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GENESIS AND GEOGRAPHY OF SOILS

Assessing the Effect of Possible Global Climate Changes on the Fertility of Mexican Soils and the Prediction of Crop Yields

Yu. N. Nikol'skii[a], M. Castillo-Alvarez[b], O. S. Bakhlaeva[a], J. Gama-Castro[c], and C. Landeros-Sanchez[a]

[a] *Colegio de Postgraduados, Montecillo, Carretera Mexico-Texcoco Km. 36.5, CP 56230 Mexico*
E-mail: nikolski@colpos.mx
[b] *Universidad Nacional Autonoma de Mexico, Carretera Mexico-Texcoco Km. 36.5, CP 56230 Mexico*
[c] *Instituto Geologico de la Universidad Nacional Autonoma de Mexico, Ciudad Universitaria, Cd. de Mexico, CP 04510 Mexico*

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Abstract—The existing predictions of the changes in the yield of agricultural crops depending on the expected climatic scenarios for the end of the 21st century are usually performed without consideration for the soil fertility alteration under the effect of the climate changes. This work deals with an attempt to assess the effect of the possible changes of the fertility of agricultural soils on the yield of corn and wheat under non-irrigation conditions with reference to the predicted scenario of climate changes at the doubling of the CO_2 in the atmosphere at the end of the 21st century. Studies were performed for typical regions of growing these crops in different climatic zones of Mexico.

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INTRODUCTION

predictions have been developed for changes in the average monthly air temperature, the global solar radiation, and the precipitation up to the end of the 21 century in the case of the doubling of the CO_2 in the atmosphere [27, 28]. The climate change could affect the properties of the soils and the yielding capacity of agricultural lands [4, 13, 24, 29]. Apparently, this can be especially true for rainfed lands. The available predictions for changes in the yielding capacity of agricultural crops usually consider only the expected climate change and ignore the possible changes in the soil fertility under the effect of the changed climate [14, 16, 21]. This is primarily related to problems in assessing the effect of climate changes on soil properties.

It is known that the quality of the predictions for the changes in the soil properties based on the mathematical simulation of the soil processes deteriorates with the increasing duration of the predicted period [6, 31]; therefore, other principles unrelated to mathematical simulation should be used. We previously described a prediction method based on the established quantitative relationship between the Budyko radiative index of dryness and the modal values of some regional agrochemical properties of virgin soils located on almost horizontal (with slopes less than 0.003) geomorphologically similar areas at elevations ranging from 0 to 2500 m asl. The Budyko radiative index of dryness I is calculated as follows [2]:

$$I = R/(LW), \quad (1)$$

where R is the average annual net radiation (kJ/m^2 per year); W is the average annual depth of the water layer infiltrating into the soil (mm/year), which is equal to the difference between the precipitation Pr and the natural surface runoff; and L is the latent heat of evaporation equal to 2.51 MJ/(m^2/mm). It was shown that, when the index I is calculated for the areas with slopes less than 0.003 under the climatic conditions of Mexico, the surface runoff can be ignored in the zones with annual precipitation of less than 2000–2500 mm, and it can be taken that $W = Pr$ [8]. In the calculations of the index I for the Russian plains, the surface runoff is also frequently ignored [1, 3, 7].

This work also presents the results of predicting the changes in some agrochemical properties and the integral fertility index of virgin Mexican soils depending on the scenarios of the expected climate changes [9]. In the last years, an approach based on the correlation between some soil properties and the index of dryness I has been developed for describing the distribution and evolution of soils on different parts of landscape [30].

METHODOLOGY

To predict the estimated effect of the climate changes on the productivity of the rainfed agricultural lands of Mexico with consideration for the changes in the soil properties, an approach similar to that described in the literature [10, 21] was used:

$$Y^j = Y^j_{\max} K^j_w \Phi^j_a, \qquad (2)$$

where Y^j is the long-term average annual yield of the agricultural crop (kg of dry mass/ha) on the selected area under the climatic conditions of the beginning ($j = 2000$) and the end ($j = 2100$) of the 21st century; $Y^j_{\max}$ is the maximum possible agroclimatic yield of this crop in the absence of diseases at the complete supply of the plants with nutrients and water (kg of dry mass/ha) in the beginning ($j = 2000$) and the end ($j = 2100$) of the 21st century, which depends on the average monthly air temperature, the photosynthetically active radiation, and the biological features of the plants (including the averaged terms of the phenological phases); and K^j_w and Φ^j_a are the dimensionless indices of the soil water content and soil fertility for the agricultural land, respectively, which vary in the range from 0 to 1. The calculation according to Eq. (2) obviously considers only the direct effect of the climate changes on the crop yield and their indirect effect due to the possible alteration of the soil fertility up to the end of the 21st century. A number of important but undetermined factors are ignored, including the effect of diseases and weeds, which are probably dependent on the climate changes; the future changes in the technologies of the agricultural production; and some other factors. These factors are conventionally taken to be constant but should be further considered.

The existing predictions for the expected changes in the climatic conditions of Mexico up to the end of the 21st century that were made in Mexico, the United States, and Canada deal only with the scenario of doubling the CO_2 concentration in the atmosphere [27, 28]. This work is based on the forecast made by Princeton University (the United States) using the GFDL-R30 coupled ocean–atmosphere general circulation model, which showed the best agreement of the retrospective climate prediction with the direct observations during the last decades of the 21st century [27].

The $Y^j_{\max}$ value was calculated using the FAO procedure [21]:

$$Y^j_{\max} = d\sum_{i=1}^{n} \frac{0.36 a_i b_i}{\frac{1}{i} + 0.25 c_i}, \qquad (3)$$

where a_i is the maximum possible rate of increase in the total dry biomass of the crop (kg/ha per month) in the ith month of the vegetation depending on the photosynthetically features of the plants, the temperature, the photosynthetically active radiation, and the CO_2 content in the atmosphere; the a_i value corresponds to the conventional relative leaf area equal to 5 (dimensionless); n is the total number of months in the vegetation period; b_i is the coefficient correcting the $Y^j_{\max}$ value for the changes in the relative leaf area during the plant development (dimensionless); c_i is the coefficient accounting for the loss in biomass during the plant respiration (dimensionless); the c_i value depends on the crop type and the air temperature; and d is the proportion of target product in the total plant biomass (dimensionless).

Sufficient additional information is available in the literature to calculate the $Y^j_{\max}$ values for different agricultural crops, including corn and wheat, in the beginning and the end of the 21st century from the average monthly values of the temperature and the global radiation with consideration for the geographical position of the area (the latitude, longitude, and altitude) [11, 12, 17, 19, 21].

The index K^j_w characterizes the availability of soil water to the plants. This index can be calculated from the soil water balance with account for the precipitation, evapotranspiration, surface runoff, and soil water percolation. Taking into consideration the limited data for assessing the soil water content of soils and the fact that the aim of the work was to compare the Y^j values calculated for the beginning and the end of the 21st century using the same procedure, the index K^j_w was calculated from the average monthly values of the index of dryness I_i during the vegetation period of the agricultural crops:

$$K^j_w = \frac{1}{n}\sum_{i=1}^{n} \frac{1}{I^j_i} K^j_w = \frac{1}{n}\sum_{i=1}^{n} \frac{1}{I^j_i}, \qquad (4)$$

where I^j_i is the index of dryness in the ith month of the vegetation; $j = 2000$ and $j = 2100$ for the beginning and the end of the 21st century, respectively; n is the total number of months in the vegetation period; and $\sum_{i=1}^{n} \frac{1}{I^j_i}$ is the sum of the monthly $\frac{1}{I^j_i}$ values for the vegetation period. At $K^j_w > 1$, the relationship $K^j_w = 1$ was taken as the condition for reaching the maximum water-retention capacity of the soil. The calculations were approximate, and the contributions of the separate months to the total water supply of the plants were not considered.

The average monthly indices of the dryness I^j_i were calculated from Eq. (1), where R and W are the average monthly values of the net radiation (kJ/(m^2 month)) and the water layer infiltrated into the soil (mm/month). The average monthly values $W^{j=2000}$ and $W^{j=2100}$ were taken from the reported data [20, 28]. The average monthly values of the net radiation

R_i^{2000} and R_i^{2100} were calculated from the average monthly values for the global solar radiation $Qg_i^{j=2000}$ and $Qg_i^{j=2100}$, the air temperature, and the precipitation measured in the second half of the 20th century and predicted for the end of the 21st century using the known formula

$$R_i^j = (1-\alpha_i^j)Qg_i^j - Qw_i^j, \quad (5)$$

where α denotes the average monthly values of the albedo for the areas occupied by the selected crops (corn and wheat), and Qg_i^j and Qw_i^j are the average monthly values of the global radiation and the long-wave net radiation (kJ/(m^2 month)), respectively.

The monthly albedo values of these crops during their development were taken from the reported data [15]. It was supposed that the expected climate changes will have no significant effect on the albedo of each crop, i.e., $\alpha_i^{j=2000} = \alpha_i^{j=2100}$. The procedure for the calculation of Qw_i^{2000} and Qw_i^{2100} depending on the average monthly air temperature and precipitation was reported earlier [9].

The index Φ_a^j reflects the regional integral fertility of the agricultural soils (which is denoted below with the subscript a), which is calculated with consideration for the available data on the contents of organic matter G_a, the available phosphorus P_a, the exchangeable potassium K_a, and the pH$_a$ (pH$_{KCl}$) in the beginning of the 21st century ($j = 2000$) using the equation [10]

$$\Phi_a^{2000} = 0.46\frac{G_a^{2000}}{G_{a\max}^{2000}} + 0.28\sqrt{\frac{P_a^{2000}}{P_{a\max}^{2000}}\frac{K_a^{2000}}{K_{a\max}^{2000}}} + 0.26e^{-\left(\frac{\mathrm{pH}_a^{2000}-6}{2}\right)^2}, \quad (6)$$

where G_a^{2000}, P_a^{2000}, K_a^{2000}, pH$_a^{2000}$ a denote the properties of the agricultural soils at the selected sites; and $G_{a\max}^{2000}$, $P_{a\max}^{2000}$, $K_{a\max}^{2000}$ max are the maximum values of these properties (in the same unites as G_a^{2000}, P_a^{2000}, K_a^{2000}, pH$_a^{2000}$) for the entire group of analyzed soils.

Pegov et al. [10] included the content of nitrogen in the soil into Eq. (6). Because of the absence of nitrogen data on the Mexico maps, this value in Eq. (6) is indirectly accounted by the coefficient related to the organic matter content. For this purpose, the contribution of nitrogen to the integral fertility index was related to the contribution (coefficient) of the organic matter. The Φ_a^{2000} value is dimensionless and varies from 0 (for completely degraded soils) to 1 (for the maximum possible fertility level of the studied Mexican soils).

To determine the fertility index Φ_a^{2100} changing up to the end of the 21st century, the relationship between the index Φ_a^{2000} and the average annual values of the climatic index I^{2000} for the conditions of the early century was established. For this purpose, we selected areas composed of automorphic soils with a similar texture of the soil-forming rock and on slopes less than 0.003 used for growing corn and wheat and located on the relief elements excluding the effect of water erosion on the pedogenesis or the deposition of erosion products. The Mexico territory is a mountainous area with altitudes varying from 0 to more than 3000 m asl. Agricultural lands occupy about 16% of the area and are located at different altitudes. Slopes less than 3% are typical for an area of about 16 million ha, which makes up 45% of the total agricultural land (or 7% of the country). About half of this land is used for growing corn and wheat [18, 32]. A total of 2378 soil profiles (sites) were selected from the available databases. Major information on the properties of the soils used for growing corn and wheat without irrigation is available from the following Mexican states: Northern and Southern Baja California and Sonora (12% of the total number of soil profiles in each state), Jalisco (8%), Guanajuato (7%), Mexico (6%), Veracruz (4%), San Luis Potosi and Zacatecas (3% each), and Tlaxcala (2%) [23]. These states are also the major producers of these crops.

The soils are mainly Phaeozems in the semiarid and semihumid regions of the central part of the country (19.0% of the total area of rainfed agricultural lands and forest plantations minus pastures); Xerosols, Rendzinas, and Kashtanozems in the arid and semiarid regions of the central and northern regions (10.5, 14.0, and 3.0%, respectively); and Luvisols and Vertisols in the regions of the temperate and tropical (arid, semiarid, and humid) climate in the southeastern part of the country (9.1 and 8.6%, respectively) [23, 25]. The depth of the soils usually exceeds 1.5 m.

The values of G_a^{2000}, P_a^{2000}, K_a^{2000}, pH$_a^{2000}$ for the 0- to 20-cm layer of the soils were taken from the available database. Then, their averaged values were found for each group of sites located in the zones with similar I_i^{2000} values (more exactly, within similar variation ranges: from 0.25 to 4.5 with an interval of 0.5 and above 4.6 with an interval of 1.0). About 150–200 values, on the average, were determined for each soil property in each of the separated I_i^{2000} ranges. On the presumption that the dependence of each property and the fertility index Φ_a^{2000} on the index of dryness can be ignored within these relatively small I_i^{2000} ranges, each point value of a property was normalized to its average arithmetic value within the selected I_i^{2000} range. The totality of the normalized values of each property (a total of 2378 values) was considered as a statistically homogeneous population, and the statistical character of its distribution was determined. The procedure for the automated selection and processing of the data on the soil properties and the determination of the relationship Φ_a^{2000} (I_i^{2000}) was also described previously [9]. The model values of the properties G_m^{2000}, P_m^{2000}, K_m^{2000} and pH_m^{2000} and the confidence limits of the variation of the primary data for the selected agricultural sites within each indicated I^{2000} range were determined.

The coverage of the digital geographical maps of Mexico (the topographical, climatic, soil, hydrogeological, vegetation, and land-use ones) on scales of 1 : 50000 and 1 : 250000 [23] and the applied soil database were used, as well as the databases of the Mexican Ministry of Agriculture, Livestock, Rural Development, Fishing, and Food (SAGARPA); the National Water Commission (CONAGUA) of the Ministry of the Environment and Natural Resources (SEMARNAT); and some other sources.

Curves describing the modal values of the indicated soil properties as functions of the climatic index I_i^{2000}, were plotted using the corresponding software [22]. Taking into consideration the relatively slow change of the climate (occurring over a century) and the relatively rapid response of these properties to the climatic changes [13], it can be supposed that the tendencies established in the beginning of the century will persist to the end of the century if the same agricultural technologies are used. However, the changes in the technologies are not directly related to the climate changes. Therefore, these plots can be used for predicting the evolution of the changes in these soil properties depending on the scenarios of the climate changes.

On the whole, the agricultural soils of Mexico have low or moderate contents of organic matter, phosphorus, and potassium. In the major part of the country, the content of organic matter G_a^{2000} a varies in the range of 0.5–4% and reaches 8% in some regions. The content of the plant-available forms is 1.5–3 meq/100 g (with a maximum of 5 meq/100 g) for P_a^{2000} (P_2O_5) and 0.5–1 meq/100 g (with a maximum of 1.5 meq/100 g) for K_a^{2000} (K_2O). According to the current classification [5], the soils containing more than 6–8% organic matter, 4–5 meq/100 g of phosphorus, and 1–1.5 meq/100 g of potassium are considered as well-supplied with these nutrients. Therefore, after the analysis of the database [23], the values $G_{a\max}^{2000} = 8\%$, $P_{a\max}^{2000} = 5$ meq/100 g, and $K_{a\max}^{2000} = 1.5$ meq/100 g were used in the calculation of the fertility index Φ_a^{2000} at the first approximation.

The fertility index Φ_a^{2000} was calculated from the local (primary) data on the indicated soil properties using Eq. (6), and the statistical processing of the data and the calculated fertility index values was performed.

Using the Φ_a^{2000} (I^{2000}) plot and the initial value of the fertility index Φ_1^{2000} inherent to the selected site in the beginning of the century, the changed value of the fertility index Φ_1^{2100} in the end of the century can be estimated depending on the change in the climatic index from I^{2000} to I^{2100} as follows:

$$\Phi_1^{2100} = \Phi_1^{2000} + (\Phi_1^{2100} - \Phi_1^{2000}), \tag{7}$$

where Φ_1^{2100} and Φ_1^{2000} are the modal values of the fertility index on the plot Φ_a^{2000} (I^{2000}) corresponding to the climatic index values of I^{2100} and I^{2000} for the selected site. An increase or decrease in the soil fertility at the site is expected depending on the sign of the difference $(\Phi_1^{2100} - \Phi_1^{2000})$.

According to the available literature data, the expected climate changes will not appreciably affect the requirements of the plants for nutrients [11, 12, 14, 21, 26]. Therefore, the integral index of the soil fertility Φ_a^j entering into Eq. (2) for predicting the crop yield is calculated without consideration for the effect of the climatic changes on the normalizing values $G_{a\max}^{2000}$, $P_{a\max}^{2000}$, and $K_{a\max}^{2000}$, and the optimum value $\mathrm{pH_{KCl}}$. The prediction of the crop yield Y^j for the beginning and the end of the 21st century is performed for the same crop cultivar.

RESULTS AND DISCUSSION

The distributions of the modal values of the regional properties of the Mexican soils (G_a^{2000}, P_a^{2000}, K_a^{2000}, pH_a^{2000}) in the regions of the corn and wheat production on the rainfed land depending on the climatic index I^{2000} in the beginning of the 21st century, as well as the confidence intervals for the changes in the properties at the same values of the climatic index I^{2000}, are shown in Fig. 1. The statistical analysis of the set of normalized values G_a^{2000}/G_m^{2000}, P_a^{2000}/P_m^{2000}, K_a^{2000}/K_m^{2000}, and pH_m^{2000} showed that their distributions were close to the lognormal law. Therefore, the confidence interval for the variation of these properties (φ) within the separated I^{2000} intervals was calculated as $\varphi_m \pm 2\sigma_{\ln\varphi}$, where φ_m is the modal (rather than the arithmetic mean) value of the property φ, and $\sigma_{\ln\varphi}$ is the antilogarithm of the standard deviation of the property φ logarithm. According to the plots $\varphi(I^{2000})$,

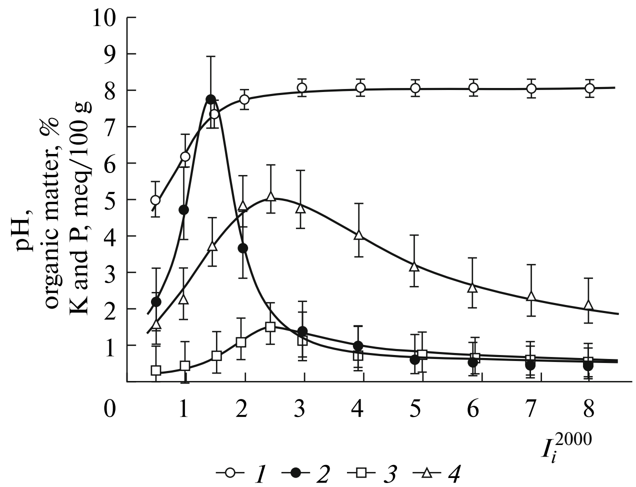

Fig. 1. Modal values of some agrochemical properties of unirrigated agricultural soils of Mexico under corn and wheat as functions of the radiative index of the dryness I^{2000} in the beginning of the 21st century: (*1*) pH; (*2*) organic matter; (*3*) exchangeable potassium; (*4*) available phosphorus; the confidence intervals of the variation of the properties with a probability of 95% are shown.

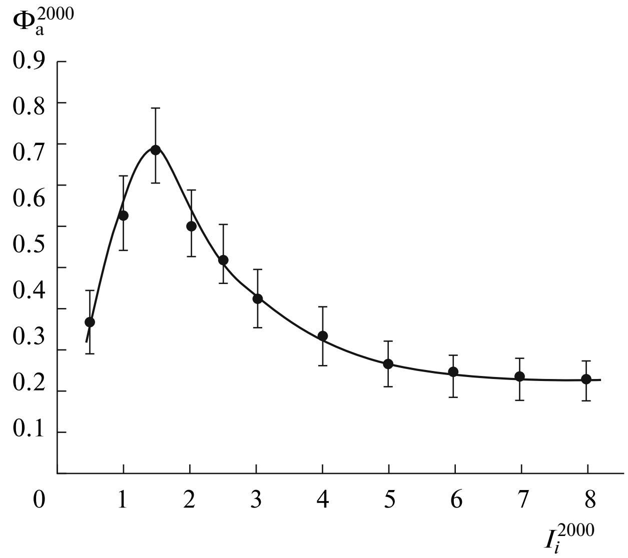

Fig. 2. Modal values of the integral index of the soil fertility Φ_a^{2000}, calculated from Eq. (6) for the unirrigated agricultural lands of Mexico with slopes of less than 0.003 as a function of the index of dryness I^{2000} in the beginning of the 21st century; the confidence intervals of the Φ_a^{2000} variation with a probability of 95% are shown.

the confidence intervals are within ±35% of the modal values of φ_m and do not exceed ±20% in most cases.

No statistically significant differences were noted in the distribution of the local (point) data on the agrochemical properties of the virgin soils reported earlier [9] and the soils of the agricultural plots with corn and wheat grown without irrigation depending on the climatic index I^{2000} in the Mexican regions with slopes less than 0.003. The local data spread for each property of the virgin soils within each selected interval I_i^{2000} was found to be within the established confidence intervals for the variation of these properties of the agricultural soils. This could be related to the extensive use of agricultural lands for the production of corn and wheat grain without irrigation. The analogous comparison of the relationships Φ_a^{2000} (I^{2000}) for the virgin soils and the agricultural soils under these crops also revealed no significant differences.

The Φ_a^{2000} (I^{2000}) plot is shown in Fig. 2, as well as the confidence intervals for the changes in the fertility index Φ_a^{2000}. It can be seen that the relationship Φ_a^{2000} (I^{2000}) corresponds to a specific tendency in the distribution of the soil fertility index depending on the climatic index. The confidence intervals are within ±20% of the modal values of Φ_a^{2000}. The calculations show that the fertility index Φ_a^{2000} in the slight slope areas of Mexico varies from 0.23 to 0.33 in the arid regions, where the index of dryness I^{2000} is higher than 4; reaches 0.7–0.79 in the regions of the temperate climate, where I is about 1.5; and decreases to 0.37–0.6 in the regions of the humid tropical climate, where I is lower than 1. According to the curve's shape, the most significant changes in the integral index of the soil fertility depending on I are observed in the region of $0 < I^{2000} < 3$.

The Φ_a^{2000} (I^{2000}) plot was used for predicting the changes in the fertility of the unirrigated agricultural lands of Mexico due to the expected climate changes to the first approximation.

To predict the changes in the integral index of the soil fertility, the net radiation R was calculated from Eq. (5), and the dryness index I^{2000} was then calculated for the territories for which the climate changes were predicted for the beginning and the end of the 21st century. The values of the fertility indexes Φ_a^{2000} and Φ_a^{2100}, were estimated for each territory from the curve in Fig. 2. Taking into consideration the reported data [11, 12, 26], the effect of the increase in the CO_2 concentration in the atmosphere on the changes in the organic matter content and the index Φ_a^{2100} can be ignored.

The average annual climatic parameters of the beginning and the end of the 21st century for some Mexican territories where corn and wheat are grown without irrigation are given in Table 1.

Table 1. Average annual climatic parameters in the beginning and the end of the 21st century for some Mexican territories typical for the production of corn and wheat

State	Temperature, °C		Precipitation, mm		Index of dryness (I)	
	2000	2100	2000	2100	2000	2100
Regions of corn production						
Mexico	15.6	18.3	610	761	1.76	1.47
Veracruz	19.3	22.0	1800	2244	0.64	0.57
Jalisco	24.5	27.3	1026	1319	1.32	1.14
Sonora	27.4	30.7	365	481	3.90	3.17
Regions of wheat production						
Guanajuato	16.1	18.8	499	622	2.13	1.83
San Luis Potosi	17.5	20.1	406	503	2.97	2.59
Tlaxcala	13.4	14.1	826	1031	1.11	0.90
Zacatecas	16.7	20.0	623	763	1.69	1.51

These territories were selected among the major regions of grain production in order to reflect the different climatic conditions. It follows from Table 1 that corn and wheat are produced in the zones with the average precipitation being from 400 to 2000 mm, where the index of dryness I varies in the range from 0.5 to 4. According to the predictions, along with the universal temperature rise by 3–20%, an increase in the annual precipitation by 20–35% and in the net radiation (to 10%) is expected for a major part of the Mexican territory [16, 17, 27, 28]. This will decrease the index of dryness by 10–20% (Table 1).

To compare the contributions of the separate components of Eq. (2) to the predicted changes in the crop yield with consideration for the possible variations in the soil fertility under the effect of the climate changes, the results of comparing the relative values of the yield $\frac{Y^{2100}}{Y^{2000}}$, the maximum possible yield $\frac{Y^{2100}_{\max}}{Y^{2100}_{\max}}$, the soil water content index $\frac{K^{2100}_w}{K^{2000}_w}$ and the integral index of the soil fertility $\frac{\Phi^{2100}_a}{\Phi^{2000}_a}$. are given in Table 2. We considered the ratio of the values predicted for the end of the 21st century (j = 2100) and those calculated for its beginning (j = 2000) from Eq. (2) written in the form

$$\frac{Y^{2100}}{Y^{2000}} = \frac{Y^{2100}_{\max}}{Y^{2000}_{\max}}\frac{K^{2100}_w}{K^{2000}_w}\frac{\Phi^{2100}_a}{\Phi^{2000}_a}. \quad (8)$$

It follows from Table 1 that, according to the calculations performed for the selected territories of Mexico located in different climatic zones (from the arid to the tropical humid ones) using the FAO procedure [21], the maximum possible yield of corn will remain almost constant and that of wheat will increase in some places by 25% under the effect of the changes in the air temperature, the photosynthetically active radiation, and the doubled CO_2 content in the atmosphere. The expected increase in precipitation (and increase in the soil wetting index K_w) could result in an additional increase in the crop yield by 20–40%. The

Table 2. Assessment of the effect of the changes in the soil fertility under the effect of the global climate changes on the prediction of the crop yield

State	$Y^{2100}_{\max}/Y^{2000}_{\max}$	K^{2100}_w/K^{2000}_w	$\Phi^{2100}_a/\Phi^{2000}_a$	Y^{2100}/Y^{2000}	
				without consideration for the soil changes	with consideration for the soil changes
Regions of corn production					
Mexico	1.04	1.21	1.08	1.26	1.36
Veracruz	0.99	1.00	0.86	0.99	0.85
Jalisco	0.98	1.00	0.92	0.98	0.90
Sonora	0.99	1.42	1.21	1.41	1.70
Regions of wheat production					
Guanajuato	1.21	1.19	1.15	1.44	1.66
San Luis Potosi	1.19	1.18	1.14	1.40	1.59
Tlaxcala	1.26	1.00	0.85	1.26	1.07
Zacatecas	1.20	1.04	1.05	1.25	1.31

corn yield will be the most affected. The relative value $K_w^{2100}/K_w^{2000} = 1$ obtained for some territories in Table 2 indicates that the wetting index K_w^{2000} in the beginning of the 21st century is 1; therefore, the increase in the annual precipitation does not affect it.

Without consideration for the changes in the soil fertility under the effect of the climate changes, as is usual according to the FAO procedure [16, 21], the yield of corn and wheat will vary in the range from 98 to 144% depending on the geographical location of the territory. However, when the soil fertility index Φ_a is taken into account, the yield of these crops can vary in a wider range: from 85 to 170% for corn and from 107 to 166% for wheat. The error caused by the neglecting of the soil fertility alteration under the effect of the climate changes can be ±15% for the wheat and from –14% to +21% for the corn compared to the yield predicted with consideration for this factor, which is significant. The actual error could be essentially higher, because the diversity of the natural conditions in Mexico significantly exceeds that given in Tables 1 and 2. This indicates that the changes in the agrochemical properties of the soils under the effect of the varying climatic conditions over the century should be taken into consideration in the prediction of the changes in the agricultural land's productivity. Unfortunately, the effect of the gradual changes in the climatic conditions on the soil fertility has usually been ignored in most predictions until now. This can entail significant errors in the predicted yield of the agricultural crops. It can be supposed that the effect of the soil fertility changes in the predictions of the crop yields becomes less significant with the decreasing prediction period (e.g., up to 10–20 years).

CONCLUSIONS

(1) The changes in the soil fertility under the effect of the varying climatic conditions should be taken into consideration in the predictions of the changes in the agricultural land productivity related to the expected global climate changes. The neglect of the soil factor can result in an error of more than 20% in the calculated yields of the corn and wheat.

(2) An approach based on the established quantitative relationship between the Budyko radiative index of dryness I and the modal values of some regional agrochemical properties of the geomorphologically homogeneous soil groups, as well as between the index I and the integral index of the soil fertility Φ_a, was used.

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