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Electing Cropland Management as an Article 3.4 Activity under the Kyoto Protocol

Considerations for Norway

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Sammendrag:.Innen utgangen av 2006 må Norge beslutte om de ønsker å velge å få kreditter for 3.4-aktiviteter under Kyoto-protokollen. Tiltak i jordbruket er en opsjon for slike aktiviteter. Valg av jordbruksaktiviteter må ta hensyn til potensiell gevinst i form av opptak av karbon i jord, men også synergier og konflikter med andre mål inkludert erosjonskontroll, biodiversitet, bevaring av kulturlandskap og matproduksjon. Skogplanting på dyrkede myrer vil kunne føre til reduserte CO_2 og N_2O-utslipp på lengre sikt, men denne aktiviteten faller inn under artikkel 3.3 (tilskoging) og kan ikke velges under artikkel 3.4.. Restaurering av dyrkede myrer tilbake til naturtilstanden (våtmark) og naturlig degradering vil også redusere utslippene av CO_2 og N_2O på lang sikt (over flere tiår) men metan-utslippene vil øke. Denne økningen kombinert med stor usikkerhet med hensyn til utslipp fra restaurerte og dyrkede myrer er det viktigste argumentet mot slik restaurering som klimatiltak. Satsing på dyrking av energivekster kan gi gevinster i form av binding av karbon i jord

Effekten av tiltak i jordbruket innen 2012 (utgangen av første forpliktelsesperiode) er imidlertid små. Valg av jordbruksaktiviteter vil kreve bedre overvåkning av karbon i jord og utslipp av klimagasser som medfører store kostnader. I lys av de små gevinstene, store usikkerheter, mulig økning i utslipp av klimagasser og konflikter med andre miljø- og jordbrukspolitiske mål samt overvåkingskostnader, er det lite hensiktsmessig å velge jordbruksaktiviteter for første forpliktelsesperiode. Valg i senere forpliktelsesperioder forutsetter bedre kunnskap.

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Abstract: By the end of 2006, Norway will need to decide whether to seek credits for 3.4 activities under the Kyoto Protocol, of which Cropland Management is one option. Electing cropland management as an Article 3.4 activity requires consideration not only of benefits in terms of greenhouse gas mitigation, but also synergies and conflicts with other environmental and agriculture policy goals like erosion control, biodiversity, protection of farmed landscapes and food production. Afforestation of farmed organic soils (peatlands) will have a substantial benefit in reducing CO_2 and N_2O emissions in the longer term, but is not eligible under Article 3.4 (as it would fall in under Article 3.3, Afforestation). Restoration of farmed peatland to its original state and natural conversion will also reduce emissions of CO_2 and N_2O in the longer term (time scale of decades), but CH_4 emissions will increase. This increase in methane emissions and current uncertainty associated with all fluxes of emissions are the key arguments against such restoration as a climate mitigation measure. Energy crops will sequester carbon in soil.
The climate and carbon credit benefits until 2012 would be small. Electing to undertake cropland management will require improved monitoring of soil organic carbon and greenhouse gas emissions, which can be costly. In light of small benefits and conflicts like increases in non-CO_2 emissions and other environmental and agriculture goals as well as anticipated monitoring costs, electing cropland management for the first commitment period is not feasible. Cropland management as a mitigation strategy in future commitment periods would require better knowledge.

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1 Summary

The decision to elect 3.4 Activities under the Kyoto Protocol must take into account not only the carbon credits, but also uncertainties, increases in emissions of non-CO_2 greenhouse gases (GHG), monitoring and data collection costs and tradeoffs/synergies with other objectives (e.g. environmental and food productions) and necessary incentives.

In general, the soil sampling undertaken in Norway is not of sufficient frequency and spatial resolution to monitor the soil organic carbon in a piece of land over the commitment period and relative to 1990. Enhanced sampling combined with better modelling would be needed for this purpose. In principle, data for 25-30 years prior to 1990 are also needed to obtain an accurate estimate of changes after 1990. Furthermore, given election of an activity, improved estimates of flux gases (methane (CH_4) and nitrous oxide (N_2O)) would be necessary. Because monitoring is costly, improvements would only be cost-effective if the credits are high. The lack of data prior to 1990 means that if Norway elects cropland management, it would need to report conservative estimates for 1990 (and credits would be reduced accordingly). For some mitigation options this problem may not be a real obstacle.

The following options have been considered:

Management of cultivated peat soils
Pristine boreal peatlands are natural emitters of CH_4 but at the same time sequester substantial amounts of carbon dioxide (CO_2), while the nitrous oxide emissions are negligible. Drainage and cultivation profoundly modifies the greenhouse-gas budget of peatlands. CH_4 emissions are drastically reduced, while CO_2 and N_2O emissions to the atmosphere increase substantially. There are large uncertainties in the estimates of emissions prior to drainage, after drainage and after implementation of mitigation measures.

Options for decreasing greenhouse gas emissions from cultivated peat soils:

Change in crop: Drained peatlands most likely emit less greenhouse gases with grass cover than if they are converted to cropland. Although conversion of row crops to grass cover could still bring substantial GHG emission savings per unit land area, the total capacity of reducing GHG emissions is limited because the potential surfaces of row-crop fields are very limited.

Restoration: Restoration of drained peatlands to their original water-logged status raises the risk of drastically increasing methane fluxes, and this is the main argument against using this mitigation option. How much land would be suitable for restoration has not been assessed here, but clearly this option would require considering associated issues in terms of food production, settlement policies, agricultural landscapes and the need for incentives. If the agriculture area nevertheless is reduced as a result of agriculture policies, restoration of mire-type ecosystem might be more desirable than forest growth on drained organic lands, in places where landscape quality is an issue.

Afforestation: Afforestation appears to be the best solution for minimizing greenhouse gas emissions from formerly cultivated peatlands, mostly because of the large carbon storage potential of the tree biomass.[1] This option can be in conflict with goals for preserving agricultural landscapes. In addition, cultivated soils are spatially patchy and might be difficult to manage as productive forests.

If management of cultivated peat soils is elected as a form of cropland management, improved monitoring would be required, including recommended improvements in the method to estimate emissions of N_2O.

[1] This option would fall under Article 3.3 afforestation and is therefore not eligible as a 3.4 activity.

Erosion control
This includes crop rotation, use of catch crops, reducing bare fallows, planting of more legumes, de-intensification and tillage residue management. Incentives to implement measures are currently in place as part of agriculture policy to reduce runoff of nutrients. This has resulted in changed management and subsequent carbon sequestration since 1990.

Current estimates of removals are highly uncertain and conservative due to lack of data on historical land use. The latter (and historical soil organic matter) will be impossible to obtain retrospectively. Election of erosion control as an Article 3.4 mitigation option would require better soil monitoring, and the costs appears too high compared to the potential. This mitigation option will also be saturated after 20-25 years. Measures to reduce erosion will modify N_2O emissions from soils, and both increases and reductions (such as resulting from de-intensification measures) are possible. This effect should be considered if this activity is elected. The synergies with the goal of reduced erosion and nutrient runoff are high for this option.

Reduced use of lime
Application of lime has been reduced since 1990. Further reduction in lime application would have to be balanced against losses in agriculture production. The overall mitigation potential is nevertheless small, and given the principle of net-net accounting, article 3.4 credits are even smaller. It should not be necessary to implement additional monitoring if this mitigation option is elected as an Article 3.4 activity, but data on lime application would need additional verification and data are not spatially explicit.

Land-use (cover) change – cropland to grassland
The exact potential is not known, but it is unlikely that the potential is sufficiently large to defend the monitoring costs (enhanced soil sampling). It should also be considered that increased grassland area would be associated with higher meat production, which would imply increased methane emissions. Furthermore, this option would require structural changes and therefore strong incentives from the government.

Horticulture and energy crops
Compared to “traditional” agriculture, horticulture will change the above-ground and soil biomass and will sequester biomass carbon in woody stands until they reach maturity and in soil organic carbon for a longer period. This option would require structural changes and therefore strong incentives from the government. Monitoring costs are likely to be relatively small, but better sampling of soil organic carbon and above ground biomass is recommended.

Increased cultivation of energy crops can sequester more CO_2 than traditional agriculture until it reaches saturation. Energy crops are fast growing and have a short-term mitigation effect. The plantation of energy crops, such as salix, in lieu of food crops is likely to result in substantial carbon storage in the soil, as organic matter and root biomass. Increased cultivation of energy crops can also be in line with other climate policy goals with respect to more use of bioenergy and therefore indirectly contribute to higher reductions in greenhouse gas emissions than sequestration. Although for some species this option can be in conflict with the goal of preserving traditional farmed landscapes, it is likely much less so than afforestation. There is currently no data for Norway on exactly how much carbon sequestration that will result from this crop growth. The synergy with goals for increased use of bio energy is high.

Conclusion

None of the mitigation options will result in sizable benefits up to 2012 because processes are slow, incentives are not in place and implementation is practical only in limited areas. Some of the measures will be saturated shortly after 2012, while others can have large benefits in the longer term. Taking into account lack of monitoring data for 1990, the costs of building up necessary monitoring for the period 2008-2012, the need for strong incentives, and conflicts with other goals, cropland management is not feasible as an elected Article 3.4 activity for the first commitment period. Targeted research projects would be necessary to reduce uncertainties as required for implementation of efficient mitigation measures and for possible election of cropland management in future commitment periods. Election in future commitment periods should be considered at an early time due to the slow changes in biological system and necessary time to build up data series to comply with requirements for reporting and verification.

2 Introduction

Emissions and removals from land use, land-use change and forestry (LULUCF) under the Kyoto Protocol are reported separately from the main inventory. All Parties are committed to report and will be credited/debited for "human-induced land use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990" taking place in the commitment period (2008-2012). These are the so-called Article 3.3 activities and are often abbreviated AR and D.

A Party may also elect other activities (Article 3.4 activities as elaborated in the Marrakesh Accords[2]): forest management (FM), cropland management (CM), grazing land management (GM) and revegetation (RV). Special accounting rules apply for these activities. For FM there is a predefined cap for credits. The other Article 3.4 activities are credited on a net-net basis, meaning that annual average change in emissions and removals over the commitment period are calculated relative to the change in the base year. Election of an activity would mean an obligation to report on that activity also in subsequent commitment periods and receive credits/debits accordingly. Before the end of 2006, Norway will need to make a decision about whether to elect any 3.4 activities, including cropland management, and report this decision to the United Nation Framework Convention on Climate Change (UNFCCC).

Guidance for reporting emissions and removals from the Article 3.3 and 3.4 activities of the Kyoto Protocol is included in the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC 2004). Chapter 4 of that report specifically addresses reporting under the Kyoto Protocol, while relevant methodology guidance is also given in Chapter 3 as recommended for UNFCCC reporting.

The objective of this report is to present options for CM 3.4 Activities for Norway and arguments for and against electing these for the first commitment period.

[2] FCCC/CP/2001/13/Add.1

3 General factors to consider in electing 3.4 Activities

There are some general considerations to take into account when considering electing 3.4 activities (Smith 2005).

- Carbon benefits and their uncertainty ranges resulting from the adoption of each Article 3.4 activity;
- Risk of potential need to report carbon liabilities as a result of the adoption of each Article 3.4 activity;
- Monitoring/data collection and reporting costs;
- Trade-offs and synergies with other objectives, such as environmental or socio-economic considerations;
- The range off incentives (if any) that may be required to achieve the desired GHG reductions and other objectives.

According to Smith (2005), typical uncertainty ranges of mitigation options are around ±50%, although clearly this range is dependent on the quality of available data.

Potential benefits:
The maximum value of a mitigation potential has a biological upper limit, but will be further biologically and physically constrained in practice (for example due to land suitability). Furthermore, there will be additional economic and social/political constraints. The typical realistically achievable potential has been estimated at around 10% of the biological potential (Smith 2005).

It is important not to consider mitigation limited to carbon alone. If a land area has been elected, fluxes of CH_4 and N_2O also need to be estimated and included in the accounting. Consideration of these fluxes may change the picture of the efficiency of a mitigation option.

For the LULUCF sector it is also necessary to consider the time-horizon. Some mitigation options will only be efficient in the long term (and have only a small effect until 2012). On the other hand, some mitigation options (e.g. related to enhancing soil carbon) get saturated and will only have a benefit up to 20-25 years after implementation.

Monitoring/data collection costs:
In general the soil sampling undertaken in Norway is not of sufficient frequency and spatial resolution to monitor the soil organic carbon in a piece of land over the commitment period and relative to 1990. Enhanced sampling combined with better modelling would be needed for this purpose. In principle, data for 25-30 years prior to 1990 are also needed to obtain an accurate estimate of changes after 1990. This problem may, however, in practice not be an obstacle for all mitigation options. Furthermore, given election of an activity, improved estimates of flux gases (CH_4 and N_2O) would be necessary. This can require measurements. The monitoring/data collection costs have only been considered qualitatively in this report and data specific for Norway have not been included.

The following rules of thumb are taken from Smith (2005) with respect to sampling needed to detect a certain amount of carbon:

- 1 t C/ha over 5 years needs 100 samples costing $300-2000; C value = $55: never feasible
- >5 t C/ha over 5 years needs 16 samples, costs $48-320, C value = >$275: if sample costs are low, could be feasible

- >8.5 t C/ha over 5 years needs 12 samples costing $36-240, C value = $462.5: always feasible

A conclusion from this was that monitoring only is cost-effective with extremely high gains per ha.

The sampling costs per ha may be higher in Norway. However, a good sampling strategy with stratification with respect to soil type, climate and land management can help reduce the costs, although the potential is limited by the fact that agricultural areas in Norway in many areas are patchy and the country is climatically and geographically inhomogeneous. Thus, if an agricultural 3.4 activity is elected, the spatial allocation of elected activities needs to be carefully considered in light of monitoring costs. The sampling depth is a critical issue that would need to be addressed, and especially in the case of annual to perennial plant conversions (or the opposite) changes in the deeper soil carbon content will certainly not be negligible.

If CH_4 and N_2O emissions have to be monitored and included in the GHG budgets, then concomitant measurements of net CO_2 fluxes might not be so expensive, and might save on a lot of soil carbon inventories (although having both is always better). For modelling purposes, measured CO_2 fluxes provide a much better constraint to model estimates than carbon stocks, because of the much higher frequency of measurement: Over 5 years, you would have 1 data point for soil carbon, and about 250 000 data points from continuous CO_2 measurements with a technique such as eddy covariance. Similar methods are now being developed for N_2O and CH_4. A few well instrumented experimental sites are probably the only way to obtain a reliable CO_2, CH_4 and N_2O budgets corresponding to specific land-use changes.

Development of appropriate models can also help reduce monitoring costs. But again, as Norway is inhomogeneous, models may nevertheless be data intensive. A further analysis for each measure is needed to determine actual monitoring costs. Different costs and strategies would apply to organic soils (see below).

Tradeoffs/synergies to consider in election of an activity include associated changes in

- Productivity
- Biodiversity
- Run off/leakage of nutrients
- Soil acidification
- Livestock welfare
- Emissions of greenhouse gases
- Ammonia emissions
- Water quality

Incentives

Norway has over many years used economic incentives to enhance environmental performance in farms. This has been used extensively to reduce erosion losses (e.g. to reduce autumn till). In addition, it is possible to use legal incentives and ban certain practices. Entrance into WTO sets restriction on use of certain incentives.

It is also important to take into consideration that some changes in agriculture may occur without specific incentives. Examples are abandonment of marginal agriculture areas (e.g. on farmed peatlands). Furthermore, Norway may want to shift agriculture production in the direction of energy crops as a part of its energy policy.

4 Mitigation options in Norway

Below we list and discuss benefits, tradeoffs and monitoring requirements for each theoretical option for electing agricultural 3.4 activities.

There are also "Cropland Management" mitigation options that cannot be elected as 3.4 activities since the targeted sources are listed in Annex A of the Kyoto Protocol. The most important are related to fertilizer application and manure management. Nutrient management includes fertilizer placement, timing, precision farming, and fertilizer free zones. Nutrient management may influence N_2O emissions as well as soil organic content.[3] It is expected that reduced fertilizer use reduces N_2O emissions, while CO_2 emissions can increase (IPCC 2004). The uncertainty of effects of measures will be very high, as the effect depends on factors like moisture, temperature and soil quality, and there are few data and no suitable models available for Norway. All farmers are obliged to plan their fertilizer use and are informed about optimal use. There is, however, no reporting or control of its implementation. In addition there are voluntary implementations of quality systems. Good systems have proven to reduce fertilizer use. Due to the associated decrease in production and reduced soil organic carbon it is not expected that nutrient management will have a large potential as a mitigation option. At present, uncertainties related to the effect of measures are high.

All manure produced in Norway is used as a nutrient source. Better techniques for application can increase efficiency. However, there can be a tradeoff between N_2O and ammonia emitted, and the uncertainties are large.

4.1 Management of cultivated peat soils

Pristine boreal peatlands are natural emitters of CH_4 but at the same time sequester substantial amounts of CO_2, while the nitrous oxide emissions are negligible (Kasimir-Klemedsson et al. 1997). Drainage and cultivation profoundly modifies the greenhouse-gas budget of peatlands. On the positive side, CH_4 becomes oxidized in the aerobic surface soil layer created by drainage, and therefore CH_4 emissions are drastically reduced. On the negative side, the organic peat material undergoes rapid mineralization, which results in substantial emissions of CO_2 to the atmosphere. In addition, drainage and fertilization associated with cultivation can greatly enhance N_2O emissions (Freibauer et al. 2004).

The extent of areas of drained and cultivated organic soil has been estimated at about 85,000 ha. The area has in the Norwegian reporting to UNFCCC been assigned to two different land use classes: 90% has been considered to belong to the category "grassland" (used for fodder production), while the rest has been assigned to "cropland" (Table 1). Of the 76,500 ha of grassland, 1/3 has been considered highly organic, expecting a loss factor of 10 Mg C/ha/year. For mixed organic soils the factor would be lower, applying a factor of 5 Mg C/ha/year.

[3] The latter will not be reported if CM is not elected, but should nevertheless be considered.

Table 1 Estimates of areas of different crop categories on peat soils, based on the distribution of soil samples.

	Hectares	%
Grass and parks	55 160	87.6
Row crops	506	0.8
Cereals and green fodder	7 288	11.6
Sum	62 953[4]	100

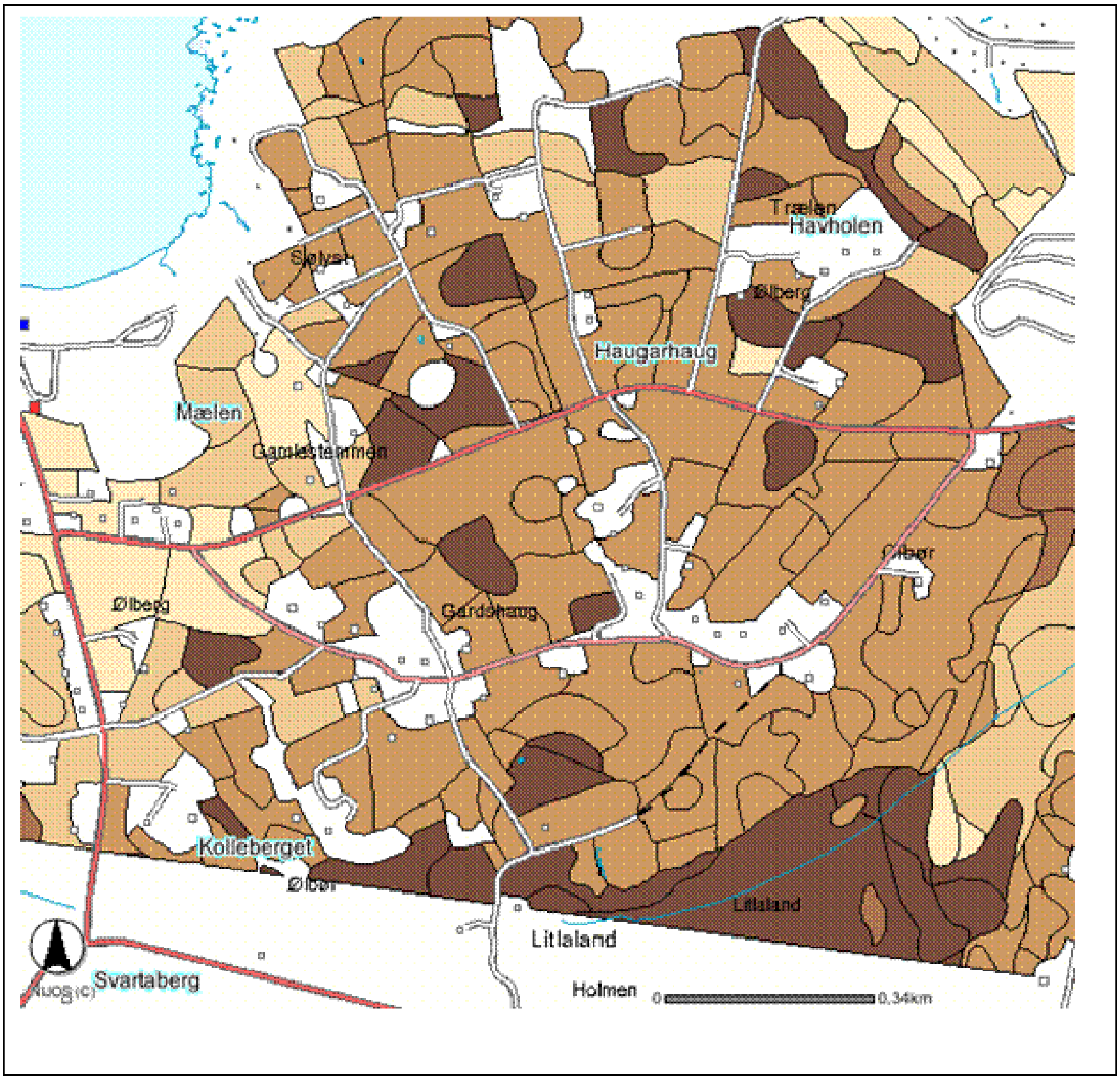

Figure 1 Example of Norwegian soil type map. Areas with high contents of organic matter are shown in dark brown (Norsk institutt for skog og landskap)

[4] The actual area is larger than this. 85 000 ha was assumed in NIJOS (2005).

According to NIJOS (2005), emission of CO_2 from grassland and cropland on organic soil is the most important individual net source of emissions within the LULUCF sector. Estimates of greenhouse gas emissions from peatlands are highly variable and appear to depend on the type of peatlands and on environmental conditions. Although the response of peatlands to drainage and cultivation in terms of GHG emissions also appears highly variable, consistent patterns have emerged throughout several studies. Drainage and cultivation increases the GHG emission of peatlands by an estimated 10 Mg to 30 Mg CO_2-equivalent[5] ha^{-1} y^{-1} (Nykanen et al. 2005). Most of this negative effect on GHG emission is due to the release of CO_2, while increased N_2O emissions and decreased CH_4 emissions would roughly cancel each other out.[6]

The observed peat subsidence has been used as an indicator of carbon loss from cultivated peat. It should be noted that peat subsidence results not only from carbon loss but also from compaction of the peat layer. Therefore, translating subsidence rates into carbon losses requires data on initial and final bulk densities and carbon concentrations throughout the entire depth of the peat soil profile.

In Norway, the mean annual subsidence has been calculated to be 2 cm from grass production and 4 cm from production of row crops like carrots and potatoes (Sorteberg 1983; Hovde 1987; Frøseth and Celius 1991). No data from Norway exists about peat subsidence from other crops than grass and row crops. It can be assumed that the losses from cereal and green fodder production are somewhat intermediate to the losses from grass and row crops. When considering carbon losses from drained peatlands with different crops, the area of each crop type needs to be taken into account. Table 1 shows that most of the cultivated peat soils in Norway are used for grass production, and that the area of row crops (potatoes and carrots) is estimated to represent less than 1% of cultivated peat area.

This large estimated emission of greenhouse gases from cultivated peatlands has led to the idea that peatland "restoration" could significantly contribute to meeting the Kyoto Protocol commitments of Northern countries (Neufeldt 2004; Freibauer et al. 2004). In Germany, it was estimated that peatland restoration could decrease GHG emissions from 1 to 12 Mg CO_2-equivalent ha^{-1} y^{-1} (Neufeldt 2004). A similar reduction in GHG emission of about 6 Mg CO_2-equivalent ha^{-1} y^{-1} was estimated across Europe (Freibauer et al. 2004).

What is the best management strategy for maximizing the decrease in greenhouse gas emission per unit area of formerly drained and cultivated peat lands? Conversion of crops to grass appears to be an option because the subsidence of peat from row crops has been observed to be twice the subsidence from grass. Indeed, drained peatlands have been reported to emit less greenhouse gases with grass cover than with crops (Kasimir-Klemedsson et al. 1997). Crop-to-grass conversion should theoretically reduce emission by an equivalent amount of CO_2 as emitted by grass-planted peatland, i.e. 6000 kg C ha^{-1} y^{-1} in our case (which is equal to 22 Mg CO_2 ha^{-1} y^{-1}). In addition, N_2O emissions from drained peatlands were reported to be 2 Mg CO_2-equivalent m^{-2} y^{-1} higher from crops than from grass cover. Nevertheless, greenhouse gas emissions from drained grass-planted peatlands remain high (Grønlund 2005). In addition, perennial grasslands do not appear better than annual grass covers at reducing GHG emissions from peatlands (Kasimir-Klemedsson et al. 1997). Although conversion of row crop to grass cover could still bring substantial GHG emission

[5] A common basis is needed to express and compare the climate effect of CO_2, CH_4 and N_2O: the GWP which converts all gases into CO_2 equivalents. The GWP per unit of CH_4 and N_2O are 21 and 310 times that of CO_2, respectively (IPCC 1996). Here, we will report all GHG emissions exclusively as CO_2-equivalents.

[6] This decrease in CH_4 emissions is not allowed accounted for when reporting under the Kyoto Protocol.

savings per unit land area, the total capacity of reducing GHG emissions is limited because the potential surfaces of row-crop fields are very limited (Table 1).

Restoration of drained peatlands to their original water-logged status raises the risk of drastically increasing methane fluxes, and this is the main argument against using this mitigation option. A shallow drainage could be a possible option to create a thin aerated surface layer that would promote CH_4 oxidation while remaining hospitable to grass plant growth. The cost of a drainage system with 0.2 m depth and 2-5 m distance can roughly be estimated to 1000 – 5000 NOK per hectare. In addition come administrative and monitoring costs. How much land would be suitable for restoration has not been assessed here, but clearly this option would require considering associated issues in terms of food production, settlement policies, agricultural landscapes and the need for incentives. Nevertheless, one has to consider that the loss of agricultural lands in Norway may happen anyway in Norway, e.g. under free trade agreements. Under this scenario, restoration of peatland ecosystems might be more desirable than forest growth on drained lands, in places where landscape quality is an issue.

Afforestation appears as the best solution for minimizing greenhouse gas emissions from formerly cultivated peatlands (most of them presently with grass cover), mostly because of the large carbon storage potential of the tree biomass. Recent studies even suggest that drained forested peatlands emit less greenhouse gases than undrained mires (Minkkinen et al. 2002). In Sweden, some drained forest mires were estimated to be net GHG sinks of up to 7 t CO_2-equivalent/ha/y, while some pristine mires can emit as much as 4 Mg CO_2-equivalent ha^{-1} y^{-1} (Von Amold et al. 2005). In Finland, afforestation has also been reported as reducing GHG emissions from formerly cultivated peatlands (Maljanen et al. 2001). In this latter study, afforestation compensated only partially for the drainage-induced emission of greenhouse gases. Afforestation brings the largest reduction in greenhouse gas emission from formerly drained peatlands when the water table can be managed at steady state (von Arnold 2005b), which implies that excessive drainage is negative, while some remaining drainage capacity is required for tree growth.

How much reduction in greenhouse gas emissions can we expect with afforestation of formerly drained and cultivated peatlands? This important question has never been studied in Norway. In this context, we are left with providing only a rough estimate. Based on the few Finnish and Swedish studies, we will make the hypothesis that forested peatlands can emit about as little greenhouse gases as pristine mires. So, as compared to drained peatlands under grass production, we hypothesize that emissions from forested peatlands would be about 20 Mg CO_2 equivalent ha^{-1} yr^{-1} lower (Table 2).

It is, however, still questionable what effects can be expected from afforestation of formerly cultivated peatlands during the first commitment period. At the earliest, the plantation could have been established in 1990, and the trees would be allowed to grow until 2012. As we are now in 2006 and no systematic planting of such peatlands has yet started, the maximum theoretical time for the stands to grow until 2012 would be six years. However, it must be expected that the reporting of CO_2 sinks will continue in the future. The effect of the possible afforestation could be quite noticeable when the areas have been followed over a few decades. At 15-16 years after planting, the estimated uptake of carbon in living biomass would be about 0.13 Mg C ha^{-1} y^{-1}, while the annual change after 22-23 years would be nearly 0.50 Mg C ha^{-1} y^{-1}. After another 10-20 years, however, the biomass will increase substantially (see Annex 2). Assuming that half of the area is suitable for the purpose (arbitrary assumption), this amounts to 100 Gg C (367 Gg CO_2) per year (sequestered in living biomass).

In addition are reductions in soil emissions (CO_2 and N_2O). The emissions of soil greenhouse gases from afforested organic soil croplands have been described by Hytönen et al. (2006). According to the study, the annual soil CO_2 fluxes varied from a level of 2.07 to

5.39 Mg/ha/year of CO_2 -C. The soil CO_2 fluxes after afforestation appeared to be lower than fluxes measured from soils in active agricultural use, but higher than those measured on the sites drained for forestry. In Finland, the emissions due to heterotrophic soil respiration from drained forested peatlands have been estimated within a range from 1.85-4.26 Mg C ha^{-1} y^{-1}r (Minkkinen et al. 2002). A Swedish study concluded with emission factors for heterotrophic respiration of 1.9 Mg C ha^{-1} y^{-1} for poorly drained sites and 3.0 Mg C ha^{-1} y^{-1} for well drained sites (Von Arnold et al. 2005a). These estimates differ considerably from the IPCC (2004) default value for boreal drained organic soils of 0.16 Mg C ha^{-1} y^{-1}r. The CO_2 emissions from drained organic (non-forested) soils are in the range of 10 to 30 Mg CO_2-equivalent[7] ha^{-1} y^{-1}. Assuming a reduction of 7 Mg CO_2-equivalent ha^{-1} y^{-1} by tree planting, with 30 000 ha converted, this would be equivalent to 210 Gg CO_2 annually. If we assume a linear increase, this figure would amount to 1 Mg CO_2 equivalent ha^{-1} yr^{-1} at the year of onset of the measure.

When it comes to non-CO_2 gases, Hytönen et al. (2006) concluded that afforested organic soil cropland sites acted mainly as minor sinks of methane, similarly to forestry drained peatlands and peatlands under cultivation. Afforestation does not appear to change the soil CH_4 flux on former arable lands, provided that the drainage is adequate. For N_2O, the results suggested that even 20-30 years after afforestation, there is still a high availability of mineral nitrogen for nitrification and denitrification responsible for the N_2O emissions. Consequently, afforestation of cropland on peat soils does not abruptly terminate the N_2O emissions.

A sample map (Figure 1) shows an area with patches of cultivated land on organic soil. In most regions these lands will have a similar distribution, with smaller areas scattered around at various frequencies. Since the possible afforestation areas will be mainly smaller patches interspersed in cropland or grassland, they generally cannot be expected to be suitable for efficient forestry activities in the future. Most cultivated areas on organic soil may be spatially identified by using data from the national map series N5 and specific soil type maps covering about 50% of the cropland in Norway (Norsk institutt for skog og landskap).

The cultivated areas on drained organic soil are mostly located on areas used for grass production. Afforestation of substantial areas would somewhat reduce the agricultural production (although less in marginal agricultural areas). It is also a concern that such activities would change the visual characteristics of the landscape and be in conflict with goals for preservation of farmed landscapes. This is a major concern, e.g. related to the development of rural tourism. These potential conflicts should be further evaluated on a regional basis prior to selecting this mitigation option.

Unpublished soils surveys (Bioforsk) indicate that peat soils at several Norwegian localities have already been transformed into mineral soils under the effect of drainage of cultivation. This trend will likely continue in the years to come if nothing is done. In addition, drainage systems have a limited life span for: First, drainage pipes installed in peat soils become progressively clogged with soil and stop functioning after about 20 years. Second, the soil subsidence is often so rapid that drainage ditches or pipes progressively stop providing sufficient drainage capacity. This means that continued agricultural production over drained peatlands will require new drainage and exploitation of new lands in the course of the 21st century. Such an option would lead to continued massive GHG emission. Studies are needed on how to manage drained and cultivated (and formerly cultivated) peatlands to maintain attractive landscapes and food production while containing as much as possible GHG emissions.

[7] A common basis is needed to express and compare the climate effect of CO_2, CH_4 and N_2O: the GWP which converts all gases into CO_2 equivalents. The GWP per unit of CH_4 and N_2O are 21 and 310 times that of CO_2, respectively7 (IPCC 1996). Here, we will report all GHG emissions exclusively as CO_2-equivalents.

Interestingly enough, the highest GHG emissions probably occurred in the late 1980s to early 1990s, which include the reference year (1990) for Kyoto Protocol GHG accounting. Indeed, for a long period of time, the Norwegian state provided subsidies for the drainage of organic soils. These subsidies were progressively phased out from Southern to Northern Norway in the late 1980s to early 1990s. It is likely that drainage has substantially decreased since then. Given the lifespan of these drainage systems, we should currently be witnessing a substantial decrease in GHG emissions from cultivated peat soils, although the exact magnitude is not known and would warrant investigation.

The conclusion is that afforestation of organic soil croplands will not have a substantial effect on the carbon balance during the first decades of growth. After 30-40 years or so, however, the annual increment of the trees will have reached such a level that it may compensate for the elevated levels of carbon dioxide emissions from organic soil matter. Reductions in N_2O emissions have been reported to take at least two decades following afforestation to reach baseline levels (Maljanen et al 2000). This length of time will be also needed at minimum before forest productivity is high enough to compensate for CO_2 losses from peat mineralization.

Table 2 Summary of GHG emissions from peatlands under different land uses and effects of change, compiled from literature data (Kasimir-Klemdtsson et al. 1997; Grønlund et al. (in press); Maljanen et al. 2001).

Land use category	**CO_2** **t ha^{-1}**	**N_2O** **kg ha^{-1}**	**CH4** **kg ha^{-1}**	**CO_2-eqv** **Mg ha^{-1}**
Row crops	40 to 70	4 to 14	-2 to 0	40 to 70
Cereals and green fodder	20 to 40	4 to 26	0 to 20	20 to 50
Grass	10 to 30	4 to 14	0 to 20	15 to 40
Afforestated former cultivated peatland*	-5 to 5	1	0 to 20	0 to 5
Pristine peatland	-0,6 to -1	0	20 to 400	0 to 8
Effects of changes :				
From row crops to grass	20 to 40	0	-20 to 0	15 to 30
From cereals and green fodder to grass	5 to 15	0 to 10	0	5 to 15
From grass to forest	10 to 30	3 to 13	0	10 to 30

It is important to take into account that if Norway chooses to afforest cultivated peatlands this should not be elected as a 3.4 activity, but is considered as afforestation under Article 3.3. Monitoring will partly be covered by the National Forest Inventory, but additional monitoring would be required, including recommended improvements in the method to estimate emissions of N_2O. Sampling of soil organic carbon increment in peatlands is not practical (as it is for mineral soils). Monitoring of organic soils would require a network of automated surface elevation measurement, coupled to some SOC and density measurements. In addition, monitoring of CO_2 fluxes can be used to constrain the carbon budget (this cannot be done in numerous locations, but can be used to verify estimates).

4.2 Erosion control

This includes crop rotation, use of catch crops, reducing bare fallows, planting more legumes, de-intensification and tillage residue management

Because of the tendency toward more specialized farming (previously a combination of grain and animal/grass production was common), it is likely that crop rotation has been reduced since 1990. Due to lack of data (present and historical), carbon sequestration from crop rotation was not estimated in NIJOS (2005). Farmers can claim economic support for using cover crops to reduce erosion. All farmers can get support, but the compensation is largest in the most vulnerable areas. It is difficult to separate the potential of the listed options from the tillage-practice management discussed below as they may be integrated for the purpose of erosion control.

Crop residues contain about 40% carbon and enhance soil organic carbon (SOC) and sequester carbon if returned to soil. There is, however, no statistics to monitor changes in crop residue management. Singh and Lal (2001) have estimated the potential top at 1.74 Tg SOC/year (based on a SOC sequestration factor of around 100 Mg/ha/year). The level of this practice is not known. On-site burning of agricultural residue is regulated in some areas, there has been more focus on air quality problems, and the practice has decreased. Today around 5-10% is being burned annually (expert estimate). However, some straw is collected and used for animal fodder. In areas without animal production it is more common to leave the residue. Around 5-10% can be assumed used for fodder today. Because there are fewer combined farms and onsite burning is highly regulated, it is likely that that more residue is left now than previously and around 80-85% is left today. Due to lack of data, NIJOS (2005) assumed that there has not been any change in management, and carbon sequestration was not estimated. Any changes would nevertheless be small – in the order of 10 Gg C (37 Gg) per year nationally.

Tillage practices have been changing over the last 10 years with the aim of reducing N-leakages and runoff. Farmers are informed and rewarded for reducing the tillage rates in vulnerable areas (particularly autumn tillage). The fraction of area tilled during the autumn was 82% in 1989/2000, and reduced to 43% in 2001/2002 (based on annual surveys). Singh and Lal (2001 and 2004) cite data on the effect of *reduced plowing* on soil organic carbon. By changing from traditional plowing to minimum till, there is a SOC gain (20 cm depth) of *33.8 Mg/ha* over 13 years (this value is based on limited data from a single site and is higher than values reported from other sites in Norway or other countries).

Mitigation that reduces erosion will sequester CO_2, but the sequestration will level off after 20-25 years. NIJOS (2005) estimated a quite small annual sequestration of 40 Gg C/year (146 Gg CO_2) for current practices: with 100% no till it would amount to around 100 Gg C/year (367 Gg CO_2). The net-net effect for 3.4 accounting is similar since the sequestration from change in tillage practice in 1990 was close to zero. It should be noted that no-till may enhance N_2O emissions from soil. This effect is currently not accounted for in the inventory due to high uncertainties. Nevertheless this factor should be considered if the activity is elected. This estimate is highly uncertain and conservative due to lack of data on history of land use. The latter (and historical soil organic matter) will be impossible to obtain retrospectively. Election of erosion control as an Article 3.4 mitigation option would require better soil monitoring and the costs appear too high compared to the potential. This mitigation option will also level off after 20-25 years. However, the synergy with the goal of reduced erosion and runoff is high. Erosion control probably also affects N_2O emissions, while the exact effect has not been studied for Norway.

4.3 Reduced use of lime

Emissions from liming in agriculture account for around 100 Gg CO_2. Emissions have been halved from 1990 to the present. Further reduction in lime application would have to be balanced against losses in production. The overall mitigation potential is nevertheless small. It should not be necessary to implement additional monitoring if this mitigation option is elected as an Article 3.4 activity, but data on lime application would need additional verification. Furthermore, consumption data are not spatially defined.

4.4 Land-use (cover) change – cropland to grassland

The potential is not known since the inventory (NIJOS 2005) is conservative in its estimate and assumes no change in emissions or removals in case of a conversion. It is, however, unlikely that the potential is sufficiently large to defend the monitoring costs (enhanced soil sampling). The mitigation options should also consider that increased grassland would be associated with higher meat production, which would imply increased methane emissions. Furthermore, this option would require structural changes and therefore strong incentives from the government.

4.5 Horticulture and energy crops

Compared to "traditional" agriculture, horticulture will change the above-ground and soil biomass and will sequester carbon in the period prior to maturity and for soil organic carbon for a longer period. The potential in living biomass is 2.1 Mg C/ha/year per ha (GPG, 2004). (In addition comes sequestration in soil). Horticulture has, however, been reduced in Norway over the last years, and the economic potential is weak. The possible suitability is furthermore limited to parts of the country. This option would require structural changes and therefore strong incentives from the government. Monitoring costs are likely to be relatively small, but better sampling of soil organic carbon and above-ground biomass is recommended.

Increased cultivation of energy crops can sequester more CO_2 than traditional agriculture until it has reach saturation. Energy crops are fast growing and have a short-term mitigation effect. Increased cultivation of energy crops can also be in line with other goals in the climate policy with respect to more use of bioenergy compared to fossil fuels and therefore indirectly contribute to higher reductions in greenhouse gas emissions compared to sequestration. Although for some species this option can be in conflict with the goal of preserving traditional farmed landscapes, it is likely much less so than afforestation. Indeed, energy crops might be an alternative to cropland abandonment, which leads to forest encroachment and is detrimental to landscape quality.

One has to consider that energy crop production is likely to increase dramatically in the coming years. For example, the Norwegian Pollution Control Authority (SFT) has recommended the imposed sale of biofuel: From 2007 all fuel merchants should be required to sell 2% of their volume (80 million liters) as biofuels, increasing to 4% by 2010 (160 million liters). The plantation of energy crops, such as salix, in lieu of food crops is likely to result in substantial carbon storage in the soil, as organic matter and root biomass. At present, we have no hard data for Norway, which limits our ability to commit carbon accounting for the 2008-2012 period.

With reference to experiences from Sweden, the average annual production in a plantation of energy forest would be of the order of 5-7 metric tons biomass, or 2.5–3.5 Mg C/ha/year. This is a rule of thumb if the area has been planted with some fast-growing tree species as salix. Also in this case it will take a number of years until the production has reached such a level, so that any effect can hardly be expected in the first commitment period, regardless of the intensity of the activities over the coming years.

5 Maximum gain from Cropland Management

We have not in this report considered the area suitable for 3.4 activities. The calculations here are based on total available area, although implementation of mitigation measures on only a fraction of that area may be feasible. These should only be considered rough estimates for illustrative purposes. These numbers also give the potential for a longer time horizon than 2012. Generally the effect of measures until 2012 will be small, since processes are slow and incentives are not in place. One exception is erosion control, which on the other hand will become saturated.

Targeting peatland:

- Change in crop to grass: Maximum 300 ktonnes CO_2 eq./year (assuming all area converted)
- Restoration: Maximum 85-1020 ktonnes CO_2 eq./year (assuming all area restored).
- Forest planting: Maximum 600 ktonnes CO_2 annually (assuming all area tree planted)

These measures can be combined, but not on the same area.

Erosion control: 367 ktonnes CO_2/year (assuming no autumn till, not taking into account any increases in N_2O emissions)

Reduced application of lime: Maximum 200 ktonnes CO_2/year (assuming no liming in the commitment period, current level of liming emits 100 Gg CO_2, level was 200 in 1990)

Land cover change cropland to grassland: Not estimated

Horticulture and energy crops. Not estimated. 20 000 ha of energy crops would as an example amount to an annual sequestration of 220 ktonnes CO_2 in a period.

6 Relation to other 3.4 Activities and accounting principles

The Marrakesh Accords do not rank the 3.4 activities. According to GPG2004, a Party should develop a hierarchy of 3.4 activities that should be applied consistently if they have elected more than one. With respect to Norway, if FM is elected, it should have precedence over all the other activities due to the importance of forest in Norwegian vegetation, data quality and verification possibilities. We suggest that cropland Management (if elected) should have precedence over grazing land management and revegetation, because the CM activities are more well-defined and easier to verify.

In electing a 3.4 activity, Norway will also need to decide whether to carry out its accounting (i.e. for issuance of Removal Units (RMUs)) on an annual basis or at the end of the commitment period. Generally, data constraints and random uncertainties make accounting at the end of the period desirable. However, there are exceptions and this decision should be made on a case-by-case basis.

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8 Annex: Estimating CO_2 emissions from peat soils

8.1 Calculating the carbon loss from changes in ash concentration

Here, we suggest that carbon loss can be estimated from the change in the mineral concentration of the topsoil of cultivated peat. Under the effect of mineralization, the peat becomes more concentrated in minerals (represented by the ash content). We hypothesize that this effect results from 1) application of lime and mineral fertilizers and 2) the loss of organic matter within a homogeneous peat layer where mineral particles become more concentrated due to the loss of the surrounding organic matrix. Calcium is assumed to be the main component in lime and fertilizers accumulated in peat soil. Accumulation of other elements like phosphorous, potassium and magnesium are assumed to be negligible because of leaching and uptake by plants. The mean concentration of soluble Ca in cultivated peat soils in Norway is 0.3% or 0.42% CaO (calculated from the Bioforsk soil database).

We can therefore write that:

$$MF_{ini} = \frac{M_{fin}}{M_{fin} + OM_{fin} + OM_{loss}} \tag{1}$$

where MF_{ini} is the initial fraction of mineral particles, M_{fin} is the final mass of mineral particle in the 20-cm layer corrected for the added Ca, OM_{fin} is the final mass of organic matter in the 20-cm layer, and OM_{loss} is the loss of organic matter between the initial and final sampling. Equation (1) can be rewritten as:

$$OM_{loss} = M_{fin} \times \left(\frac{1}{MF_{ini}} - 1 \right) - OM_{fin}\,, \tag{2}$$

The sum of OM_{fin} and M_{fin} is the final weight of soil the soil layer:

$$OM_{fin} + M_{fin} = BD_{fin} \times Thick\,, \tag{3}$$

where BD_{fin} is the final bulk density and *Thick* the layer thickness. Combining (2) and (3):

$$OM_{loss} = \left(MF_{fin} \times BD_{fin} \times Thick \right) \times \left(\frac{1}{MF_{ini}} - 1 \right) - \left(\left(1 - MF_{fin} \right) \times BD_{fin} \times Thick \right), \tag{4}$$

where MF_{fin} is the measured final mineral content.

Equation number 4 contains only measured parameters. If data on MF_{ini} are lacking, MF_{fin} in similar uncultivated soil or peat subsoil can be used as a substitute. From the study of 11 localities with peat soils under grass cultivation in Western Norway (Sorteberg 1983), the mean values for BD_{fin}, MF_{ini} and MF_{fin} in the upper 20 cm were as follows (Table A1).

Table A.1 Summary of peat subsidence parameters from published values from Norway (Sorteberg 1983)

Parameter	Unit	Value
Thick	M	0.2
BD_{fin}	Kg m^{-3}	0.208
MF_{ini}	-	0.045
MF_{fin}	-	0.108

Solving equation (4) with these values yields an average OM loss of 56 kg OM m^{-2} over a 30-year period. Assuming 40% carbon in the peat OM, this translates as 23 kg C m^{-2} over 30 years, which is equivalent to 750 g C m^{-2} y^{-1} and 2.75 kg CO_2 m^{-2} y^{-1} assuming linear mineralization kinetics. The loss due to leaching of soluble carbon is assumed to be small compared with the CO_2 emission. Moreover, leached organic substances should also be expected to be vulnerable to mineralization and gas emissions from aquatic ecosystems.

8.2 Measurements of CO_2-fluxes from cultivated peat soil

Through CO_2-flux and herbage-export measurements near Bodø, we recently estimated a net loss of 600 g C m^{-2} y^{-1} from a drained peatland site under grass production (Grønlund et al. 2006). This measurement-based value is quite close to the value of 750 g C m^{-2} y^{-1} that we computed from literature data, as explained above. Logically, estimates based on long-term changes in soil property and depth are likely to be higher than those obtained from current measurements because carbon loss and subsidence happen at a faster rate in the years immediately following drainage. So to be conservative, we will use our current estimate of 600 g C m^{-2} y^{-1} (2.2 kg CO_2) in the rest of our discussion.

9 Annex 2: Estimating biomass in forested peatlands

By applying the following assumptions, a rough estimate can be obtained of the standing volume and the associated biomass that would be expected on the area in the future.

Assumptions:

Site quality class: H40=14 (production capacity for spruce = 5.5 m^3/ha/year)

Number of trees per hectare = 1800

Simplified equations for the relationship between diameter at breast height (dbh) and height, and between stem volume and dbh have been used:

$d=1.4h-1.8$

$v=0.2(1+d^2)$

Total volume of all biomass of a tree has been estimated at 1.5*stem volume.

Dry matter has been estimated at 0.4 tonnes/m^3 of total volume.

Carbon content has been estimated at the fraction of 0.5 of total dry matter.

Table A.2 Estimated growth of trees and carbon uptake in tree biomass.

Year	Height	dbh	Volume/tree	Cu.m./ha	Tonnes C/ha
13	1.3	0.02	0.200	0.360	0.108
14	1.65	0.51	0.252	0.454	0.136
15	2	1	0.4	0.72	0.216
16	2.35	1.49	0.644	1.159	0.348
17	2.7	1.98	0.984	1.771	0.531
18	3.05	2.47	1.420	2.556	0.767
19	3.4	2.96	1.952	3.514	1.054
20	3.75	3.45	2.580	4.645	1.393
21	4.1	3.94	3.305	5.948	1.784
22	4.45	4.43	4.125	7.425	2.227
23	4.8	4.92	5.041	9.074	2.722