ᲡᲐᲥᲐᲠᲗᲕᲔᲚᲝᲡ ᲛᲔᲪᲜᲘᲔᲠᲔᲑᲐᲗᲐ ᲔᲠᲝᲕᲜᲣᲚᲘ ᲐᲙᲐᲓᲔᲛᲘᲘᲡ ᲛᲝᲐᲛᲑᲔ, ტ. 5, №2, 2011
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 5, no. 2, 2011

Soil Sciences

Global Climate Change Effects on Soils

Hans-Peter Blume

Institute of Plant Nutrition and Soil Science, Kiel University, Kiel, Germany

(Presented by Member of the Academy Tengiz Urushadze)

ABSTRACT. With progressing earth history temperatures and precipitation have globally, regionally and locally changed. In addition to extraterrestrial reasons also terrestrial reasons like volcanism, forest fires, changes of global ice, snow and vegetation cover have caused such changes. For the last 100 years the global mean temperature has increased to actually more than 15°C, which is widely assumed to have not only natural but anthropogenic reasons: A reduced water evaporation from agricultural land in contrast to natural forest, emissions of warmth and carbon dioxide especially in urban-industrial agglomerations, and the release of methane and nitrous oxide in agriculture are the most important impacts. It is assumed that in the 21st century the global mean temperature will rise by another 2-3 C, mainly caused by a higher use of fossil fuels and an intensified conventional agriculture.

Increased temperatures, higher CO_2-concentrations near the soil surface and higher precipitation rates lead in principle to a higher formation of biomass. More crop residues and higher temperatures also stimulate the activity of soil organisms. Higher soil temperatures also stimulate chemical weathering. On the other side higher rainfall can wash out more solved nutrients. But the expected climate changes and their effects on soils can vary to a large extent. The predicted rising sea level will increase the flooding of coastal soils, so that dikes have to be built or heightened. Higher temperatures in coastal soils will intensify the microbial formation of *green house gases.* Permafrost soils will melt so that their agricultural use may be partly possible. *© 2011 Bull. Georg. Natl. Acad. Sci.*

Key words: *biomass production, organic matter accumulation, coastal soils, permafrost soils, rural soils, volcanism.*

1. Introduction

With progressing earth history temperatures and precipitation have globally, regionally and locally changed. Extraterrestrial reasons are (among others) a changing sun activity, the rotation of the Milky Way galaxy, the influence of meteors and meteorites as well as changing tidal forces [1: 285ff]. Terrestrial reasons are e. g. volcanism (volcanic ashes impede the solar radiation as atmospheric dusts), forest fires, circulation and material changes of the atmosphere (ecologically relevant gases like CO_2, CH_4, nitrous oxide increase temperature) and changes of global ice, snow and vegetation cover. Regional changes are also caused by mountain formation (orogenesis) and deformation, by changes of coastal ocean currents (the warm Gulf Stream also warms up the eastern coastal regions of the North Atlantic, cold ocean currents increase the desertification at the southern west coasts of Africa and South America) as well as the shifting of the poles together with the lower, middle and higher latitudes [1]. The actual *global mean temperature* (GMT) is about 15°C. In the Devonian period until the Tertiary (A1 in Fig. 1) it was distinctly higher than 20°C, which even resulted in ice-free polar caps. Glacial periods (C1 Weichselian, Wisconsin cold stage, C2 Saalian cold stage) with global mean

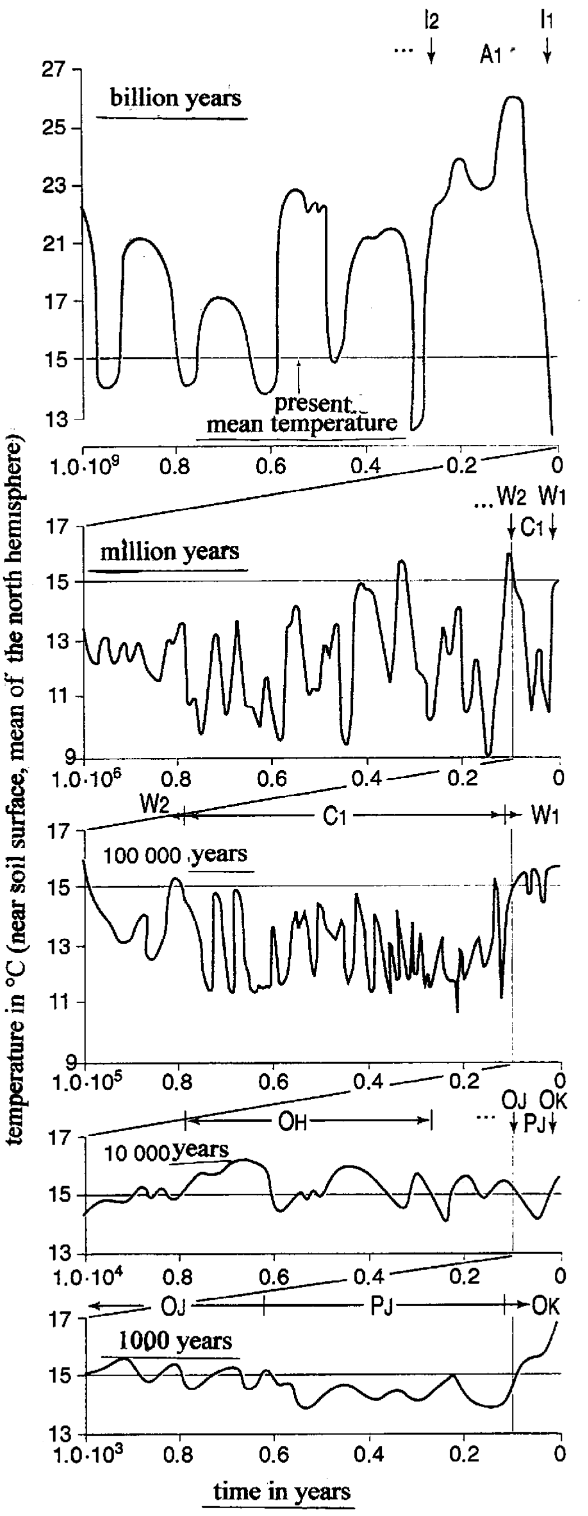

Fig. 1. Northhemispheric mediated soilsurface-near air temperature-variations in different temporal resolutions of 10^9 to 10^3 years; I 1 Quarternary Ice Stage, A1 Acryogenic warm climate (here Devonian to Tertiary), W2 Eemian warm stage, W1 Holocene warm stage, C1 Weichselian (Wisconsin) cold stage, OH Holocene warm stage, Oj Medieval warm period, Pj small glaciations (little "ice stage"), OK Modern warm period (after many sources from [1])

temperatures below 14°C showed a distinctly stronger ice and snow cover on the lower latitudes and high mountains, and a sea level which was up to 100 m lower than today.

During the Eemian warm stage (W2) it was warmer than in the Holocene (W1). 7800 to 2500 years (OH) und 1000 to 600 (OJ medieval optimum) years before today it was warmer than now (the Vikings had agriculture on Greenland, the *green island* [3, 4]; afterwards until the end of the 19th century a short *cold period* (little ice stage) followed (PJ).

Regionally to globally working volcanic eruptions with strong emissions of fly ash and SO_2 as aerosols into the stratosphere additionally had a short cooling effect on the global atmosphere [1: 425ff,2]. The Tambora eruption in Indonesia (8.3° S, 118.0° E) in April 1815 led to crop failure for several years even in Central Europe [3: 273]. The mean summer temperature of the year 1816 was the lowest in Germany during the last 250 years. It was 5.8 °C lower than those of the hottest summer in 2003 (Fig. 2): As a consequence of a lack of light and warmth it led to a total crop failure of cereals, potatoes and vine in parts of Central Europe and North America [5].

For the last 100 years the global mean temperature has increased to actually more than 15°C (OK = modern optimum). This latest temperature rise is widely assumed to have not only natural but anthropogenic reasons [1, 6, 7]. A reduced water evaporation from agricultural land in contrast to forest (Tab. 1), emissions of warmth and carbon dioxide by domestic fuel, traffic, commercial and industrial business especially in urban-industrial agglomerations [8, 9, 10], as well as the release of methane und nitrous oxide in agriculture are considered to be the most important impacts [1: 324ff]. It is assumed that in the 21st century the global mean temperature (as well as the regional one in North Germany) will rise by another 2 – 3° C [6] which is generally considered to be caused by an increase of the so-called *greenhouse gases* like carbon dioxide, methane, nitrous oxide and fluorinated hydrocarbonates (FCKWs). This anthropogenic increase is mainly caused by a higher use of fossil fuels and an intensified conventional agriculture [6]. The strongest impact is caused by the great volume of carbon dioxide, but the effectiveness of the other gases in the process of the *anthropogenic greenhouse effect* cannot be neglected (Tab. 2). In spite of higher water evaporation the melting of ice on the pole ice caps and high mountains will lead to rising sea levels up to 3-4 m (Tab. 2).

Table 1.

Real and predicted global changes of the soil surface-near air temperature (T), the sea level (Ms), as well as of the concentrations of climate-relevant gases in the atmosphere without a reduction of anthropogenic emissions [1, 6]

	T	**Ms**	**CO_2**	**CH_4**	**N_2O**	**FCKW***
	°C	m	ppm	ppm	ppm	ppb
conditions around 1800	14.5		280	0.80	0.28	0
conditions around 2000	15.5		370	1.75	0.31	0.5
possible cond. around 2100	17-19	+ 3-4	520	2.0	0.39	2.5
Relative greenhouse potential			1	24.5	320	4000
Anthropog. greenhouse pot.			61 %	15 %	4 %	11 %

* fluorochlorinated hydrocarbons

Table 2.

Water balances of loess soils under different use in Southern Germany using HTO as a tracer for soil water (in mm)* [11: Tab. 20.4]

	Hohtnloher Ebene (1970)			Filder, Stutgart (1970)			
	beech 10.3.-13.10.	**spruce** 10.3.-13.10.	**farm land** 10.3.-13.10.	**hard wood** 9.3.-20.11.	**spruce** 9.3.-20.11.	**meadow** 9.3.-20.11.	**farm land** 9.3.-20.11.
precipitation (P)	530	530	480	425	425	425	425
HTO-maximum in cm soil wafer	38 63	55 72	60 90	89 96	64 68	105 130	54 81
until HTO -maximum	147 179	208 212	268 344	325 292	215 228	435 565	153 251
until 120 cm	462 418	456 430	530 468	430 396	406 400	491 528	380 385
accumulation (ΔA)	44	-26	-62	-34	-6	-37	+5
transpiration (T)	498	526	404	458	412	295	327
infiltration (I)	76	30	148	1	19	93	93

*The total transpiration (T) is the result of the precipitation (P) and the difference of the contents of soil water above the HTO-maximum at the beginning and the end of the shown time period; additionally bound water in the rooting zone (Δ A) is the difference of the water contents above 120 cm; the loss of percolated soil water (I) can be calculated from P = T + I ± Δ A. It was assumed that there was no water uptake by plant roots below 120 cm soil depth, and the input of laterally moving water was as high as the output.

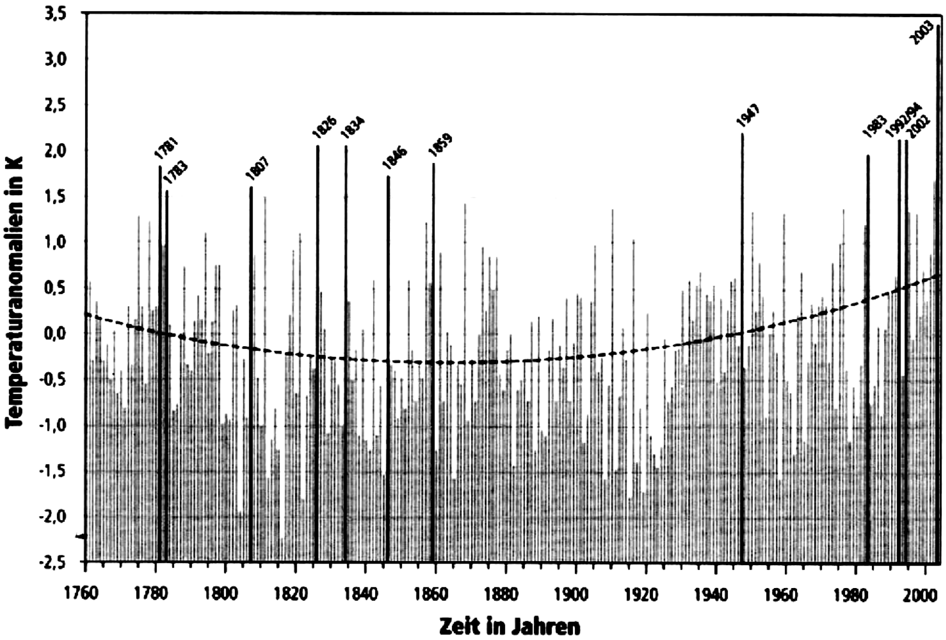

Fig. 2. Summer temperatures in Germany during the last 250 years, shown as deviations of the mean temperatures between 1961-1990. The summer of 1816 is an extreme with -2.2 K as an absolute minimum. At the same time there is a period of distinctly cooler summers in the first two decades of the 19th century (German climate research program DEKLIM, Project Vasclimo 2001-2006)

2. Effects on rural soils

Increased temperatures of the soil surface-near air layer lead to a higher formation of biomass from wild and crop plants (Fig. 3) as well as higher precipitation rates as a consequence of an increased evaporation above the oceans. A higher concentration of carbon dioxide in the surface-near air layer also stimulates the formation of biomass (see e.g. [12, 13]): For this reason gardeners increase the CO_2-concentration of the air in their greenhouses. In [14: 302] the suggestion of the physico-chemists W.H. Nernst (1864-1941) can be found *to burn unused hardcoal in polar areas in air shafts to press carbonic acid into the atmosphere by ventilation in order to increase the crop yields (globally) by an enrichment of the air.* The average yields in the agricultural production of Schleswig-Holstein in Northern Germany were extended by 10% during the last 20 years, although mineral fertilization had distinctly been reduced [15] which cannot be explained only by a more successful cultivation of crop plants, so a consequence of a climate change probably takes priority.

A higher biomass production of wild plants as well as more crop residues as a consequence of higher crop yields (and possibly a higher manure supply) increase the nutrient offers for soil organisms. Higher soil temperatures also stimulate the activity of soil organisms (Fig. 3). Therefore in aerated soils of the lower and middle latitudes higher humus contents can be expected. In contrast, in the soils of the higher latitudes smaller humus contents will occur (Fig. 3). Wet soils with low air contents, even in humid tropical areas, will be characterized by increasing humus contents.

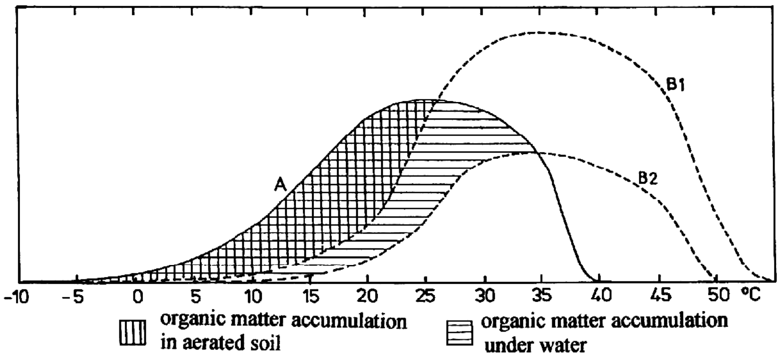

Fig. 3: Range of destruction and accumulation of soil organic matter as related to temperature A – production of organic matter; B – destruction of organic matter B1 – with plenty water B2 – under water (after [16]; widened in [17]).

Globally the mean water contents of soils will not considerably change, because the increased precipitation is compensated by an increased evapotranspiration, but differences of water contents mainly in the topsoil will occur more often, for the evaporation on rain-free days and weeks will become more relevant [18].

Fig. 4 shows that in an artificially warmed topsoil in contrast to a normal soil the decomposition of the soil fauna increases in spring. In the following dry period it decreases faster again in the top soil. Higher soil temperatures will also stimulate the activities of the aggregate forming and soil mixing animals among the soil organisms, in fact mainly the activities and efficiency of earthworms.

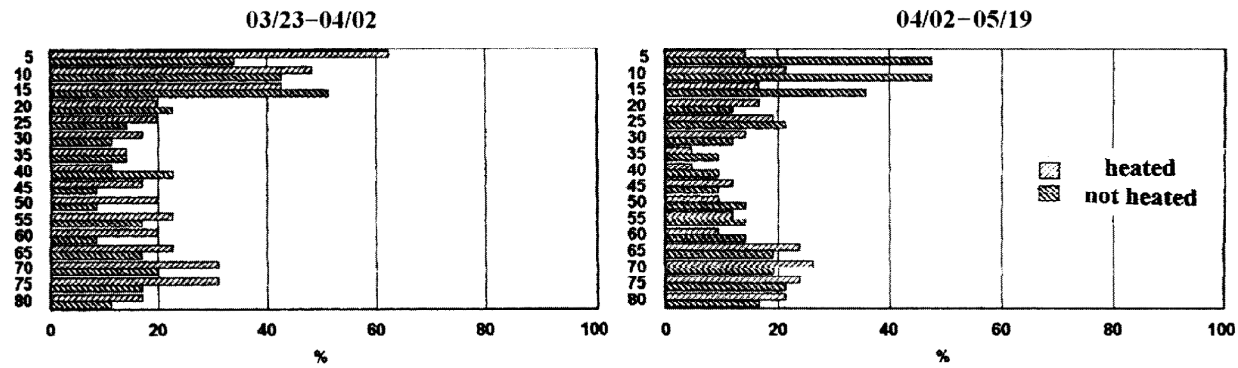

Fig. 4. Decompositon activity (Köderlamellentest after [19]: in % of 10 days) of soil organisms in different soil depths (5 – 80 mm) of an artificially (like a floor heating) by 1.5-2.5 warmed salt- and carbon-containing raw marsh of the North Sea coast of Schleswig-Holstein, compared with a not-warmed variant (from [20]).

Higher soil temperatures also stimulate the chemical weathering of soil minerals, of which dissolved weathering products become plant-root-available nutrients. With a stronger water movement after rainfall, however, they are faster washed out from the root zones.

The expected climate changes as well as their effects on soils can regionally or locally vary to a large extent. So it is expected that in North Germany there will be more rainfall in the following decades mainly in winters, while in summers the weather will become dryer which will have ecologically negative effects on sandy soils. There the yields will decrease even more, mainly in the state of Brandenburg which is already suffering from dryness/drought [21].

3. Effects on coastal soils

The rising sea level predicted for the coming century will increase by 4 m (Tab. 1) and lead to a flooding of the deeper situated coastal regions. Soils will be lost which, mainly in the moist tropics and subtropics, belong to the most fertile soils of the world. Furthermore, the storm intensity will increase as well as the amplitudes between floods and low waters. As a consequence, also higher situated soils will at least periodically be flooded by saltwater, which will also have a negative influence on their productivity.

Such a development is supposed not to occur at the Middle European North Sea coast. For 1,000 years the marsh soils have been protected by dykes. People in Germany have been used to resisting increasing sea water levels by heightening the dykes to 8.6 m. This successful method will not be changed in future. Additionally dykes influence the coastal sedimentation strongly. In wide coastal areas the land to the seaward side of dykes will extend. As a consequence, raw marshes will only partly get lost by an increasing sea water level [20]. Higher soil temperatures support soil and root respiration. The methane production increases in the reduction horizons of the marsh soils which will increase the concentration of the *greenhouse gases* in the atmosphere [20].

4. Effects on permafrost soils

In the permafrost regions of the lower latitudes and the high mountains additionally to the described changes (see chapter 2) there will occur a progressing melting of the upper permafrost and consequently a deeper permafrost boundary. Actually such predicted future effects can be observed where already for decades local changes have occurred.

In the Bolschesemelskaja-(shrub) tundra of North Russia with 500 mm annual precipitation and -6°C annual mean temperature, permafrost occurs in organic soils from 30-50 cm, in mineral soils from 80-150 cm [22]. In this region hardcoal-mining has been practised since the 1940s for electricity production. At the same time Workuta, a mega-metropolis, developed. A strong warming of the surface-near air layer by power stations, domestic fuel and traffic lead in the city to a decreased permafrost boundary by several meters. Meantime in the city park originally 0.3-0.5 m low-growing birches and willows of the tundra have grown higher than 10 m (which besides by a higher temperature can also be caused by increased CO_2- and NO_x-concentrations of the surface-near air layers. In the outskirts of the city there is agriculture with permafrost boundaries deeper than 2 m.

ნიადაგმცოდნეობა

გლობალური კლიმატის ცვლილების გავლენა ნიადაგებზე

ჰ.-პ. ბლუმე

კილის უნივერსიტეტი, მცენარეთა კვებისა და ნიადაგმცოდნეობის ინსტიტუტი, კილი, გერმანია

(წარმოადგინა აკადემიის წევრმა თ. ურუშაძემ)

დედამიწის ისტორიის მანძილზე აღინიშნება ტემპერატურის და ნალექების გლობალური, რეგიონალური და ლოკალური ცვლილებები. კოსმოსურ მიზეზებს ემატება ვულკანიზმი, ტყის ხანძრები, გლობალური ყინულის, თოვლის და მცენარეული საფარის ცვლილებები. უკანასკნელი 100 წლის მანძილზე დედამიწის ტემპერატურა საშუალოდ გაიზარდა 1,5 °C-ით, რასაც აქვს არა მარტო ბუნებრივი, არამედ ანთროპოგენური მიზეზები. ბუნებრივი ტყეებისგან განსხვავებით, სასოფლო-სამეურნეო მიწებიდან წყლის აორთქლების, სითბოს და ნახშირორჟანგის შემცირება, განსაკუთრებით ურბანიზებულ-ინდუსტრიულ აგრომელიორაციებში და მეთანის და აზოტის ქვეჟანგის განთავისუფლება სოფლის მეურნეობაში არის მეტად მნიშვნელოვანი ზეგავლენა გარემოზე. ვარაუდობენ, რომ 21-ე საუკუნეში საშუალო გლობალური ტემპერატურა გაიზრდება 2-3 °C-ით, რაც ძირითადად გამოწვეული იქნება ნამარხი საწვავის გამოყენებით და სოფლის მეურნეობის ინტენსიფიკაციით. ტემპერატურის ზრდა, ნიადაგის ზედაპირთან CO_2 მაღალი კონცენტრაცია და ნალექების გადიდებული რაოდენობა განსაზღვრავენ ბიომასის გადიდებული რაოდენობის ფორმირებას. მოსავლის ნარჩენების მეტი რაოდენობა და მაღალი ტემპერატურები აგრეთვე ზრდიან ნიადაგის ორგანიზმების აქტიურობას. ნიადაგის უფრო მაღალი ტემპერატურები აგრეთვე ხელს უწყობენ ქიმიურ გამოფიტვას. მეორეს მხრივ, გადიდებულ ნალექებს შეუძლიათ უფრო მეტი რაოდენობით გამორეცხონ საკვები ნივთიერებები. კლიმატის მოსალოდნელი ცვლილებები და მათი გავლენა ნიადაგებზე შეიძლება იცვლებოდეს ფართო ფარგლებში. ზღვის დონის ზრდა გამოწვევს სანაპირო ნიადაგების დატბორვას, რაც აუცილებელს გახდის ახალი კაშხლების მშენებლობის ან ძველის გაძლიერებას. სანაპირო ნიადაგების გადიდებული ტემპერატურები გაზრდის მიკრობული ფორმაციების სასათბურე აირების ზრდას. მშრალი ნიადაგები დაიწყებენ ლღობას და შესაძლებელი გახდება მათი ნაწილობრივი გამოყენება სოფლის მეურნეობაში.

REFERENCES

1. *C.-D. Schönwiese* (2003), Klimatologie, 2nd ed.; E. Ulmer, Stuttgart
2. *J. Z. de Boer, D. T Sanders* (2002), Vulcanos in human history – The far-reaching effects of major eruptions. Univ. Press, Princeton/Oxford.
3. *H.H. Lamb* (1989), Klima und Kulturgeschichte. Der Einfluß des Wetters auf den Gang der Geschichte. Rowohlt V., Hamburg.
4. *K. J. Hsü* (2000), Klima macht Geschichte. Menschheitsgeschichte als Abbild der Klimaentwicklung. Orell Füssli V., Zürich.
5. *R. Dannowski, C. Dalchow, H.Sell* (2009), Thaer Heute. Die Agrarregion um Möglin, 6: 89-104. Fördergesellschaft Albrecht Daniel Thaer, Reichenow-Möglin, Brandenburg.
6. *J. Houghton, Y. Ding, D. Griggs, et al*. (eds.) (2001), Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Univ. Press, Cambridge.
7. *J. McCarthy, O. Canziani, N.Leary, et al*. (eds.) (2001), Climate change 2001: Impacts, adaption, and vulnerability. Contribution of working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Univ. Press, Cambridge.
8. *H.-P. Blume* (1989), Catena, **16**, 3: 269-275.
9. *H. Meuser*, (2010), Contaminated urban soils. Springer, Heidelberg.
10. *H. Sukopp, R.Wittig* (eds.) (1998), Stadtökologie, 2nd ed.; G. Fischer v., Stuttgart.

11. *H.-P. Blume, R. Horn, S.Thiele-Bruhn* (eds.) (2011), Handbuch des Bodenschutzes, 4th. ed.; Wiley-VCH, Weinheim.
12. *P. Pinter, R. Kimball, R. Garcia, et al.* (1996), in: G. Koch & H. Moony (eds.), Carbon dioxide and terrestrial ecosystems. Acad. Press, San Diego, USA. p. 215-249.
13. *J. Morison, M. Morcroft* (eds.) (2006), Plant growth and climate change. Wiley-Blackwell, San Francisco, USA
14. *F. Aerebo, J. Hansen, Th. Roemer* (ed.; 1929), Handbuch der Landwirtschaft, 2. Band – Ackerbaulehre. P. Parey, Berlin.
15. St La (Statistisches Landesamt) Schleswig-Holstein (ab 2004 mit Hamburg)(1980-2008), Bodennutzung und Ernte in Schleswig-Holstein, ab 2004, Ernteberichterstattung über Feldfrüchte und Grünland. Kiel/Hamburg.
16. *E. Mohr, F. van Baren, J. van Schuylenborgh* (1972), Tropical soils. A comprehensive study of their genesis. 3rd ed., Mouton, The Hague.
17. *H.-P. Blume, L. Beyer, M. Bölter, et al.* (1997), Adv. in GeoEcology, 30: 69-90.
18. *T. Lenhart, K. Lenhart* (2008), Effects of climate change on soil hydrological processes – A simple risk assessment. S07.L.01 in Book of Abstracts, EUROSOL Congr. 25-29 August 2008, Vienna, Austria.
19. *E.Törne* (1990), Pedobiologia, **34**, 4: 269-279.
20. *H.-P.Blume, U. Müller-Thomsen* (2007), J. Plant Nutr. Soil Sci., 170: 145-156.
21. *P. Kabat, M. Claussen, P. Dirmeyer, et al*. (eds.), (2004), Vegetation, water, humans and the climate. Springer, Berlin.
22. *I.B. Archegova, G. Mazhitova* (1997), Guide to scientific soil excursion. Tundra zone (Vorcuta area). II Internat. Conf. Cryopedology' 97. Syktyvkar, 24 p.

Received May, 2011