Predicting greenhouse gas emission from peat soils depending on water management with the SWAP–ANIMO model

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Summary

A process-based model was developed to simulate for peat lands emission of the greenhouse gasses (GHG) CO_2, CH_4 and N_2O, soil subsidence and nutrient loading of surface waters. The model was calibrated and validated against data from two experimental fields in the Netherlands. With the validated model scenario studies were performed to quantify the effects of water management on GHG emission, soil subsidence and nutrient loading. Raising ditchwater level was an effective measure to diminish GHG emission and subsidence. Submerged drains enhanced subsurface irrigation greatly and as a result decreased subsidence and GHG emission considerably. For nutrient loading of surface waters the optimal drain depth was around 50-60 cm below soil surface.

Key index words: GHG emission, subsidence, nutrient loading, water management, modelling

Introduction

Most peat lands in The Netherlands are in agricultural use, mainly as pasture land. The agricultural user equires drainage and fertilization of the peat soil. Result of these practices is disappearance of peat by decomposition of organic matter, mainly as aerobic decomposition or oxidation. Due to peat oxidation the soil surface subsides, the greenhouse gasses (GHG) carbon dioxide (CO_2) and nitrous oxide (N_2O) are emitted to the atmosphere and organic nitrogen (N) and phosphorus (P) compounds are mineralized so that they become subject to leaching to ground and surface waters. The last process is enhanced by fertilization. These processes are recognized as major problems in the peat areas of The Netherlands.

Rewetting of drained peat soils by raising ditchwater levels is the common approach to diminish oxidation of peat soils in The Netherlands. Presently, submerged drains to enhance subsurface irrigation with ditchwater are studied and seem very promising. Questions in this context are : which water management options are the most effective and what are the consequences for agricultural or other use of rewetted peat soils?

The objectives of this study were to develop, calibrate and validate a process-based model to predict GHG emission, soil surface subsidence and nutrient loading of surface waters and perform scenario studies on the effects of water management strategies on these processes.

Materials and methods

Model description

The process oriented model combination SWAP -ANIMO exists of two dynamic models: SWAP (Kroes and Van Dam, 2003) for simulating the hydrology of saturated and unsaturated zone and soil temperature, and ANIMO (Groenendijk *et al.*, 2005; Renaud *et al.*, 2006) for simulating the carbon(C)-, N- and P-cycles, C-, N- and P-leaching to ground – and surface water and evolution of CO_2. Because N- and P -cycles are based on the carbon cycle, the model is suitable for organic soils. The detailed hydrological basis of the model allows for detailed studies of effects of water management measures.

For this study, the model was extended with a description of soil surface subsidence and evolution, transport and emission of the GHGs nitrous oxide (N_2O) and methane (CH_4). N_2O evolution is related to nitrification and denitrification in the model.

Model calibration and validation

The model was calibrated and validated against data of two field experiments at Zegveld experimental farm on peat soil in the West of the Netherlands. At these two fields with two different ditchwater levels, 55 and 15 cm below soil surface, measurements were carried out in the period 2003-2005. Different parameters were measured continuously, or with intervals of 2-4 weeks: precipitation, air temperature, phreatic water levels, piezometric levels, ditch water levels, pressure heads, moisture contents and soil temperatures at different depths, and concentrations of C-, N- and P-compounds in soil moisture at different depths and in ditchwater. Soil (bio)chemical and physical properties were measured in the laboratory on (undisturbed) samples of the soil taken at different depths: organic matter and clay content, C-, N- and P-content, decomposition rates of organic matter at different temperatures, soil hydraulic functions and bulk densities.

First the SWAP model was calibrated against time-series of groundwater levels, pressure heads, moisture contents and soil temperatures. Thereafter, ANIMO was calibrated against concentrations of C-, N- and P-compounds on basis of the SWAP hydrology. Measurements of 2003 and 2004 were used for calibration and those of 2005 for validation.

For realistic simulation of subsidence and CO_2-emission the model was calibrated against data of long-term (1970-2004) subsidence measurements at the same fields. These measurements provide a good basis for subsidence modelling since subsidence measurements are mostly disturbed by soil movements due to shrinkage in and delayed swelling after dry years. Because long -term subsidence is mainly the result of peat decomposition, long-term subsidence measurements also provide a good basis for modelling of CO_2-emission. For modelling of CH_4- and N_2O-emission the model was calibrated against data on ranges of these emissions from measurements at Zegveld in other years than 2003 -2005.

Results and discussion

Calibration

Model calibration against long-term soil surface subsidence data showed that the model is well able to simulate this subsidence, but is less accurate in simulating the measured erratic vertical movement of the soil surface (Fig. 1A). Measured values show 'negative subsidence', rise of the soil surface, due to slow swelling of the peat soil after extreme dry years. This soil mechanical process, which is not directly relevant for the decomposition of organic matter of peat, was not included in the model. Figure 1.B illustrates that model results include the effects of differences in governing conditions between years on subsidence simulations. As the model is well able to simulate long -term cumulative subsidence as a result of peat decomposition, it consequently is well able to simulate CO_2-emission on a (half-) yearly base.

The simulated N_2O-emission amounts to 12-28 kg N_2O-N per hectare per year and is within the measured range of 8 -30 kg N_2O-N per hectare per year. Measurements show a negative or no CH_4-emission. Simulated emissions are always less than 1 kg CH_4-C per hectare per year.

Scenario results

Simulated soil surface subsidence occurs for 80%-90% during the summer half -year with high temperatures and low groundwater levels (Fig. 2.A). Simulations show that subsidence and GHG emission are strongly affected by drainage level (Fig. 2). The higher the ditchwater level, the lower the subsidence and the GHG emission. This is in accordance with experimental results (Van den Akker *et al.*, 2008). Raising the ditch water level from 70 cm below soil surface (ss) to 30 cm below ss decreases subsidence with 41% and GHG emission with 37%. For a ditchwater level rise from 70 cm below ss to soil surface this decrease is nearly twice as high: 60% for subsidence and 68% for GHG emission. Even in this extreme scenario CH_4-emission is negligible. The reason for this, and for the fact that subsidence and CO_2- and N_2O-emission are not completely terminated, is that in this scenario the lowest groundwater level is still about 20-30 cm below ss. This is due to high infiltration resistances that hamper subsurface irrigation.

To decrease infiltration resistances and promote subsurface irrigation in order to raise groundwater levels in dry periods, submerged drains we re included in the scenarios. Drains were at a spacing of 4 m and at a level of 10 cm below ditchwater level. For high ditch water levels (30 and 40 cm below ss) the effect of submerged drains is an additional decrease of subsidence and GHG emission of 25%-45% (Fig. 2). At 30 cm below ss subsidence is even lower than in the scenario with ditchwater level at soil surface without drains. For a level of 50 cm below soil surface the decrease is much less: around 15%. For the deeper levels the effect is even a slight increase of subsidence and GHG emission of maximal 5%. This is due to dryer conditions in winter time as a result of the d raining effect of the drains. This draining effect is an extra positive effect of submerged drains, because it allows for agricultural practice s at higher ditch water levels. Drains at spacing of 8 m yield just slightly smaller effects than drains at 4 m spacing.

Additional scenarios runs were performed to evaluate the effects of climate change. The worst case climate change

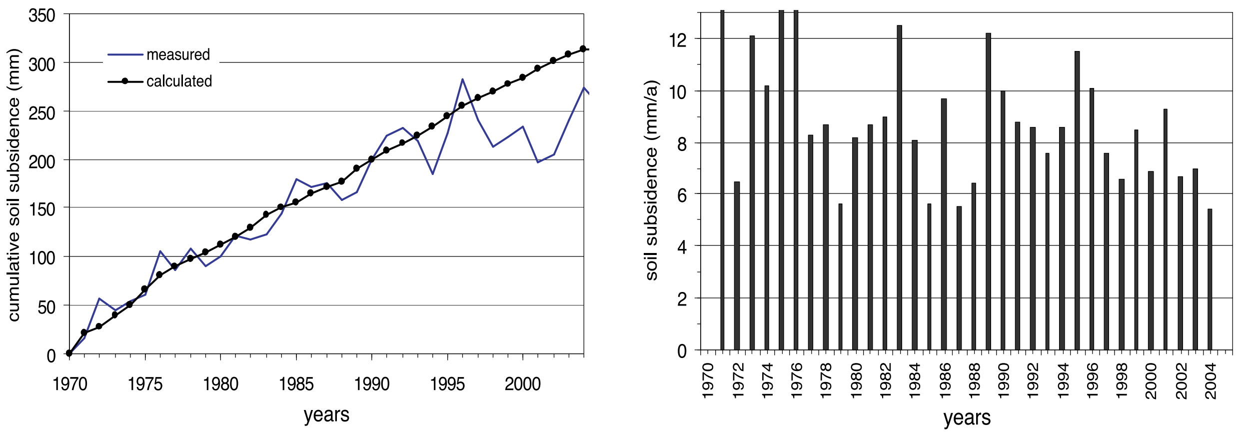

Figure 1. A (left) Measured and calculated cumulative soil surface subsidence for the period 1970 -2005; B (right) calculated subsid ence per individual year showing the effect of differences in governing conditions (temperature, precipitation, evapotranspiration, hydrological conditions)

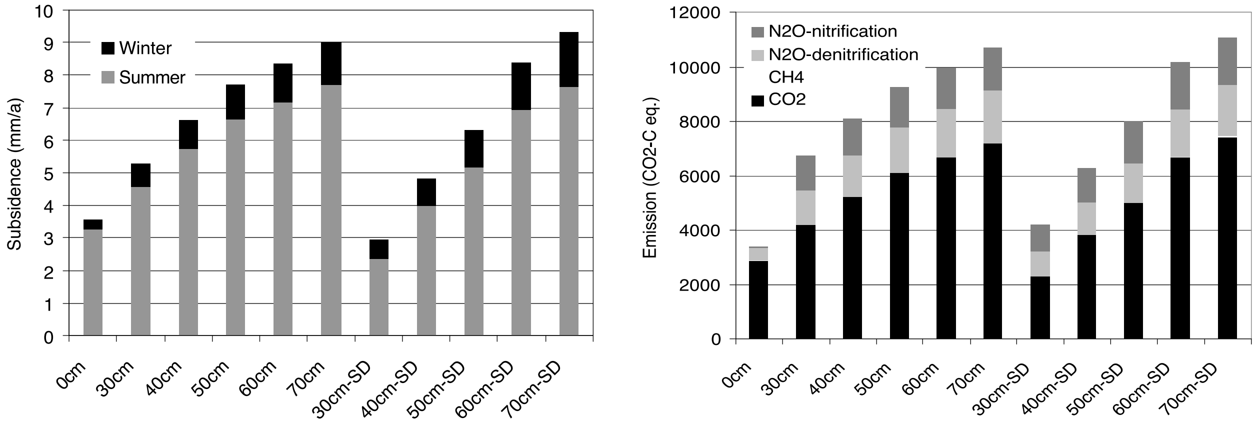

Figure 2. Effects of water management measure s on: A (left) subsidence and B (right) Greenhouse Gas emission. 30cm = ditchwater level 30 cm below soil surface, 30cm -SD = ditchwater level 30 cm below soil surface with submerged drains.

scenario results to almost doubling of subsidence and GHG emission at the end of this century, mainly as a result of temperature rise. With this prospect, submerged drains may be crucial for reducing the negative effect s of global climate change.

To assess the environmental effects of water management scenarios, their effects on nutrient loading of the surface water were studied. Figure 3 depicts that the contribution of fertilization to the N- and P-loading increases with rising of the ditchwater level. The contribution of the peat soil (mineralization and leaching out of the N- and P-rich peat soil complex) decreases with rising ditchwater level, strongly for P and slightly for N. The overall effect is the highest N-loading with the highest ditchwater level, and the highest P-loading with the lowest ditchwater level.

In the case of submerged drains the same counts. Shallow drains draw off N and P from fertilizers, while deep drains (below mean lowest groundwater level) draw off N and P from N and P rich layers deeper in the peat profile. For N the first process prevails and for P the second. The optimal scenario is a ditchwater level of 50 cm below ss with a drain at 60 cm below ss. Also for other ditchwater levels the optimum drain depth is around 50-60 cm below ss with similar N - and P-loading as scenario '50cm-SD'.

Conclusions

In the simulations, raising ditchwater level from 70 cm below ss to soil surface level reduces subsidence and GHG emission with a factor 2.5-3.Raising ditchwater level from 70 to 30 cm below ss yields a decrease of about 40%. Increase of CH_4-emission is always negligible. Submerged drains advance the reduction of soils surface subsidence and greenhouse gas emission considerably. Submerged d rains at spacing of 4-8 m and at depth of 10 cm below ditchwater level yield reductions of subsidence and GHG emission of 25%-45% for shallow ditchwater levels (30 and 40 cm – ss). For intermediary levels (50 cm – ss) this effect is less (15%) and for deeper levels even slightly negative (increase of 3-5%).

From the point of view of diminishing disappearance of peat and GHG emission, the best scenario is to raise ditch water level to soil surface. Even for the highest ditch water level, submerged drains still contribute extra to this effect.

Besides the positive (diminishing) effects of submerged drains on subsidence and greenhouse gas emission, the drains also promote favorable conditions for agricultural use because of the enhanced drainage by the drains. As a consequence of this, agricultural practice is possible with higher ditchwater levels than commonly used.

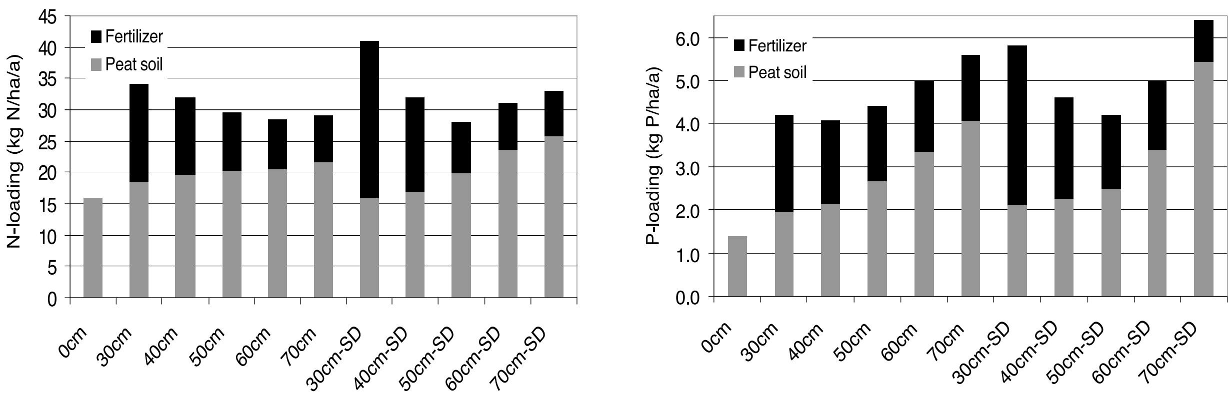

Figure 3. Effects of water management measures on: A (left) N-loading of the surface water and B (right) P-loading of the surface water. 30cm = ditchwater level 30 cm below soil surface, 30cm -SD = ditchwater level 30 cm below soil surface w ith submerged drains.

The higher the ditchwater level, the greater the loading of surface waters with nutrients from fertilizers. Submerged drains at shallow depths in combination with high ditch water level s promote this N- and P-loading from fertilizers strongly.

Drains installed below the mean lowest groundwater level will drain the permanently saturated zone of the peat profile where often high concentrations of ammonium and phosphate occur. At these depths, submerged drains will increase N- and P-loading substantially.

From the point of view of N- and P-loading of the surface water, there is an optimum drain depth. In the simulations this depth is around 50-60 cm below ss. In other peat areas this optimum may be different, depending on soil profile and hydrological conditions.

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