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Soil erosion from sugar beet in Central Europe in response to climate change induced seasonal precipitation variations

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Abstract

This study estimates the implications of projected seasonal variations in rainfall quantities caused by climate change for water erosion rates by means of a modeling case study on sugar beet cultivation in the Central European region of Upper-Austria. A modified version of the revised Morgan–Morgan–Finney erosion model was used to assess soil losses in one conventional and three conservation tillage systems. The model was employed to a climatic reference scenario (1960–89) and a climate change scenario (2070–99). Data on precipitation changes for the 2070–99 scenario were based on the IPCC SRES A2 emission scenario as simulated by the regional climate model HadRM3H. Weather data in daily time-steps, for both scenarios, were generated by the stochastic weather generator LARS WG 3.0. The HadRM3H climate change simulation did not show any significant differences in annual precipitation totals, but strong seasonal shifts of rainfall amounts between 10 and 14% were apparent. This intra-annual precipitation change resulted in a net-decrease of rainfall amounts in erosion sensitive months and an overall increase of rainfall in a period, in which the considered agricultural area proved to be less prone to erosion. The predicted annual average soil losses under climate change declined in all tillage systems by 11 to 24%, which is inside the margins of uncertainty typically attached to climate change impact studies. Annual soil erosion rates in the conventional tillage system exceeded 10 t ha^{-1} a^{-1} in both climate scenarios. Compared to these unsustainably high soil losses the conservation tillage systems show reduced soil erosion rates by between 49 and 87%. The study highlights the importance of seasonal changes in climatic parameters for the discussion about the impacts of global climate change on future soil erosion rates in Central Europe. The results also indicate the high potential of adaptive land-use management for climate change response strategies in the agricultural sector.

Keywords: Climate change; Soil erosion; Precipitation; Sugar beet; Conservation agriculture; Erosion modelling

1. Introduction

Climate change of anthropogenic origin is widely accepted as being reality by most scientists (IPCC, 2001b). Weather records from meteorological stations around the world document a long-term trend of rising average global temperature of 0.6±0.2 °K over the 20th century (IPCC, 2001b). Besides temperature, climate change affects other weather parameters. Precipitation patterns are predicted to change and extreme weather events (floods, hurricanes, droughts, etc.) are likely to occur more frequently. Karl et al. (1996) quantified the chance to less than 1 in 1000 that the recent increase in extreme weather events and in the number of wet days in the USA could have taken place under a quasi stationary climate. But considerable uncertainty exists with regard to the specific character of climate change impacts, because most impacts will vary widely in scale, intensity and time of occurrence among different regions (IPCC, 2001a). Also the individual vulnerability and adaptive capacity of the affected biophysical and socioeconomic systems will strongly influence the severity of climate change impacts (IPCC, 2001a). It is likely that continued climatic change will aggravate the problem of accelerated soil erosion in most areas around the world, which are affected by human activities. This is especially true for agricultural land, where many parameters influencing the soil's vulnerability to erosion are likely to be

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altered with global warming, such as precipitation amounts and intensities. Plant growth conditions and agricultural practice may also change as land-use management strategies become adapted to a changing climate (e.g. Parry, 1990; Rosenzweig and Hillel, 1998; Williams et al., 2002). The specific degree of change in soil loss rates will depend on the climate sensitivity of each system and the intensity of local climate change effects.

Yang et al. (2003) estimated a global average increase in soil loss of 14% under climate change using a GIS-based RUSLE model (Revised Universal Soil Loss Equations (Renard et al., 1997)). They used a numerical climate change simulation and considered future changes in land cover based on actual and historical land-use data, present trends in land-use development and assumptions about future economic development. Lal (1994) pointed out, that such global estimations often depend on numerous extrapolations and assumptions, which are likely to produce huge errors. But there is also a small number of more specific modelling studies trying to appraise the potential impact of climate change on soil erosion rates for selected areas around the world (Table 1).

Table 1
Selected studies on regional impacts of climate change on soil erosion

Publication	Reseach design and results			
	Study area	Models and tools	Studied parameters	Soil erosion rate
Farvis-Mortlock and Boardman (1995)[1]	UK South Downs	$2\times CO_2$ climate scenario WXGEN[2] EPIC[3]	Rainfall amount temperature	+150%
Farvis-Mortlock and Guerra (1999)	Mato Grosso, Brazil	HADCM2[5] WEPP[4]	Precipitation temperature CO_2	Annual mean: +27%
Nicks (1993)	USA, 69 sites	$2\times CO_2$ climate scenario CLIGEN[2]	Mean temperature Rainfall amount and frequency	+10.7 to 83.9%
Pruski and Nearing (2002b)	Various sites in the USA	WEPP	Rainfall amount and intensity	+0.85 to 2.38% per +1% precipitation
Savabi and Stockle (2001)	Indiana, USA	WEPP	Temperature vegetation growth CO_2	Down to −5.5%
Michael et al. (2005)	Saxony, Germany	ECHAM4-OPYC3[5] EROSION 2D[6]	Precipitation intensities/extreme weather events	+22 to 66%
O'Neal et al. (2005)	Midwestern USA, 11 sites	HadCM3-Ggal[5] CLIGEN WEPP-CO2	Precipitation, temperature, soil cover, adaptive management	+10 to 274%
Zhang and Nearing (2005)	El Reno, Oklahoma, USA	HadCM3[5] CLIGEN WEPP	Precipitation, temperature, tillage systems, crop growth	+18 to 30%

Pruski and Nearing (2002b) extended their research on the sensitivity of erosion processes to changes in rainfall (as quoted in Table 1) by using a modified version of the WEPP model to include the impacts of climate change on plant biomass production, such as CO_2 fertilization, and changes in soil moisture and solar radiation (Pruski and Nearing, 2002a). Based on this method and climate simulations of the HadCM3 model, the following qualitative conclusions on the impact of climate change on soil erosion were drawn: (i) both a change in precipitation amounts and a shift in precipitation intensities are important aspects to consider in predicting future soil loss; (ii) significant precipitation increases are likely to increase soil losses at disproportional higher rates; (iii) soil erosion rates are more sensitive to runoff than to biomass production. Nearing (2001) investigated the impact of climate change on rainfall characteristics related to their ability to cause soil particle detachment and transport (rainfall erosivity). The author used the output of global circulation models (GCMs) and statistical relationships on erosivity values from the RUSLE model to compute climate change induced alterations of the erosive power of rainfall in the USA. Despite certain inconsistencies, the results showed critical changes in rainfall erosivity of up to 58% at some locations, which may considerably affect future soil erosion rates. Walling and Webb (1996) suggested on basis of empirical data from the Dnestr River in Ukraine that climate forcing already affected soil erosion rates on local scale. The study analysed historical land-use data from the catchment area and attributed a recorded five-fold increase in sediment loads carried by the river since the 1950s in part to major land-use changes, such as forest clearances, but more importantly to observed climatic changes.

In central Europe, especially the cultivation of root crops, such as potatoes, carrots and sugar beet is often associated with a high risk of severe soil losses by water (e.g. Jones et al., 2003). This is accounted for by the coincidence of two factors: ground and canopy cover are low during the time of seedbed preparation and in the first weeks of vegetative development, and secondly this period concurs with the time of the year showing the highest amount of erosive rainfall (Strauss et al., 1995).

There is a large toolbox of soil conservation measures (e.g. Hudson, 1995; Morgan, 2005). One such measure is conservation agriculture, which seeks to avoid unsustainable soil losses while maintaining stable yields. Common approaches include reduced tillage and no-tillage systems, often combined with intercrop cultivation and mulching, to preserve the natural soil structure and a vegetative soil surface cover (e.g. Cannell and Hawes, 1994; Tebrügge and Düring, 1999). Maintaining a soil cover by utilising post-harvest residues or living vegetation to protect soil surfaces from raindrop impact is particularly important to limit soil erosion (e.g. Pimentel et al., 1993; Rose, 1994; Stocking, 1994).

The potential impacts of climate change on European agriculture have been the focus of a number of studies. For example Downing et al. (2000) compiled a broad collection of impact studies on the effects of CO_2 fertilization, temperature variability and precipitation changes on plant growth, crop yields, nutrient cycling and pest infestation. Also the process of