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Forecasting Crops Yield Capacity in Changing Agroclimatic Conditions of Ararat Valley and Piedmont Zones

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ABSTRACT

The current research work considers the results of investigations conducted for projecting and planning crops yield capacity based on statistical indicators of the yield amounts and changes in agroclimatic conditions throughout 2006-2020 years.

To forecast the crop's yield capacity, the data on the results of crops yield amount, agroclimatic characteristics of their allocation and atmospheric precipitations for the previous years have been processed. Finally, an algorithm has been developed, which has been applied for potato crops and, as a result, changing tendencies in the potato yield capacity, when deviated from the best soil and climatic conditions, has been demonstrated.

Introduction

The global climate change, scarce soil reserves, decline in water supply and the growing tendency of population increase vulnerability of the food safety system in the Republic of Armenia. Almost 14 % GDP (gross domestic product) of Armenia is provided by the agricultural sector, moreover, plant breeding sector accounts for its 46.9 %. More than 80 % of plant-based products are obtained in irrigated conditions. Eventually, among the primary factors of crops yield capacity increase, moisture supply index, soil fertility and ameliorative conditions are distinguished. The moisture supply index is usually estimated through the ratio of atmospheric precipitation fallen in that area and evaporation level. In view of generic index, soil fertility can be addressed as the indicator of soils' qualitative evaluation. Ameliorative conditions of soils are manifested through salt, nutritional, air, thermal and humidity regimes. For the projection of crops yield capacity, yield amounts of different years, agroclimatic characteristics, atmospheric precipitations, water supply rate and characteristics of soil reclaiming regimes can serve as a background.

Materials and methods

For research implementation, agroclimatic changes of the Ararat valley, piedmont zones and partially those of mountainous areas for 2006-2020 years have been studied.

The data of 10 hydrometeorological stations, including Artashat (829 m), Yerevan Agro (942 m), Yeghvard (1336 m), Hrazdan (1756 m), Urtsadzor (1046 m) and Jermuk (2064 m) stations have been used to study the climatic conditions of the investigated areas. The scheme of the stations' allocation is introduced in figure 1.

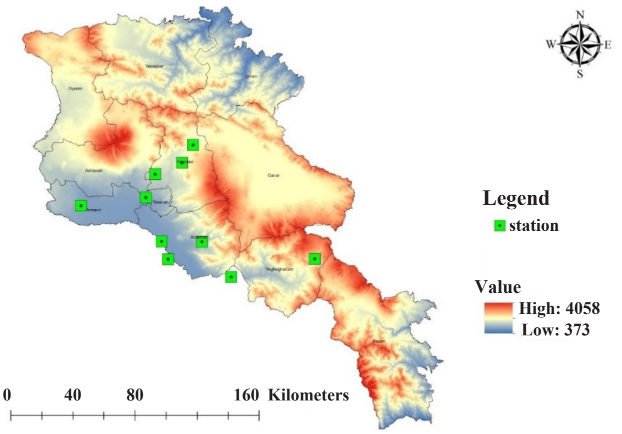

Figure 1. Allocation of hydromeeorological stations in the territory of Armenia.

Making use of the data on agroclimatic indicators, the maximum estimated evaporations per years have been calculated through FAO-56 method developed on the bases of Penman-Monteith equation.

For the projection of crops' yield capacity the following dependence is considered to be the most applicable one:

$$y = y_{max} \cdot K_0 \sum\nolimits_{i=0}^{n} K_{ri} \cdot K_{gi} \cdot K_{ci} \cdot K_{sari} \cdot \alpha_i , \qquad (1)$$

where y_{max} is the maximum crop yield capacity in the specific soil and climatic conditions, K_0 is a coefficient, which considers the crop yield capacity decline in case of deviation from the best agrotechnical terms, K_{ri} – considers it in case of deviation from the best moisture conditions in that very development stage, K_{gi} – in case of high level of ground waters, K_{ci} – in case of availability of harmful salts, K_{sari} – in case of alkalization and α_i is the specific weight of the agricultural crop's developmental stage.

In case of deviation from the best agrotechnical terms, the amount of crop yield decrease is estimated through K_0 coefficient, for the determination of which the following dependence is suggested (Dmitrenko, 1971, Gorbunova and Utina, 1968, Zhukovsky and Sanoyan, 1977, Konstantinov, et al., 1974, Kozlovskiy, 1969, Cowan, 1965, Scotler and Kerr, 1973, Goldstein and Mankin, 1972, Cowan, 1972, Day, 1947):

$$K_0 = 1 - \frac{\sum\nolimits_{i=0}^{n} \Delta T_i}{\sum\nolimits_{i=0}^{n} T_i - \sum\nolimits_{i=0}^{n} T_{0i}}, \qquad (2)$$

where $\sum\nolimits_{i=0}^{n} \Delta T_i$ is the total loss of biologically active temperatures due to the delayed agricultural activities implemented on the irrigated croplands, $\sum\nolimits_{i=0}^{n} T_i$ is the sum of biologically active temperatures (from 10 ^{0}C) during the vegetation period, $\sum\nolimits_{i=0}^{n} T_{0i}$ is the sum of minimum active biological temperatures required for the maturation of the agricultural crops.

The values for $\sum\nolimits_{i=0}^{n} \Delta T_i$, $\sum\nolimits_{i=0}^{n} T_i$ and $\sum\nolimits_{i=0}^{n} T_{0i}$ are described in Table 1.

Table 1. Values of $\sum\nolimits_{i=0}^{n} \Delta T_i$, $\sum\nolimits_{i=0}^{n} T_i$ and $\sum\nolimits_{i=0}^{n} T_{0i}$, in conditions of the Ararat valley*

Name of agricultural crops	$\sum\nolimits_{i=0}^{n} \Delta T_i$	$\sum\nolimits_{i=0}^{n} T_i$	$\sum\nolimits_{i=0}^{n} T_{0i}$
Row crops	150...360	1000...1500	3800...4200

*Composed by the author.

The maximum yield capacity of the agricultural crops is determined based on the radiation balance, a number of soil and climatic indicators, fertilization background and a number of values related to biophysical processes recorded on that specific area (Tupichev, 1973, Filipov, 1982, Frid, 1974):

$$y_{\max} = 10 \frac{R\eta_1\eta_2\eta_3}{C_h(1-r)}, \qquad (3)$$

where R is the radiation balance observed on the soil surface (kJ/cm^2 a year), which is identified via the following equation:

$$R = LE + B + S, \qquad (4)$$

where LE is the heat amount spent on the physical evaporation and transpiration, B is the heat exchange value between the soil surface and atmosphere, S is the heat exchange value between the soil strata and substrata, η_1 is the coefficient of photosynthetically active radiation,

η_2 is a coefficient that estimates the fertility index of irrigated land area based on the natural, soil and climatic conditions and fertilization background, η_3 is the ratio between the mass of fruit-producing organs and the sum of the crops' under- and above-ground weights, C_h is the heat capacity of dry matter per yield unit, r is the weighted humidity of the marketable yield (Dzekunov, et al., 1987, Golovanov and Novikov, 1974, Golochenko, 1976). The values of abovementioned factors and coefficients are presented in Table 2.

Table 2. Values of coefficients*

R	η_3	η_3	η_3	C_h	*r*
4000...4200	0.01...0.04	20...100	0.4...0.9	18.1...20.2	0.14...0.80

Table 3. Values of K_{Ci} and K_{sari}*

$\sum C$, %	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
K_{Ci}	0.98	0.96	0.85	0.79	0.65	0.55	0.38	0.25
SAR	0	1	2	3	4	5	6	7
K_{sari}	1	0.98	0.96	0.96	0.80	0.68	0.35	0.28

Table 4. Values of α_i for the row crops*

Developmental stages	1	2	3
α_i	0.33	0.34	0.33

*Composed by the author.

The values of K_{ri}, which identify the decreasing tendency of crops yield capacity in case of deviation from the best soil humidity conditions, are determined through the following pattern:

$$K_{ri} = \left(\frac{r_i(x)}{r_{good}}\right)\left(\frac{1-r_i^0(x)}{1-r_{good}}\right)^{\gamma_i(1-r_{good})}, \qquad (5)$$

where

$$r_i^0(x) = \frac{r_i(x)-B3}{A-B3}. \qquad (6)$$

Here $r_i(x)$ is the average volume humidity in the soil active stratum for the given phase of crop development, A is the porosity, $B3$ is the crop withering moisture, r_i is the best soil moisture, γ_i is a degree index, which characterizes the plant sensitivity in that specific development stage, when the soil moisture deviates from the index of best moisture (Yeghiazaryan, et al., 2021, Danielyan, 2021). For the row crops r_{good} = 0.68 … 0.75, and the values of γ_i per the developmental stages assume the following mean values: 3.2; 5.8; 5.6; 6.0. Ground waters are located at the depths of more than 2 m, and in case of drainage systems availability the values of K_{gi} fluctuate within the range of 0.8…1.0. The yield capacity decrease of the agricultural crops is also related to the total amount of harmful salts in the medium and to the alkalization degree, the effects of which are evaluated by means of K_{Ci} and K_{sari} coefficients (Table 3) (Khruslova, 1983, Shulgin and Masharipov, 1969).

Results and discussions

The analyses and discussions have been conducted on the example of potato crop. Studies show that the areas under potato fields got reduced monotonously during the observation period. The maximum sown area made 34298 ha, minimum sown area – 20477 ha in 2019, hence, the cropland area was reduced by about 40.3 %. Yield capacity fluctuated within the range of 163.4-231.6 c/ha, besides, the yield reduction against the maximum value made 29.4 %, minimum deviation was about 6 %, which was recorded in 2015.

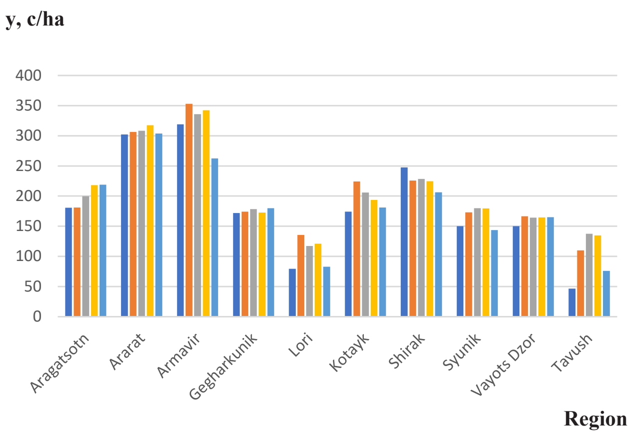

Figure 2. Potato yield capacity per the regions of the RA within 2006-2020 years *(composed by the author).*

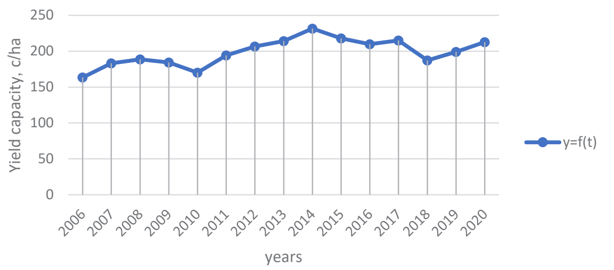

Figure 3. Dynamics of average potato yield capacity *(composed by the author)*.

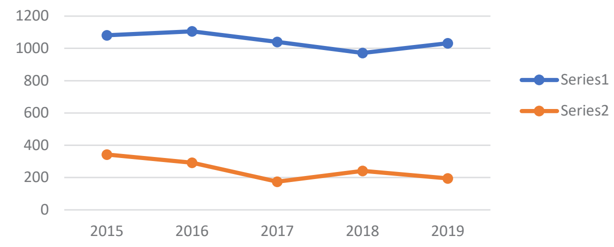

Figure 5. Dynamics of maximum evaporation and average atmospheric precipitations per the data of hydrometeorological stations *(composed by the author)*.

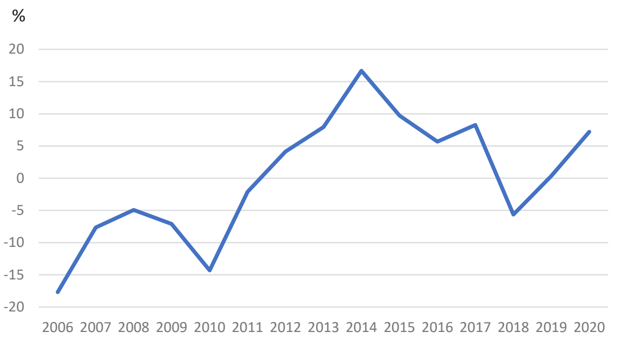

Figure 4. Increasing and decreasing dynamics of potato yield capacity per years *(composed by the author)*.

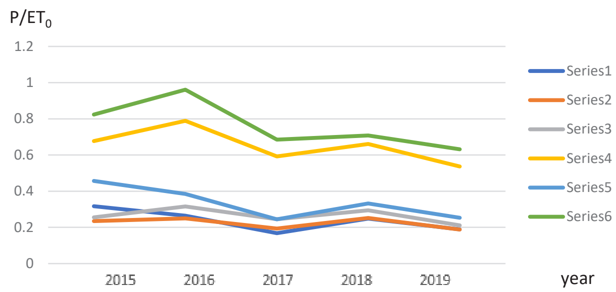

Figure 6. The change of moisture supply per years and observation data: 1-Artashat (829 m); 2-Yerevan Agro (942 m); 3-Yeghvard (1336 m); 4-Hrazdan (1756 m); 5- Urtsadzor (1064 m); 6-Jermuk (2064 m) *(composed by the author)*.

The studies on increasing and decreasing tendencies for potato yield capacity disclose that these variations are related to the complex impact of numerous factors. Anyhow, among the considered factors the hydrometeorological ones for that very period have the highest specific weight. For the evaluation of their complex effect, the estimated total evaporation and the dynamics of atmospheric precipitation have been used as a base. As it is depicted in Figure 4, throughout 2006-2011 different degree of yield capacity decline was observed with the maximum index of 18 % recorded in 2006.

There is a certain regularity between the relations of yield capacity decrease and P/ET_0. It is observed that within 2015-2019 years the coefficient of moisture supply fell from the value of 0.8 down to 0.2. In case of 40 % decrease in moisture supply potato yield capacity declines by 43 %. Parallel to the gradual increase of the altitude from the sea level, the yield capacity reduction makes 20-25 %.

Estimations of the yield capacity projections for the agricultural crops are introduces in the Tables 5 and 6.

Table 5. Forecasting potato yield capacity related to different factors in crop stress conditions (potato, y_{max}=20.1 c/ha)*

Name of agricultural crop	Ameliorative indicators	Development stages of the agricultural crops		
		1	2	3
Potato	K_{ri}	0.77	0.88	0.82
	K_{ri}	1.00	1.0	1.00
	K_{Ci}	0.25	0.25	0.25
	K_{sari}	0.28	0.28	0.28
	α_i	0.33	0.34	0.33
$K_{ri} \cdot K_{gi} \cdot K_{Ci} \cdot K_{sari} \cdot \alpha_i$		0.018	0.021	0.019
$\sum_{i=1}^{n} K_{ri} \cdot K_{gi} \cdot K_{ci} \cdot K_{sari} \cdot \alpha_i$		0.058		
K_0		0.869		
$K_0 \cdot y_{max}$		346.47		
Expected yield capacity y_{max} (c/ha)		20.1		

*Composed by the author.

Table 6. Forecasting the potato yield capacity in crop stress-free conditions (potato, y_{max}=398.7 c/ha)*

Name of agricultural crop	**Ameliorative indicators**	**Development stages of the agricultural crops**		
		1	**2**	**3**
Potato	K_{ri}	0.85	0.88	0.84
	K_{ri}	1.00	1.00	1.00
	K_{Ci}	0.96	0.98	0.96
	K_{sari}	0.98	0.98	0.98
	α_i	0.33	0.34	0.331
$K_{ri} \cdot K_{gi} \cdot K_{Ci} \cdot K_{sari} \cdot \alpha_i$		0.264	0.287	0.261
$\sum_{i=1}^{n} K_{ri} \cdot K_{gi} \cdot K_{ci} \cdot K_{sari} \cdot \alpha_i$		0.812		
K_0		0.945		
$K_0 \cdot y_{max}$		376.77		
Expected yield capacity y_{max} (c/ha)		356.05		

*Composed by the author.

Conclusion

With the aim of planning and forecasting the crops' yield capacity, a computational and analytical algorithm has been developed based on the agroclimatic factors and statistical indices of yield capacity. It has been applied for the crops grown in conditions of Ararat valley and piedmont zones along the territory of Armenia. Theoretically, the effect of different soil and climatic factors on the crop's yield capacity indices has been identified. The developed algorithm has been practically used for the potato crop, thereupon the changing tendencies in the crop yield capacity, when deviated from the best soil and climatic conditions, has been demonstrated.

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