CO_2 EMISSIONS OF PEAT SOILS IN AGRICULTURAL USE: CALCULATION AND PREVENTION

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Abstract

About 9% of the area of the Netherlands is covered by peat soils (about 290,000 ha), mainly drained and in use for dairy farming (about 223,000 ha). Decomposition (oxidation) of peat soils used in dairy farming causes subsidence rates of 12 mm.y^{-1} The objective of the research was to develop a method to calculate from subsidence the CO_2 emissions of peat soils in agricultural use and to test the possibilities of submerged drains to raise groundwater levels and diminish subsidence and CO_2 emissions. One mm subsidence by oxidation equals a CO_2 emission of about 2.3 tons of CO_2 per year per hectare. We calculated that about 3% of the annual anthropological CO_2 emission in the Netherlands can be accounted to the oxidation of peat soils. This is about 4.2 Mton CO_2 per year. In dry summers the groundwater level lowers well below ditchwater levels, exposing easily biological degradable peat to oxidation. Raising groundwater levels up to ditchwater levels by subsurface irrigation by submerged drains with a spacing from drain to drain of 4 to 6 meters is tested as a possibility to reduce subsidence and CO_2 emissions. The experiments started in 2003. Subsidence and so CO_2 emissions proved to be reduced by more than 80%. A disadvantage of the use of submerged irrigation might be the increased water usage. Model calculations showed that the amount of inlet water increased on average up to 30%, however, intelligent water management can be a possibility to reduce the extra water usage to about 5%. The modeled reduction in subsidence (and so the CO_2 emission) was about 40% of the subsidence in the situation without submerged drains. We concluded that the use of submerged drains can reduce subsidence and CO_2 emissions with at least 50%.

Key words: peat soils; CO_2 emission; submerged drains, subsidence, oxidation, GHG emission

Introduction

Peat soils in the densely inhabited western part of the Netherlands are valued as an open landscape with a rich cultural history, which should be preserved. About 40 years ago a strong modernization and mechanization of dairy farming started. This required improvement of drainage conditions and bearing capacity of peat soils in agricultural use and therefore in large areas ditchwater levels were lowered several decimeters. The lowering of ditchwater levels caused a strong increase of subsidence of the peat soils. The major part of peat soils in the western part of the Netherlands is in use as permanent pasture with ditchwater levels up to 60 cm minus surface. Organic soils above groundwater level are exposed to the air and decompose. This causes a subsidence of 3 – 22 mm per year and emission of greenhouse gasses. In the Netherlands every 10 years ditchwater levels are lowered about 10 cm and so adapted to the subsidence. However, in this way also groundwater levels are lowered about 10 cm. In time the subsidence and particular the lowering of groundwater levels is causing a lot of problems. After lowering ditchwater and so groundwater levels several times, the upper part of wooden foundation piles are exposed to oxygen and start to rot. In this way subsidence causes damage to infrastructure and buildings. Because the subsidence is not the same everywhere, water management becomes ever more complex and expensive. Many wetlands become difficult to preserve as “wetland” because subsidence of adjacent drained agricultural land results in ‘islands of peat’ surrounded by lower elevation agricultural lands. The higher wetlands drain towards the lower agricultural land, become too dry and degrade. In a time with rising sea levels, it is also not wise to allow subsidence rates of one cm per year.

The problems caused by subsidence of peat soils together with the increasing interest in GHG emissions and eutrofication of surface waters by degrading peat soil was reason to start in 2003 the EU funded project EUROPEAT (QLK5-CT-2002-01835) with the aim to identify degradation processes of agricultural peat lands and find ways to diminish peat land degradation (Van den Akker et al., 2008, Van den Akker, 2010).

Subsidence rates of peat soils in agricultural use.

In Figure 1 relationships between subsidence rates and ditchwater levels and groundwater levels are presented.

Data was available from literature on ditchwater levels and on subsidence of peat soils in the northern part of the Netherlands and a set of data based on own measurements of ditchwater levels, groundwater levels and subsidence of 14 parcels in 5 locations during more than 30 years. The subsidence ranges from 3 to 23 mm and depends strongly on ditchwater and groundwater levels. Note the effect of a thin clay cover in Figure 1b. Due to the fact that this clay cover is not prone to oxidation, the subsidence is about 6 mm less than of a peat soil without a thin clay cover.

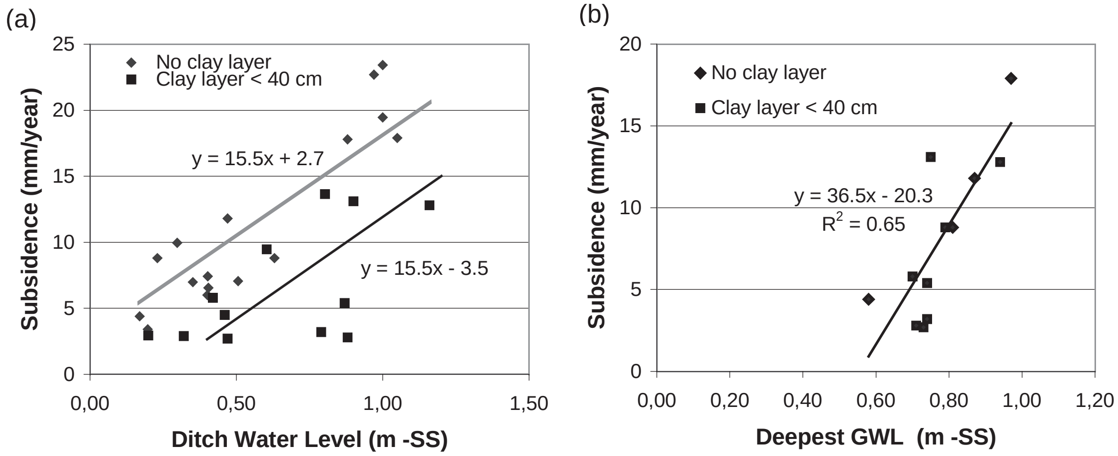

Figure 1. Derived relationships between (a) subsidence and Ditch Water Levels and between (b) subsidence and Deepest Ground Water Level (GWL) in meters below Soil Surface (m –SS). The Deepest GWL is calculated as the mean of the three deepest groundwater levels measured in 14 days intervals in the period 1992 – 1998 (Van den Akker et al., 2008).

In Figure 1b we combined the available data about subsidence and deepest groundwater levels of peat soils with and without a clay cover. We noticed that in dry summers the groundwater in peat soils with a clay cover did not lower as much as in peat soils without a clay cover. Due to this a relation between the combined subsidence data and the deepest groundwater level proved to result in the best fit. Note that raising the deepest groundwater level with just 0.1 m results in a decrease of the subsidence with 3.6 mm.

From Figure 1 we learn that water management is the key to conservation of peat soils. A logical solution to diminish the subsidence of peat soils is to raise ditchwater levels. However, this results in too wet conditions for an economic viable dairy farming, which is needed to maintain the important cultural historical landscape in the heart of the Netherlands (the so called Green Heart). A more effective way to raise groundwater levels in summer without raising ditchwater levels could be subsurface irrigation using drainage tubes below ditchwater levels (see Figure 2). Figure 1b shows that raising of the deepest groundwater level towards a ditchwater level of e.g. 60 cm below the soil surface can reduce subsidence substantially.

Objective of the research

Research on infiltration of ditchwater via submerged drains to raise groundwater levels in summer to conserve peat land started end of 2003 in the EUROPEAT project. The aim was to halve subsidence and CO_2 emission in this way.

In this paper we focus on the calculation of CO_2 from the subsidence, the measurement of subsidence of peat soils with and without submerged drains, and so indirect of CO_2 emission, and on the expected extra supply of inlet water due to the improved infiltration by submerged drains.

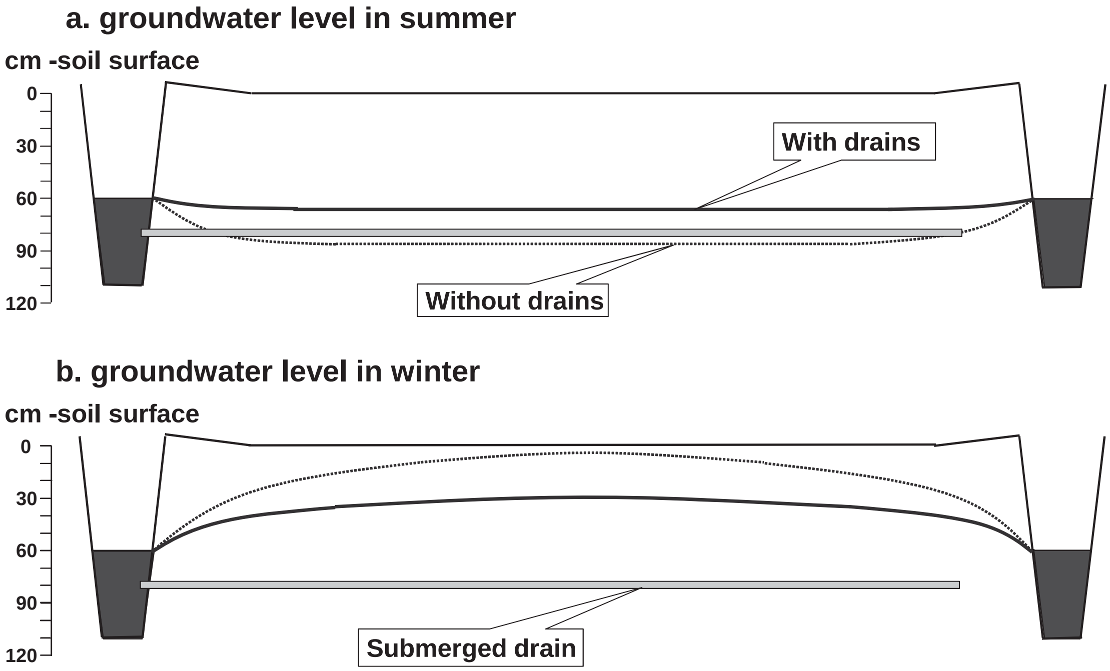

Figure 2. Raising groundwater levels by infiltration via submerged drains. In wet periods (e.g. in winter) the drains act as drainage. Distance between drains is typically 4 to 6 meters.

Methods, Measurements and Modeling

To test whether subsurface irrigation with drainage tubes will indeed reduce subsidence and so emission of CO_2 of peat soils, we started in autumn 2003 with installing submerged drains on two parcels (Zegveld 2 and Zegveld 3) on a fen peat soil without a thin clay cover. Distances between the drains were 4, 8 and 12 meter. As a reference in a part of the parcels no drains were installed. On Zegveld 3 we monitor already from 1970 on the surface level of the reference part of the parcel. The long term subsidence of Zegveld 3 is 10.8 mm per year. The ditchwater level is 55 cm below the surface level.

Determination of the reduction in subsidence

Starting in early spring 2004 the surface level was measured in three cross sections. In the reference the distance between the cross sections was 10 m. In the plots with submerged drains the cross sections were situated in the middle between two submerged drains. The measurements were performed in early spring, just before the grass starts to grow and to evaporate soil water. At that moment the swelling of the peat is at its maximum. In this way we avoid as much as possible that we measure subsidence due to temporally drying shrinkage of the peat, this can be more than 10 cm at the end of a dry summer.

Calculation of CO_2 emission from subsidence (Van den Akker et al., 2008)

According the United Nations Framework Convention on Climate Change the Netherlands has to report emissions of greenhouse gases periodically to the UNFCCC secretariat in Bonn in a national inventory. This should be based on internationally comparable methodologies, be public and transparent, include all sources and removals by sinks of all greenhouse gases. A specific source mentioned by the International Panel on Climate Change (IPCC) is the CO_2 emission caused by agricultural use of organic soils. Therefore a method was developed to calculate CO_2 emissions by agricultural use of peat soils (Van den Akker et al., 2008). We preferred the calculation of the CO_2 emission based on the subsidence of peat soils, because we consider this as a robust method. This consideration is based on the fact that the subsidence is usually measured over many years (sometimes decades) and this subsidence is in a long-term perspective mainly caused by a summation of oxidation and so CO_2 emission. The results of this method were successfully compared (Van den Akker et al., 2008) with direct measurements of CO_2 emissions and an earlier method based on subsidence, that only considers the upper 20 to 30 cm of the peat soil (Kasimir-Klemedtsson et al., 1997). Our method is accepted by the UNFCCC to calculate CO_2 emissions of peat soils in agricultural use as input for the National Inventory Report for the Netherlands.

The yearly CO_2 emission from the subsidence of peat soils has been calculated according to:

$$CO_{2,em} = F * S_{mv} \cdot \rho_{so} \cdot fr_{OS} \cdot fr_C \cdot \frac{44}{12} \cdot 10^4 \qquad (1)$$

where:

$CO_{2,em}$	=	CO_2 emission (kg CO_2 ha yr^{-1})
F	=	fraction subsidence due to oxidation of organic matter compared to total subsidence
S_{mv}	=	subsidence (m yr^{-1})
ρ_{so}	=	bulk density peat (kg m^{-3})
fr_{OS}	=	organic matter fraction peat (-)
fr_C	=	carbon fraction organic matter (-)

In equation (1) the parameters F, ρ_{so}, fr_{OS} and fr_C are generally related to the upper layers (upper 20 to 30 cm) of the peat soil. A major source of uncertainty is that the fraction F varies between 0.33 to 0.67 (Armentano and Menges, 1986). Therefore we developed another approach. We used a fraction $F = 1$ combined with values of ρ_{so}, fr_{OS} and fr_C of the fibric peat layer in the subsoil (at a depth of e.g. 120 cm). This approach is explained in Figures 3 and 4. A major advantage of this approach is also that ρ_{so}, fr_{OS} and fr_C of fibric peat (Von Post classification H1 – H3) depend mainly on the origin of the peat and that the variations in these values are small.

Modeling the subsidence and extra water supply

Scenarios with different water level strategies and climate scenarios were modeled with the SIMGRO regional hydrological model for the polder Zegveld. The analysis focused on water level control strategies, in combination with subsurface drains, with the aim of reducing subsidence and minimizing the water supply in dry periods. For more details see Querner et al., (2012). Scenario 1 is the current water management, the surface water level fluctuates with a margin of plus or minus 2 cm around the ditchwater target level of 60 cm below soil surface. When the water level margins are reached, water is pumped out respectively let in the polder. Scenario 2 is the current water management, however, with submerged drains and a target level of 50 cm. The target level of 50 cm is used to minimize subsidence. This is possible without problems for dairy farming because the drains will lower the groundwater level in wet periods and so reduce trampling and improve trafficability. Scenarios 3 and 4 can be compared with scenarios 1 and 2, however, the margins are plus or minus 10 cm around the ditchwater target level. This is a so-called flexible water regime, with the aim of reducing water movement in and out of a polder.

Further an optimal scenario O was formulated for a situation with drains. This optimal scenario O anticipates on a weather forecasting of 5 days. As much as possible a margin of 2 cm is kept. However, depending on the groundwater level and the weather forecast this margin can become 10 cm above or below the target ditchwater level of 50 cm below soil surface.

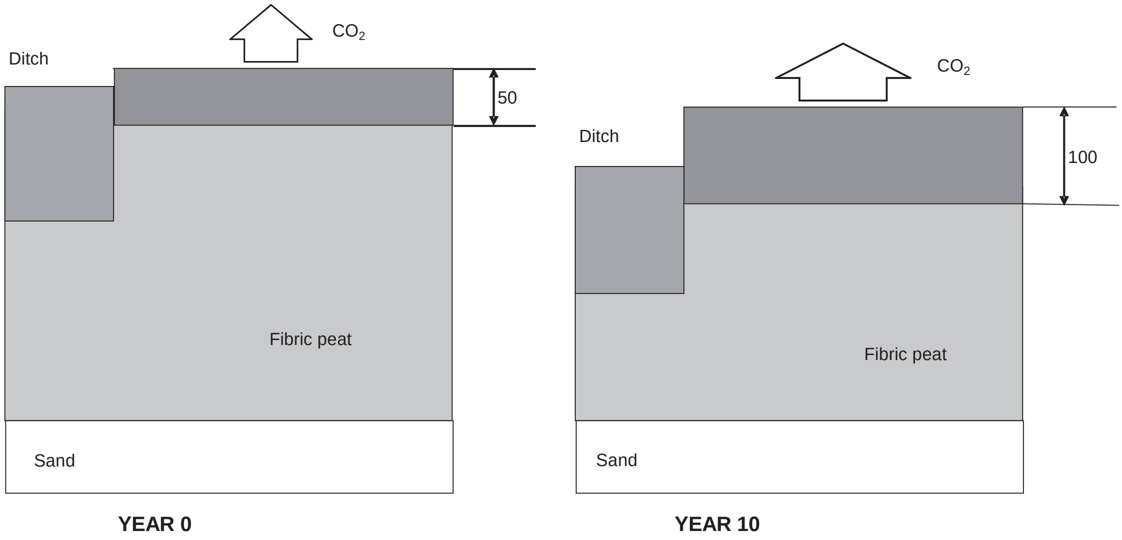

Figure 3. A schematic presentation of subsidence of peat soils in the first 10 years after drainage of a peat soil. A thick peat layer is situated above a mineral layer. Before the ditchwater levels are lowered the upper humic and mesic peat layer has a thickness of about 50 cm and the subsidence is then mainly caused by oxidation and is low. The deepest groundwater level is about 50 cm. After lowering of the ditchwater level subsidence accelerates and it takes several years before the subsoil is consolidated and the topsoil is (partly) humified by shrinkage and oxidation. From then on subsidence is mainly caused by oxidation. The deepest groundwater level is about 100 cm.

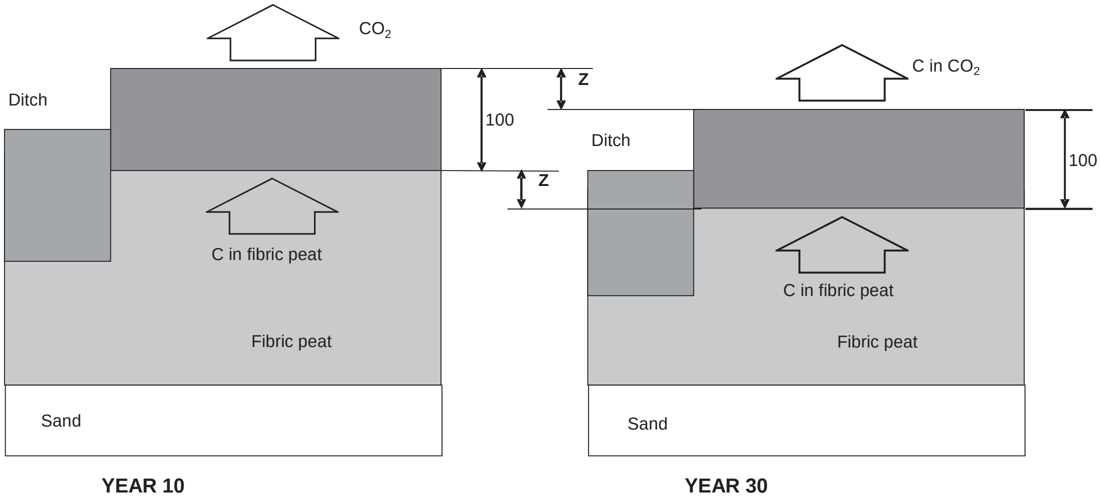

Figure 4. The next 20 years are considered. From time to time ditchwater levels are adapted to the subsidence. In 20 years the total subsidence is z cm. In this period the layer of fibric peat got z cm thinner, which is added to the top layer of humic and mesic peat above it. In this way there is an inflow of C into the top layer from below and an outflow of C as CO2 to the atmosphere above the top layer. Considering that in time subsidence is almost completely driven by peat oxidation, this means that inflow of C is equal to outflow of C. Considering long periods this is not completely true due to accumulation of mineral parts and very stable organic components.

Results and Discussion

Subsidence measurements

The results of the altitude measurements on Zegveld 3 are presented in Figure 5. The subsidence in the period 2004 – 2012 is strongly influenced by the fact that 2003 was a very dry year and that the summers in the period 2004 – 2012 were all moderately or very wet. This means that the soil was not completely rewetted and swollen in spring 2004 and had a potential of swelling in the following moderately or very wet years. These specific circumstances resulted in a subsidence rate of the reference of just 3.3 mm per year, while the long term subsidence is 10.8 mm.

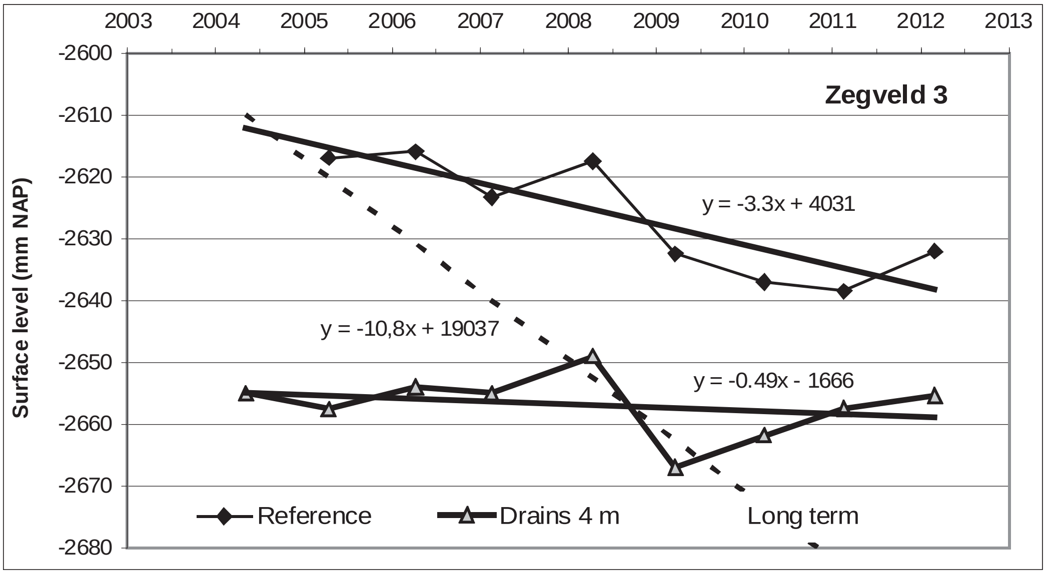

Figure 5. Subsidence 2004 – 2012 of peat soil without submerged drains (Reference) and with submerged drains at a distance of 4 meters (Drains 4 m). The long term subsidence is 10.8 mm per year. NAP = the Dutch national reference level, which is about the average sea water level.

The effect of the large swelling potential after the dry year 2003 becomes also clear in the situation with drains at a distance of 4 meter: the subsidence rate is just 0.5 mm per year and in spring 2008, after the very wet year 2007, the level of the soil surface is even higher than in spring 2004. It is clear that the subsidence rate of the reference is many times higher than the subsidence rate of the parcel area with drains at distances of 4 meter. This in agreement with the results of Zegveld 2, with subsidence rates of 6.1 and 1.3 mm per year of respectively the reference and the parcel area with drains at distances of 4 meter.

Calculation of CO$_2$ emission from subsidence

We considered a peat soil of the experimental farm "Zegveld" in the Netherlands with $\boxtimes_{so}$ = 140 kg m^{-3} , fr_{OS} = 0.80 and fr_{C} = 0.55 of the fibric peat soil at a depth of 1.2 m. These values are very common for eutrophic peat soils in The Netherlands. Using our approach with the values of the fibric peat subsoil in equation (1) with a fraction *F* = 1 results in an emission of 2259 kg CO$_2$ ha^{-1} yr^{-1} per mm subsidence.

An unknown factor in equation (1) is the subsidence. However, ditchwater levels are rather well registered in the Netherlands. So, with the relationships between ditchwater level and subsidence in figure 1 the subsidences of all Dutch peat soils in agricultural use were estimated and used to calculate the CO$_2$ emission with equation (1). This resulted in a calculated emission of 4.25 Mton CO$_2$ per year for the agricultural peat soils in the Netherlands. Per ha this is about 19 ton CO$_2$ per year. The total CO$_2$ emission per year by oxidation of peat soils is equivalent with the CO$_2$ emission of 1.7 million cars and is about 2.5 % of the national anthropological CO$_2$ emission of the Netherlands.

Table 1. Results of scenario calculations of peat soils without a thin clay cover. Scenario 1 is the reference scenario and the basis of the calculation of increase of inlet and subsidence.

Scen.	Water management	Drains	Target water level (cm)	Margin	Inlet summer (mm/y)		Calculated subsidence (mm/y)	
				(cm)	Inlet	Increase	Subsidence	Decrease
1	Current	No	60	+/- 2	116		10.7	
2	Current	Yes	50	+/- 2	155	39	6.2	4.5
3	Flexible	No	60	+/- 10	85	-30	11.7	-1.0
4	Flexible	Yes	50	+/- 10	113	-3	7.5	3.2
O	Optimal(1)	Yes	50	+/-10	122	7	6.4	4.3

(1) optimal = optimal reduction of subsidence <u>and</u> the amount of inlet water in summer.

Extra water supply

In Table 1 the results are presented of the water management scenario study. The use of drains combined with raising the target ditchwater level with 10 cm results in an extra water supply of 39 mm. This is an increase of about 30%. In an average year this will not be a problem, however, in a real dry year every extra mm inlet counts. Increasing the margins up to 10 cm results in a significant reduction of inlet water. This effect of the flexible water management regime can compensate completely the extra inlet required by submerged drains, however, on costs of the subsidence. The optimal scenario O indeed combines a very modest increase of inlet water with a strong reduction of subsidence.

Note that the effect of submerged drains on subsidence as calculated in Table 1 is much less than was measured in Figure 5. Probably the calculated values are conservative.

Conclusions

The effect of the very dry year 2003 and the wet summers of 2004 – 2012 on the subsidence rate was very pronounced and therefore a longer period of monitoring is recommended. Nevertheless the results are convincing and the use of submerged drains to minimize subsidence is very promising. Probably the aim to halve the subsidence and CO_2 emission can be fulfilled easily.

The extra inlet of water in summer can be a serious problem in very dry summers. Optimum water management regimes can reduce the problem, however, this problem requires more attention and research.

The calculated subsidence with the water management model is probably too high in the scenarios with submerged drains. In this model the use of submerged drains combined with a 10 cm higher ditchwater level results in about 40% reduction of the subsidence. We think this is too conservative.

Altogether we expect that the use of submerged drains is an effective way to diminish subsidence and emission of CO_2 of peat soils in agricultural use by at least 50%. This means that in the Netherlands the use of submerged drains in peat soils in agricultural use can decrease CO_2 emission with 2.1 Mton, which is more than can be sequestrated in all other Dutch agricultural soils together.

Farmers are firmly opposing the raising of ditchwater levels, however, are positive about the use of submerged drains for subsurface irrigation. Raising ditchwater level reduces trafficability and increases the risk of trampling by cows, while the use of submerged drains has the opposite effect. Farmers also appreciate the fact that the use of submerged drains makes farm management easier and reduces the problems in case of long wet periods. The government of The Netherlands aims to reduce subsidence and GHG emissions of peat soils and is therefore planning to subsidize 50% of the costs of submerged drains. These costs are about € 1600. Therefore we have good hope that submerged drains will be widely adopted in practice.

References

Armentano, T. V. and Menges, E. S. 1986. Patterns of change in the carbon balance of organic soil wetlands of the temperate zone, *J. Ecol.*, **74**, 755–774.

Kasimir-Klemedtsson A., Klemedtsson L., Berglund K., Martikainen P., Silvola J. and Oenema O. 1997.

Greenhouse gas emissions from farmed organic soils: a review. *Soil Use and Management 13*, 245-250.

Querner, E.P., P.C. Jansen, J.J.H. van den Akker and C. Kwakernaak, 2012. Analysing water level strategies to reduce soil subsidence in Dutch peat meadows. Journal of Hydrology, accepted.

Van den Akker, J.J.H., 2004. EUROPEAT: a European project to develop tools and scenarios for sustainable management of agricultural peat soils to protect associated landscapes and natural areas. In: Päivänen, J. 2004 (ed.). Wise Use of Peatlands. Proceedings of the 12th International Peat Congress. Tampere, Finland 6-11 June 2004. Volume 1, 817-822

Van den Akker, J.J.H., 2010. Introduction to the special issue on degradation and green house gas emissions of agricultural managed peat soils in Europe. Geoderma 154, 171–172

Van den Akker, J.J.H., P.J. Kuikman, F. de Vries, I. Hoving, M. Pleijter, R.F.A. Hendriks, R.J. Wolleswinkel, R.T.L. Simões and C. Kwakernaak, 2008. Emission of CO_2 from agricultural peat soils in the Netherlands and ways to limit this emission. In: Farrell, C and J. Feehan (eds.), 2008. Proceedings of the 13th International Peat Congress *After Wise Use – The Future of Peatlands, Vol. 1 Oral Presentations, Tullamore, Ireland, 8 – 13 June 2008.* International Peat Society, Jyväskylä, Finland. ISBN 0951489046. pp 645-648