reducing the temperature of water in the bay, hence the observed possible overheating when there is a lack of water.

4. Conclusion

The use of mathematical statistics, regression and dispersion analysis allows to identify certain patterns of natural and anthropogenic factors influence on the processes of crop yield formation, based on production information materials at the regional level.

With the help of various regression equations calculated from variations in the gross harvest of rice-growing farms in the Lower Kuban, the sensitivity of the crop for the months of vegetation in relation to the irrigation and temperature regime is shown.

Analysis of regression functions calculated for Lower Kuban three irrigation systems Kuban, Chernoerkovskaya and Kryukovskaya showed significant differences in the rice crops productivity response to environmental factors caused by soil, varietal, engineering, organizational and agro technical characteristics inherent in each irrigation system.

References

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