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Climate change and soil processes

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Abstract—The changes in the gas composition of the atmosphere may lead to increasing temperature with heterogeneous spatial and time distribution. These changes are reflected in changes of vegetation and land use pattern with considerable impacts on soil formation properties and soil characteristics. These potential changes are discussed in the paper, analysing the impact on soil formation processes, the moisture regime, and soil degradation processes under the influence of four plausible climate scenarios.

Key-words: climatic scenarios, soil formation processes, soil moisture regime, soil degradation processes

1. Introduction

Human activities lead to changes in the global environment at virtually unprecedented rates, with potentially severe consequences to our future life. The study and solution of the problems of global environmental changes require urgent and efficient actions. This crucial task formulates a challenge for science: to describe and understand the interactive physical, chemical, and biological processes that regulate the Total Earth System, the unique environment for life (*Toward...*, 1988).

2. Potential changes in climate

In the last century considerable changes took place in the *gas composition of the atmosphere* due to natural processes and human activities, such as increasing energy consumption, industrialization, intensive agriculture, urban

and rural development. This may lead to a *rise in global temperature* with a rate of 0.1–0.8°C per decade. The spatial and temporal patterns of temperature increases will be heterogeneous on Earth. The changing temperature regime pattern will be followed by considerable changes in *precipitation characteristics*: quantity of rain and snow, their spatial and temporal distribution pattern, rain intensity, etc. Their forecast is even more uncertain (Scharpenseel *et al.*, 1990).

3. *Consequences of climatic change*

Due to the increasing temperature, an increasing part of the mountain glaciers, the permafrost soil zone, and the Polar ice caps will melt. It leads to changes in the water flow dynamics, including flood waves and surface runoff will result in a *rise of the eustatic sea level*. The forecasted 0.20–1.40 m sea level rise will threaten low-lying, man-protected lands, settlements, agricultural areas, and extended seashores with low slope. Another consequence will be the further extension of salt affected territories under the direct effect of temporal sea water inundations or due to the rise of the sea level-connected water table of saline or brackish groundwaters.

The changing climate will result in considerable changes in the *natural vegetation* and in *land use practices* (Greenland and Szabolcs, 1993; Lal *et al.*, 1994). The great vegetation zones will move into the direction of the Poles, with a predicted rate of 25–200 km/100 years. Vegetation — in many cases — cannot tolerate and follow this „velocity” and it leads to considerable changes in the species distribution, dynamics, diversity, and production capacity of various ecosystems. *Land use practices* will follow or modify the natural changes, depending on environmental and socio-economic conditions (Lal *et al.*, 1994).

Changes in the vegetation or land use pattern result in a feedback effect on climate, modifying albedo, surface roughness, micro-circulation processes, the heat and energy balance of the near-surface atmosphere, the characteristics of both temperature and precipitation. Vegetation changes will considerably influence the field water cycle and soil formation processes.

4. *Impacts of climate changes on soils and soil processes*

Climate changes and their consequences will result in significant alterations in *soil conditions* (Brinkman, 1990; Greenland and Szabolcs, 1993; Lal *et al.*, 1994; Rounsevell and Loveland, 1994; Scharpenseel *et al.*, 1990; Tinker and Ingram, 1994). These impacts and their relationships are summarized in Fig. 1

(Várallyay, 1989, 1990a,b, 1994). The figure clearly indicates why the quantitative evaluation of the impact of any climate change on the soil conditions and soil processes is so difficult and far from being satisfactory. The uncertainties in the long-term global temperature and precipitation forecasts are combined here with the complex, integrated influences of changing vegetation and land use pattern and the changing hydrological cycle (Arnold *et al.*, 1990; Toward ..., 1988; VITUKI, 1989).

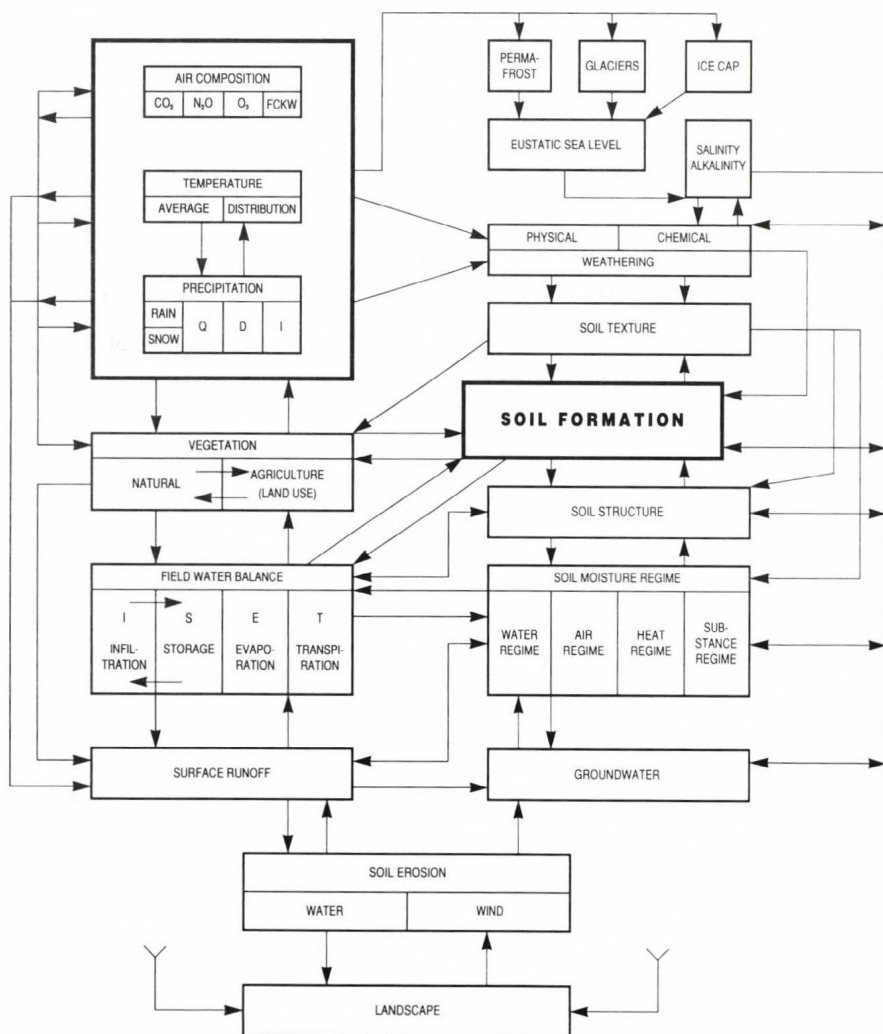


Fig. 1. The potential consequences of climate changes on soil processes.

4.1 Soil formation processes and soil properties

Climate, vegetation, and water regime determine (or at least strongly influence) *soil properties* (Arnold *et al.*, 1990; Brinkman, 1990; Rounsevell and Loveland, 1994; Scharpenseel *et al.*, 1990; Várallyay, 1990a).

Soil texture (particle-size distribution) is a rather constant soil parameter: characteristic response time is $> 10^3$ years. *Physical and chemical weathering* are slow processes. Climate changes result in only slight and slow changes in these processes, and only moderately influence the “*biological weathering*”. The influence is more expressed on the texture differentiation within a soil profile and on the organic matter turnover (Arnold *et al.*, 1990).

4.2 Moisture regime

The integral impact of climatic–hydrologic–vegetation–land use changes are reflected by the *field water balance* and *soil moisture regime* (Antal *et al.*, 2000; Várallyay, 1990a,c). Their components and the potential impact of 4 plausible climate change scenarios on these factors are summarized in Fig. 2.

An increase in *precipitation* will be followed by an increase of:

- surface runoff (R) in hilly lands with undulating surfaces and without permanent and dense vegetation, if the infiltration rate, permeability, and water storage capacity of the soil are limited;
- infiltration (I) and water storage (S) within the soil if they are not limited, in flat lands;
- groundwater recharge (G) if the soil has good vertical drainage, permeability is not limited, especially in low-lying areas;
- evaporation (E), if infiltration is limited;
- transpiration (T) in the case of well-developed plant canopies.

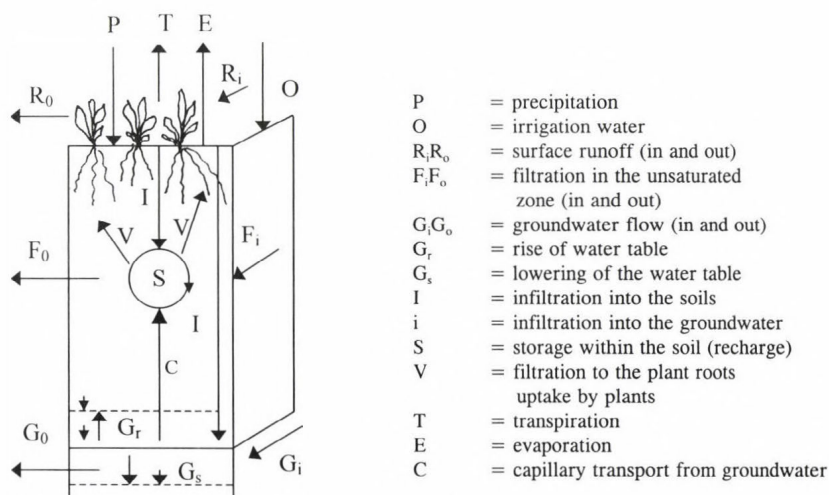
The decrease in precipitation results in adverse changes.

The rise in *temperature*

- increases the potential E and T, if the plant canopy is not suffering from limited water supply due to climatic or soil-induced drought, e.g., low precipitation or limited water storage capacity;
- decreases R, I, S, and G, especially if it is accompanied by low precipitation;
- decreases the intensity (depth) of permafrost; it will modify the geographical boundaries of permafrost, opening possibilities for increasing water storage and water movement, biological activity and soil formation processes within the unfrozen part of the soil.

The decrease in temperature will result in adverse changes.

These general influences are modified with the impact of vegetation characteristics (type, density, dynamics, species composition, biomass production, litter and root characteristics), and depend greatly on the type, intensity, spatial and temporal distribution of atmospheric precipitation. Man's influence is still more complex. Land use, cropping pattern, agrotechnics, amelioration (including water and wind erosion control, chemical reclamation, irrigation, and drainage), and other activities sometimes radically modify the field water balance and its components (*Arnold et al.*, 1990; *Lal et al.*, 1994; *Tinker and Ingram*, 1994; *Toward ...*, 1988).



Factors	CI			
	Cold, wet	Cold, dry	Hot, wet	Hot, dry
P	I	D	I	D
R	I	d, D	I	D
G	i	d	i	D
I	I	d	I	D
I	i	D	(i)	D
S	I	d	(I)	D
E	D	E	E	I
T	D	E	i	I
F	-	-	-	-
G _r	i	-	(I)	-
G _s	-	I	-	I

Fig. 2. Components of the field water balance and soil moisture regime, and the influence of four potential climate scenarios on these factors: *i* and *I*: slight and great increase; *d* and *D*: slight and strong decrease; *E*: no change (equilibrium).

5. Impacts of climate changes on soil degradation processes

Soil degradation is usually a complex process in which several features of soil deterioration can be recognized. Soil degradation may lead to the loss of land or soil; limitations in normal soil functions; decrease in soil fertility and “productive capacity” (Oldeman *et al.*, 1991; Várallyay, 1989). Soil degradation may be the result of natural factors and/or human activities.

For the assessment of soil degradation a world-wide project was initiated by UNEP. In the framework of GLASOD (GLObal Assessment of SOil Degradation), a map was prepared in the scale of 1:10,000,000 on the present status and potential future development of the various human-induced soil degradation processes.

In Fig. 3 an attempt was made to show the potential impacts of the four basic climatic scenarios on the main soil degradation processes. In the figure their main natural and human causative factors were summarized, as well.

	Sign	Climatic scenarios				Causative factors	
		Cold and dry	Cold and wet	Hot and dry	Hot and wet	Natural	Anthropogeneous
Soil erosion by water	E	4	1	4	1	1,2,3	9,10,11,12
Soil erosion by wind	D	3	4		4	3	9,10,11,12
Acidification	A	3	1	4	1	2,4	13,15
Salinization/Alkalization	S		4	1	4	5,6,8	14
Physical degradation	P	3			1	-	10,12
Extreme moisture regime (water logging)	M	4	1	4		5,6,7	11,12,14
Biological degradation	B	3			1	-	11,16
Unfavourable nutrient regime	N	3			1	(2,6)	13
Soil pollution (toxicity)	T	4	3	3	4	-	16

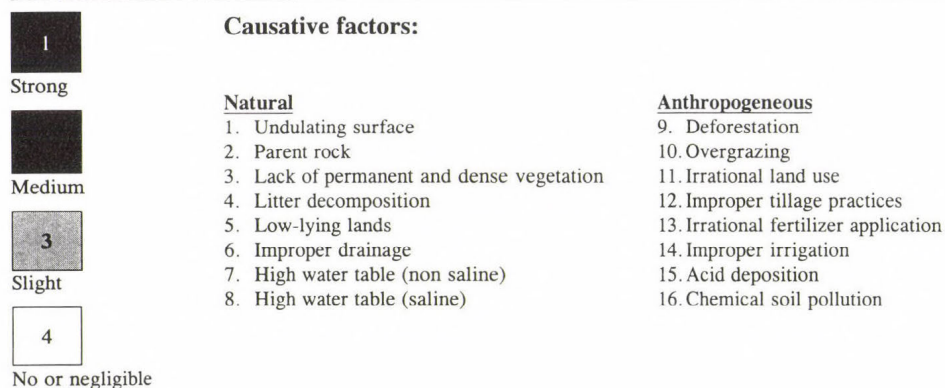


Fig. 3. The influence of four main climatic scenarios on the main soil degradation processes, and their natural and anthropogenic causative factors

(a) Soil erosion

There are no linear relationships between mean annual precipitation, surface runoff, and the rate of denudation/erosion. The rate, type, and extension of *soil erosion* depends on the combined influences of climate (primarily the quantity and intensity of rainfall), relief, vegetation (type, continuity, density), and soil erodability characteristics.

The main impacts of potential climate change on soil erosion are as follows (*Lal et al.*, 1994; *Várallyay*, 1990a):

- higher precipitation may result in an increasing rate of erosion (→ higher runoff), if it is not balanced by the increasing soil conservation influences of better vegetation due to better water supply;
- lower precipitation generally reduces the rate of erosion, but it can be counterbalanced by the less intensive soil conservation influence of poor vegetation due to the non-adequate water supply of plants; this can be the consequence of increasing temperature, as well;
- lower precipitation (or higher temperature) may intensify wind erosion;
- increasing temperature may reduce the erosion hazard moderating the permafrost influence (limited infiltration rate and water storage capacity of the soil); but may considerably increase the erosion-risk reducing the snow: rain ratio in the cold regions and in high mountains.

(b) Acidification

Increasing precipitation may intensify downward filtration and leaching, consequently may help acidification. Climate determines the dominant vegetation types, their productivity, the chemical character and decomposition of their litter deposits, and influences the development of soil reaction in this way (*Brinkman*, 1990; *Scharpenseel et al.*, 1990).

(c) Salinization/alkalization

One of the well-pronounced consequences of the forecasted global “warming up” is the rise of eustatic sea level. Higher precipitation (→ increasing rate of downward filtration → leaching) will reduce, lower precipitation and higher temperature will intensify salinization/alkalization processes: higher rate of evapo(transpi)ration → increasing upward capillary transport of water and water-soluble salts from the groundwater to the root zone + no or negligible leaching (*Rounsevell and Loveland*, 1994; *Várallyay*, 1994).

Similar tendencies characterize the leaching and *accumulation of carbonates*, which may lead to the formation of compact and impervious hardpans, petrocalcic horizons.

(d) Physical degradation (structure destruction, compaction, sealing)

The influence of climate change on the changes in soil structure is a complex process with numerous direct and indirect impacts. The most important direct impact is the aggregate-destructing role of raindrops, surface runoff, and filtrating water. The indirect influences act through the vegetation pattern and land use practices.

(e) Biological degradation

Temperature, precipitation, and vegetation changes all considerably influence biological soil processes, but only a few data are available on these consequences (Arnold *et al.*, 1990; Lal *et al.*, 1994; Tinker and Ingram, 1994, Toward ..., 1988).

(f) Unfavourable changes in the biogeochemical cycles and the plant nutrient regime

One part of these changes is connected with changes in the soil moisture regime (the ratio between downward and upward water movement in the unsaturated zone; leaching–accumulation), another part is related to the abiotic and biotic transformation phenomena (fixation, immobilization–release, mobilization; changes in solubility and redox status; etc.) in the chemical-biological cycles of various elements (Scharpenseel *et al.*, 1990). High precipitation helps leaching, filtration losses (→ potential groundwater “pollution”) and reductive processes; low precipitation → dry conditions may reduce the solubility, consequently mobility and availability of less soluble compounds.

6. Conclusion

Because of many uncertainties, more detailed, integrated multidisciplinary studies are required on the quantification of the existing facts and processes in the air–water–soil–geological deposits–plant continuum for a more real environmental forecast and for the rational control of soil processes under various potential and real climate change scenarios.

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