Soil fertility alteration due to global warming during the 21st century

Nikolskii-Gavrilov I.[1], Bakhlaeva-Egorova O.[1], Mejia-Saenz E.1

[1] *Colegio de Postgraduados, Campus Montecillo, Km.36.5, Carretera México-Texcoco, 56230, México.* nikolski@colpos.mx

Introduction

The prediction of agricultural soil properties long-term change due to the possible climate change is very important and difficult because of influence of different factors: change of agricultural technology, land use, etc. as well as climate change (Figure1).

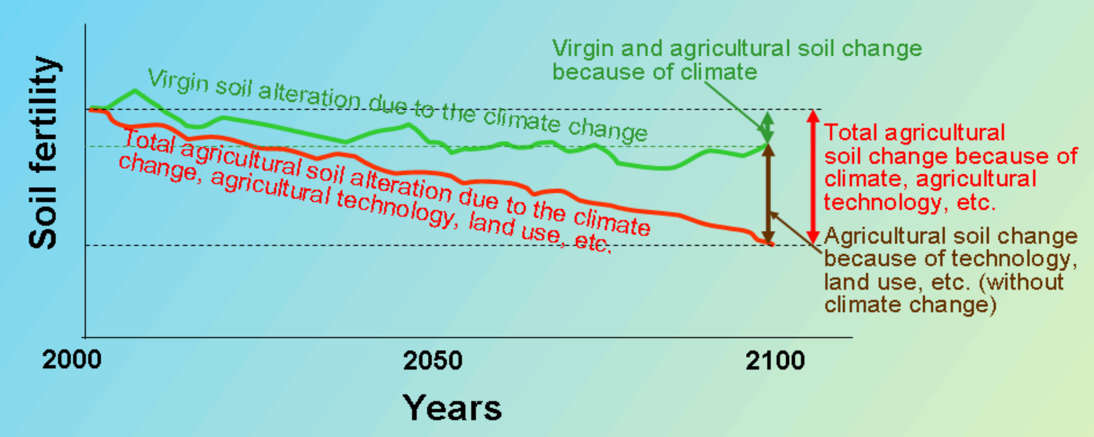

Figure 1. Sketch of possible virgin and agricultural soil change because of global warming

A mathematical modeling for a whole century usually not very reliable. A possible approach could be based on the geographic law of soil zonality and the establishment of a quantitative relationship between Budyko's radiative index of dryness (I_v^{2000}) and modal values of some regional biological and chemical virgin soil properties (φ_v^{2000}) of geomorphologically homogeneous soil groups for the beginning of present century (Volobuev, 1974). The radiative index of dryness is expresses as following $I_v = Rn_v/L(Pr - S_v)$, where Rn_v, Pr and S_v are mean annual values of net radiation, precipitation and surface runoff in not used in agriculture lands, respectively, and L is the latent heat of evaporation.

Methodology

Existing long-term climate change forecasts can be used to calculate the climatic index (I_v^{2100}) for the end of the 21st century. It is assumed that a rather slow climatic change will not break the equilibrium in $\varphi_v^{2000}(I_v^{2000})$ relationships corresponding to the beginning of the century (Figure 2).

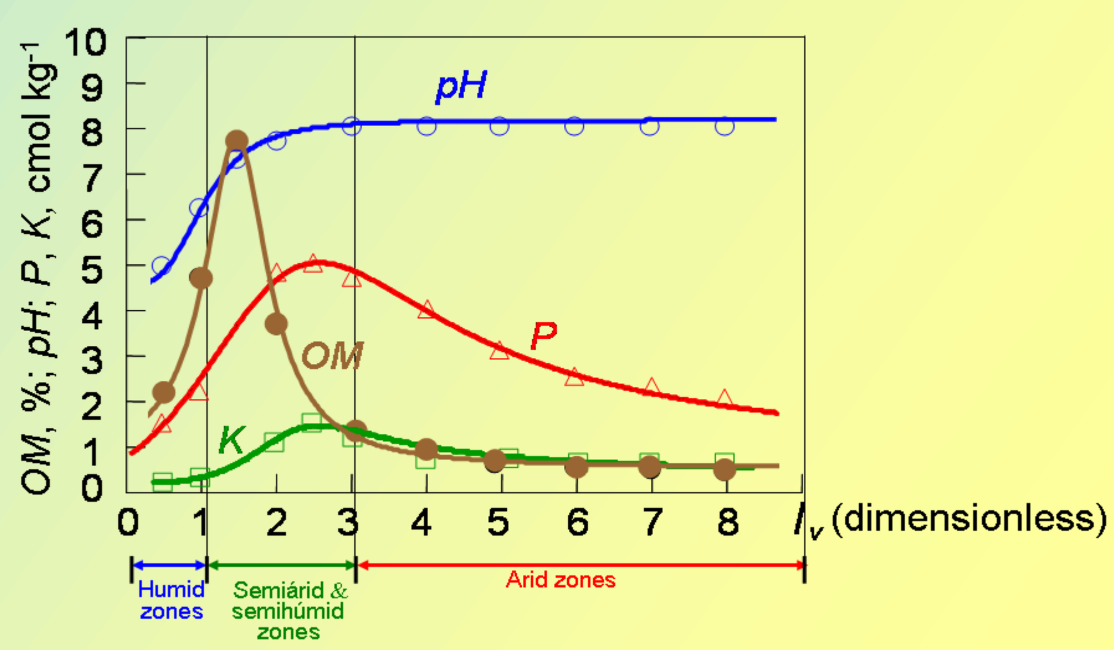

Figure 2. Dependence of modal values of some properties (φ_v^{2000}) of Mexican authomorphic virgin soils in flat lands (with slopes less than 3%) on I^{2000} climatic index. *OM*, *P* and *K* are organic matter, phosphorus and potassium content, respectively.

The relationships similar to Figure 2 have been obtained for 15 different properties of virgin (not used in agriculture) geomorphologically homogeneous soil groups from different climatic zones of Mexico.
The procedure of $\varphi_v^{2000}(I_v^{2000})$ relationship development is shown on the Figure 3.

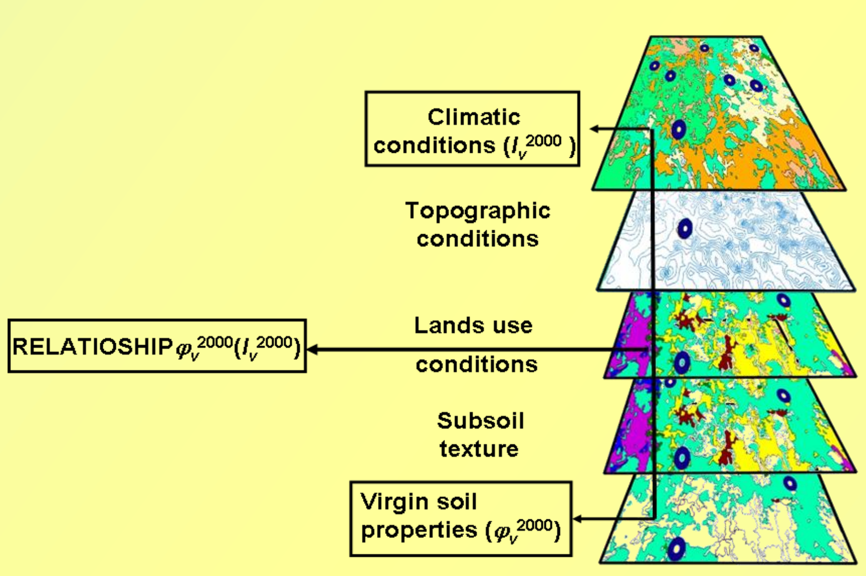

Figure 3. The procedure to develop $\varphi_v(I_v)$ relationship

Such relationships can be used to determine a new soil property φ_v^{2100} corresponding to the climatic index I_v^{2100} in selected sites. It is also possible to establish relationships of an integral soil fertility index (F_v^{2000}) and a climatic index (I_v^{2000}).
The integral soil fertility index (F) was calculated considering mainly organic matter content, plant-available P and K contents, and pH value (Pegov and Khomyakov, 1991).

$$F = 0.46\frac{OM}{OM^{max}} + 0.28\sqrt{\frac{P}{P^{max}}\frac{K}{K^{max}}} + 0.26e^{-\left(\frac{pH-6}{2}\right)^2}$$

where OM, P and K are organic matter, phosphorus and potassium content, respectively; OM_{max}, P_{max}, and K_{max} are the maximal values of these properties observed in the selected sites with geomorphologically homogeneous soils.

The difference ($F_v^{2100} - F_v^{2000}$) can be considered as assessment of the agricultural soil fertility alteration (F_a^{2100}) due to global warming: $F_a^{2100} = F_a^{2000} + (F_v^{2100} - F_v^{2000})F_{v,max}^{2000}/F_{a,max}^{2000} \approx F_a^{2000} + (F_v^{2100} - F_v^{2000})$, where $F_{v,max}^{2000}$ and $F_{a,max}^{2000}$ are maximal modal values of F index inside studied interval of I^{2000} in virgin and agricultural lands, respectively.
The fertility index (F) can be used to predict agricultural crops vulnerability to the climate change.
The diagrammatic procedure of soil property φ_v^{2100} prediction is shown on the Figure 4.

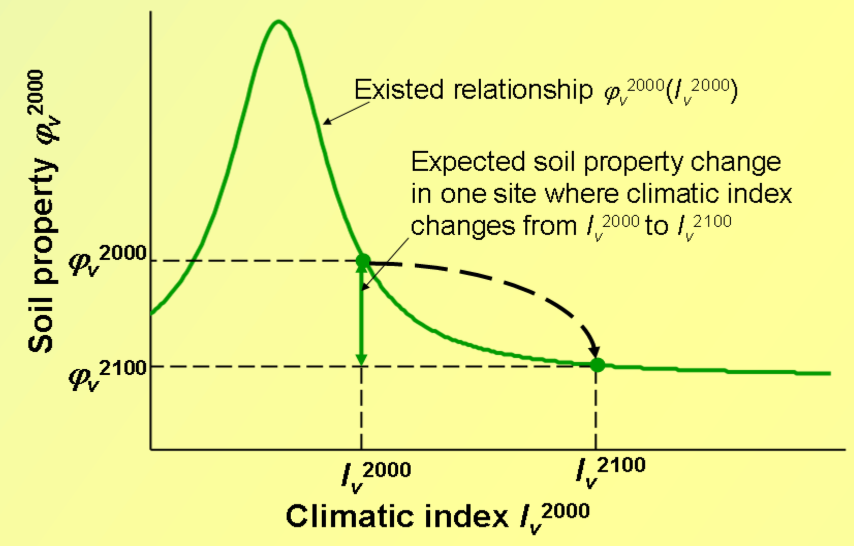

Figure 4. The diagrammatic procedure to predict a virgin soil property change from $\varphi v2000$ to $\varphi v2100$ in one site where the climatic index is expected to be changed from $Iv2000$ to $Iv2100$.

Results

The application of this approach in Mexico permitted to assess how virgin and agricultural soils will develop corresponding to existed climate change scenarios
(Figure 5), and to assess the vulnerability of maize and wheat yields to global warming (see Table).

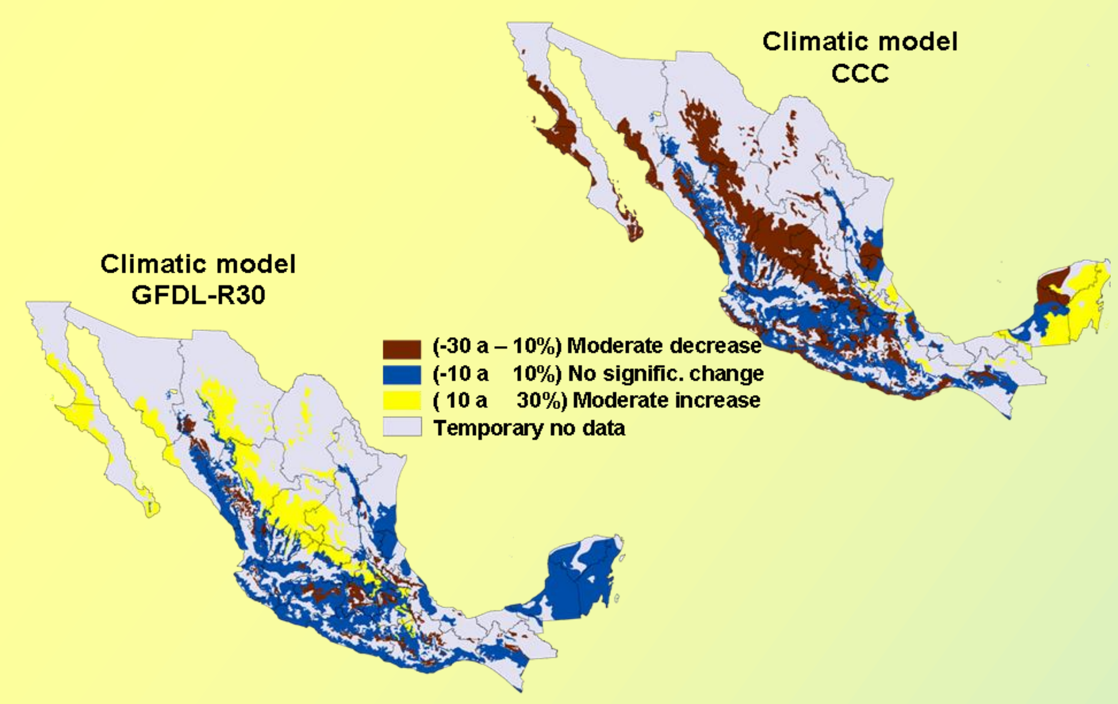

Figure 5. Example of fertility index (*F*) change at the end of 21st century in Mexico corresponding to the climatic model GFDL-R30 (Conde *et al*., 2008) and flat lands with slope less than 3%.

Preliminary assessment of influence of agricultural soil fertility alteration on assessment of crop vulnerability in Mexican rain fed and irrigated lands to climate change in 21st century

State	Climatic model	Rain fed			Irrigated		
		ΔY (%)	ΔY_F (%)	$1 - \Delta Y/\Delta Y_F$ (%)	ΔY (%)	ΔY_F (%)	$1 - \Delta Y/\Delta Y_F$ (%)
Maize							
Mexico	GFDL-R30	25	34	26	14	20	30
	CCC	-19	-30	37	-30	-40	33
Veracruz	GFDL-R30	-15	-10	-50	-30	- 25	-20
	CCC	21	19	-11	30	34	12
Sonora	GFDL-R30	30	50	40	61	75	19
	CCC	17	12	-29	26	21	-24
Wheat							
Guanajuato	GFDL-R30	21	16	-31	25	18	-39
	CCC	-20	-24	17	-31	-21	-48
San Luis Potosi	GFDL-R30	59	45	-31	42	29	-45
	CCC	-15	-19	21	-25	-50	50

Note: ΔY and ΔY_F are predicted crop yield change in case of ignorance or consideration of fertility alteration, respectively. The crop productivity has been calculated in such form (FAO, 2000): $Y = Y_{max} K_w F$, where Y_{max} is potential crop yield depending on photosynthetic radiation, temperature, CO_2 content and biological plant properties without taking into account risk of plant diseases; K_w is coefficient of water availability for plant consumption ($0 < K_w \leq 1$) and F is integral soil fertility index ($0 < F \leq 1$). It is considered case of relatively flat lands with slopes less than 3%.

Conclusion

1. Inside the analyzed part of Mexico the soil fertility index (*F*) will be changed approximately from 30 to -30% with respect to the present values depending on climate change scenarios during the present century.
2. The ignorance of soil alteration can cause errors in assessment of crop vulnerability to the climate change more than 50%.
3. This approach can also be applied to model past climate changes using paleosols, delivering insights regarding the time-frames and reversibility of soil development, and allows predicting the impact of climate change on soil carbon storage.

Bibliography

FAO. 2000. Global agroecological zones. Methodology and results of the global agro-ecological zones model.CD-ROM. Version: 1.0. http://www.fao.org (access: February 5, 2006)
Conde, C., Martinez, B., Sanchez, O., Estrada, F., Fernandez, A., Zavala, J., Gay, C. 2008. *Escenarios de Cambio Climático para México y Centro América. Temperatura y Precipitación.* CEAUNAM: http://www.atmosfera.unam.mx/gcclimatico/
Nikolskii Y.N., M. Castillo-Alvares y O.S. Bakhlaeva. 2006. The Influence of the possible global climate change on the properties of Mexican soils. Eurasian Soil Science, 39 (11):1164-1169, USA
Pegov S.A. and Khomyakov P.M. 1991. *Simulation of Ecological Systems Development.* Ed. Gidrometeoizdat, Leningrad, Russia (in Russian).
Volobuev V.R. 1974. *Introduction to the Energy of Soil Formation.* Ed. Nauka, Moscow, Russia (in Russian).