ACTUALISATIE EN VERFIJNING VAN DE ONDERBOUWING VAN EEN METHODIEK VOOR DE SYSTEMATISCHE MONITORING VAN KOOLSTOFVOORRADEN IN DE BODEM

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ACTUALISATIE EN VERFIJNING VAN DE ONDERBOUWING VAN EEN METHODIEK VOOR DE SYSTEMATISCHE MONITORING VAN KOOLSTOFVOORRADEN IN DE BODEM OMG/VPO/BODEM/TWOL/2017/1

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MANAGEMENTSAMENVATTING

Hoofddoel van dit project was de ontwikkeling van een methodiek om systematisch bodem organische koolstof stock wijzigingen in Vlaanderen te detecteren. Na een vergelijking van bestaande buitenlandse monitoring initiatieven en bestaande informatie binnen Vlaanderen werd een ontwerp voor een koolstofmonitoring netwerk geformuleerd. Daarbij werd maximaal gestreefd naar een onvertekende toekenning van 10mx10m bemonsteringslocaties over alle 5 onderscheiden landgebruiken (akkerland, grasland, bos, natuur en ruimtebeslag). De steekproef aan staalnamelocaties moet immers maximaal alle Vlaamse bodems representeren. Het aantal monitoring plots vereist voor detectie van een gemiddelde koolstofvoorraadverandering van 4‰ over 20 jaar werd vastgelegd op 2594. Met de in dit project uitgewerkte staalname en analyse protocollen (tot 1m diep in vier lagen, meting van koolstof, bodemdichtheid, stikstof, pH en textuur) vergt de koolstofinventarisatie van dit 'C-MON-grid' ongeveer 5 miljoen EUR. Gezien deze 'nul-meting' van Vlaamse bodemkoolstofvoorraden voorzien wordt over een periode van 10 jaar, spreidt deze kost zich in de tijd. Deze gefaseerde bemonstering laat een relatief snelle eerste representatieve detectie van koolstofvoorraadveranderingen toe. Dit komt tegemoet aan de noodzaak voor vijfjaarlijkse LULUCF rapportering maar laat ook een eerste interpretatie toe van trends in bodem koolstof ter evaluatie van de kwaliteit van Vlaamse bodems. Pas na de volledige herbemonstering van alle locaties na 20 jaar zal pas echter het vooropgestelde minimum detecteerbaar verschil in koolstofvoorraden worden behaald. Potentiële staalnamelocaties (en extra reserves) werden ruimtelijk vastgelegd en dit rapport sluit ook af met een voorstel tot monitoringplots voor de opvolging van koolstof voorraadveranderingen ten gevolge van landgebruikswijzigingen.

INHOUDSTAFEL

0. GENERAL CONSIDERATIONS

0.1 CONTEXT

Following Belgium's commitment to international climate objectives (UN sustainability objectives and EU ambitions for greenhouse gas emission reductions), there is an urgent demand for reliable information on the greenhouse gas balance of our terrestrial ecosystems. The soil organic carbon (SOC) stock forms an important term in this balance as its dynamics translate directly into net emissions or uptake of CO_2 that could accounted for in the regional and national greenhouse gas balances. Policy and academic attention to SOC balances already peaked in the early 2000s with research into carbon in agricultural soils. The main outcome was, first of all, that strong losses of SOC occurred during the 1990s. Secondly, the potential to store carbon in soils (albeit via net-net accounting due to a reduced SOC stock decrease) through alternative management appeared to be limited for the intensified Flemish agriculture. Subsequent MIRA reports, however, showed first an increase and then an unexplained global decrease of SOC stocks in arable land. The end result is that there is currently great uncertainty about the actual state and evolution of SOC stocks in Flemish agricultural land.

Since the beginning of the 90's the SOC stocks in Flemish forest soils were monitored on 10 Level II forest test areas that were part of the international UN/ECE ICP Forests monitoring network. Also linked to the first Flemish forest inventory, forest soil surveys were carried out between 1997-2002 all over Flanders to estimate the SOC stocks to a depth of 1 m and the results were published in 2009. Reliable estimates of the SOC stock in dominant soil types could be determined, but large uncertainties remained on stocks of the SOC rich alluvial forest areas and 'hot spots' such as peatlands. By re-measuring about 50 historical forest soil profiles it was shown that after 40 years an increase of the average SOC stock in the upper 10 cm occurred, in line with the trends in the forest soils of Germany and France. But since then, no systematic SOC measurements in forest soils have been carried out to follow this evolution. Until now, no systematic SOC measurements have been carried out for open natural areas (heathlands, grasslands, marshlands) nor in residential areas (parks, private gardens, sports fields). Fragmentary datasets exist, but methodological differences in sampling and analysis methods do not allow to make good state or trend analyses for Flanders.

Contrary to other European member states, there is therefore no systematic follow-up of SOC in Belgium and within Flanders. Current estimates are always based on ad hoc analyses of existing, non-specific, aggregated measurement data. The development of undistorted and substantiated monitoring of SOC is therefore urgently needed. Because of its central position in soil quality, SOC monitoring would also provide a first systematic instrument for evaluating the sustainability of current soil management under diverse land use.

0.2 INTRODUCTION

In a previous TWOL assignment ALBON-BOD/STUD/2010/05-F02 guidelines were formulated for the development of a monitoring network in agricultural soils (Sleutel et al., 2011). Both methodological aspects of actual measurement and a calculation of the required number of points for detection of a specific average change in SOC stocks were clarified. However, the actual selection of measurement locations did not yet follow, nor were soils with nature, forest or residential use considered. Also a methodology for representative monitoring of land use changes, not unimportant in the ever changing

Flemish landscape and for LULUCF reporting, fell outside the scope of that previous study. Prior to the actual start of a first 'baseline measurement', the cost price of SOC monitoring also has yet to be appreciated.

The here presented applied science project OMG/VPO/BODEM/TWOL/2017/1 aimed to make a critical and objective final calculation of the requirements for efficient monitoring of SOC stocks in all Flemish soils. Follow-up of SOC inventories by means of any technique will always be a trade-off between cost price and uncertainty on the SOC inventory. Following the 2011 ALBON-study, these elements are taken into account by means of power-analysis of the statistical test to detect SOC stock changes. The evaluation of spatial variation and temporal correlation will be resumed and expanded. Our methodology focuses on the development of a statistically based monitoring in **phase I**. In Phase II a proposal follows for the actual sampling locations. This is realized on the basis of GIS analysis and the use of a randomized site selection methodology developed by INBO. In phase III further recommendations on future support and re-evaluation of the survey design are given.

When starting this project, however, no central SOC stock **monitoring ambition** was pre-set. In order to calculate the number of samples (and costs) required to detect changes in SOC stocks, however, we obviously would need to know how large the **minimum detectable difference (MDD)** in SOC stock should be. However, such MDD is not readily supported by any physically meaningful reasoning applicable to all land-uses. The '4 per mille initiative' (4p1000.org) initiated by the recent French presidency of the Paris Agreement was proposed as starting point for setting out SOC monitoring ambitions. A "4‰" annual growth rate of the SOC stocks (down to 2m worldwide) would make it possible to stop the present increase in atmospheric CO_2 (i.e. net soil storage of 4.3 Pg C yr^{-1} compared to 1500 Pg OC stored in all soils in the world equals a 4‰ relative change). Obviously this 4‰ ambition is first of all a means to stipulate the potential role of soils in the fight against global warming to the wider public. But a 4‰ change in SOC in fact equates to a storage of 0.2-0.3 t OC ha^{-1} $year^{-1}$ in the topsoil of Flemish cropland, in line with perceivable occurring SOC stock changes. In fact, as will be detailed further on, current imbalances in OC inputs and outputs in cropland are within this order of magnitude. A monitoring scheme that is able to detect mean 4‰ SOC stock changes would thus also be relevant to follow-up on SOC stock changes resulting from changing OC management of agricultural land. As agreed upon with the steering group we thus adopted this ambition (detecting a monotonous 4‰ relative annual change of SOC stocks) for further derivation of required sample numbers to detect SOC stock changes in Flanders.

Further considerations on the global monitoring design are discussed at onset of 1.4. As detailed in 1.4, the choice was made to track SOC stocks by means of paired sampling in time. Unbiased selection of the inherently limited set monitoring plots was considered of key importance to ensure maximal representativeness of the monitoring grid for the entire 'population' of Flemish soils or for soils within a specific land-use. We furthermore explicitly set out to investigate if a stratified sampling design would reduce the required number of sampling sites to detect a certain MDD. Such calculations were carried out firstly per land-use individually, then followed by a global optimization of the allocation of points across land-uses and there within defined strata.

0.3 PROJECT OUTLINE

The project consisted of three phases. The bulk work was completed during **phase I** in which a **monitoring strategy** was to be developed. Key actions were a screening of foreign SOC monitoring systems, choosing a monitoring design, using existing SOC data to predict spatial variation in SOC stock (changes), assessing if a coupling of a new SOC monitoring network to existing initiatives holds added value. Thereafter, scenario analysis of required sample locations to detect SOC stock changes and further optimization of their spreading across Flanders was looked into. A final scenario with minimal number of sampling sites to detect a given mean SOC stock change was retained and used for a detailed monetary cost assessment for setting up SOC stock monitoring. Phase I lasted from Jan2018 till Jan2019. In Jan2019, a related second TWOL-project (C-Gar) started with the aim to refine estimates of variation of SOC stocks within residential land in Flanders. Based on these estimates the original scenario for SOC stock monitoring as withheld in the Phase I final-report was re-assessed.

Phase II's aim was to further operationalize SOC monitoring and consisted of three main work packages:

- A first aim was to fix the C-MON grid sampling locations of for each one of the five considered land-uses, viz. cropland, grassland, nature, forest and residential land. An updated version of the VITO-Ruimtemodel (2016) was used to randomly choose these potential sampling sites. Based on in the in Phase I derived numbers of required samples a defined selection of sites was then made for various considered strata. These sets and spare sets were inventoried using existing various geo-datasets on land-use and soil.
- A second aim was to develop protocols for soil sampling, site description, soil analyses, and soil archiving. This part of Phase II started in Jan2019. Hands-on testing of draft protocols during the parallel C-Gar project proved invaluable to produce final practical protocols.
- A third aim was to develop a methodology to obtain monitoring plots on sites with recent land-use changes. This will be realised by overlaying the 2016 and 2019 versions of the VITO Ruimtemodel, which are the two most recent versions of the map. For each pixel it can be determined whether or not the land use changed between these two years. Sampling locations of the C-MON sampling grid will be selected if they fall within pixels where a land use change occurred.

Phase III originally foresaw in support for starting up actual monitoring:

- A statistical analysis of SOC stock measurements obtained in yr1 and 2
- Assessing if re-orientation of the required sampling numbers per stratum would be needed based on the first SOC stock recordings
- Support with decision making on how to deal with excluded sampling sites & need to reorient sampling protocols
- An advisory role on how to organise quality control on sampling and analysis

Since the first zero-survey (nulmeting) did not start to date, most actions for this phase could not be completed. Only a generic outline on how re-orient sample numbers per stratum is presented in this report.

0.4 CONCEPT INTEGRATED HIERARCHICAL MONITORING OF SOC STOCKS

As explained in 0.1 Flanders needs an integrated monitoring system to underpin the state and trends of SOC stocks with objective data. A good statistically based concept is essential to connect the available and future data layers so that: (1) optimal use is made of existing data and infrastructure, (2) spatial upgrading and scaling is possible for (soil) management and policy preparation and evaluation, (3) the link can be made with Belgian and international monitoring networks.

A proven concept for European monitoring is the "four elements hierarchical monitoring system" as described in Ferretti and Fischer (2013) and shown in Fig. 1. In essence, the system consists of a pyramid based on (level 0) area-wide information obtained from remote sensing (e.g. aerial photographs, LIDAR, satellite images, ...) characterized by data pixels. Derived GIS data layers (lattice and polygon) such as the Digital Elevation Model (DHMVII), the VITO Ruimtemodel, Landgebruikspercelen kaarten, Bosreferentielaag, Groenkaart-Vlaanderen, etc.) are also part of this basic element. Even large-scale surveys, such as the Belgian soil mapping, with about 2 drillings per ha (approx. 2.10^6 observations in Flanders) that form the basis of the (digital) Belgian soil map can be counted to this basic layer (Layer 0). This element is essential to make statements about the carbon stock at the scale of Flanders.

This study mainly aimed to develop a level I measurement network (Figure 1), characterized by its link to a survey (inventory) on the basis of sample areas (plots) that are selected and sampled within the target area by means of a statistically substantiated sample. In order of magnitude it concerns 100 to 10000 plots where the in situ SOC stocks are determined. This means that more and better data is obtained than is possible from level 0 and that these plots can be used for so-called ground-"truthing" (calibration & validation) of the remote sensing based models and GIS layers.

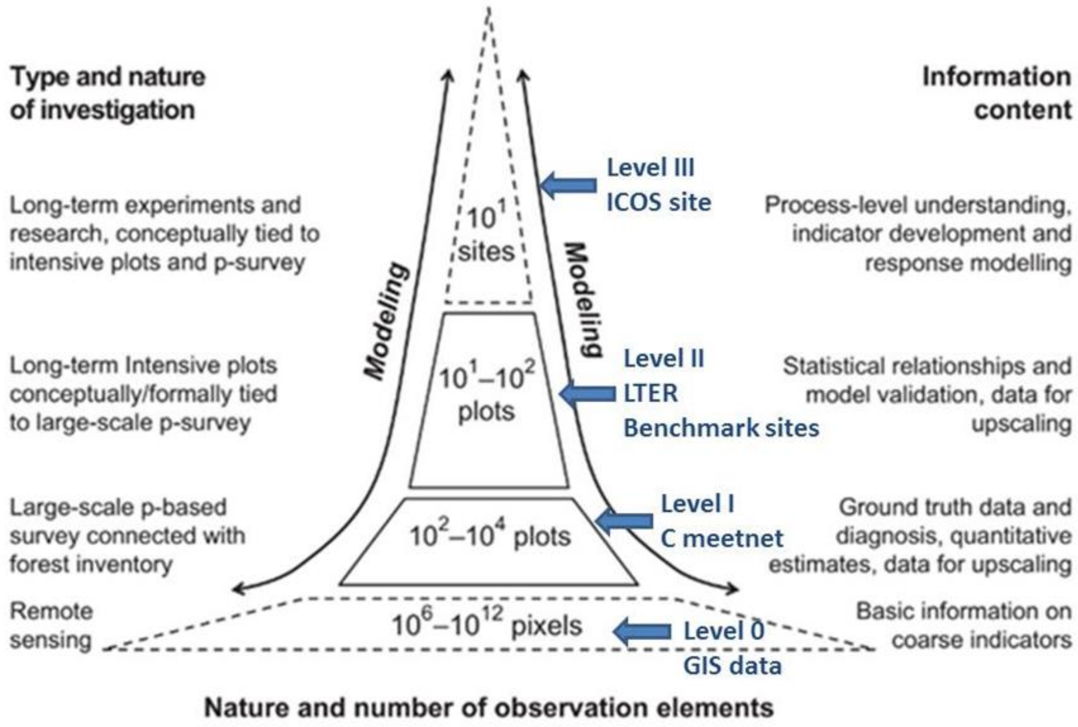


Figure 1 Schematic representation of a hierarchical monitoring system with 4 elements developed by Ferretti & Fischer (2013). The width of the elements is proportional to their sampling density, the height to the data intensity. The up and down arrows show the modelling possibilities for up and down scaling of the results.

Also essential is the third element, the so-called level II sites, consisting of a limited number of plots (10-100), selected according to specific dominant soil-land use combinations (e.g. arable land on loamy soil, Scots pine on Podzol, vegetable garden on sandy soil) where a large number of environmental and management parameters are intensively monitored. Such Level II sites are characterized by temporal monitoring of meteorological data, water levels (monitoring wells), soil solution and groundwater chemistry, fluxes of greenhouse gases, etc. They are essential to understand the dominant (short-term) processes and to calibrate and validate models. These plots follow a standard management (BAU) and can therefore also be scaled up to level I and further up to level 0 (Flanders scale). The top element (level III) of the concept consists of experimental and/or highly instrumentalized research sites equipped with measuring towers, ecotrons or other infrastructure. They allow the response of various forms of land use and tillage (anthropogenic factors) as well as variants of climate scenarios (precipitation and temperature regimes) to the C-stocks (sinks & sources) to be explored experimentally. Level III sites are often linked to Level II intensive plots with normal management which then serve as a reference.

Both for the design of the baseline measurement network and for the monitoring, this project focussed on linking the Level I C measurement network to level 0 and not really to already existing Level II and Level III infrastructure in Flanders. We did explore interconnection with some existing other Flemish monitoring networks (see 1.5).

Phase I Monitoring strategy

1 PHASE I MONITORING STRATEGY

PHASE I READING OUTLINE

The phase I reporting is subdivided into 6 parts:

In **1.1** an extensive meta-analysis of existing monitoring initiatives in the EU is presented. The methodology, extent and considerations when designing these systems are considered. In 1.1.14 first conclusions were drawn on how to move forward with a monitoring scheme for SOC stocks in Flanders. In discussion with the steering group (on 9th of January 2018, 21st of June 2018 and 2nd of October 2018) details were then set on how to proceed forward in designing a SOC monitoring net for Flemish soils.

In **1.2-1.3 required data to estimate variation in SOC stocks** under grassland, forest, nature and residential land were **collected** from existing studies. Key statistics were produced for selected strata. A recent raster-based land-use model of Flanders was used to estimate areas of relevant land-uses. During completion of this phase it soon emerged that variation in SOC stocks in residential areas was insufficiently known. As residential area takes up about 200K ha in Flanders this jeopardized robust design of a Flemish wide monitoring network. A second project was then issued by the Flemish Government in autumn 2018 to get representative and comprehensive statistics on SOC stocks in various types of so-termed 'Ruimtebeslag' (i.e. gardens, verges, parks,…). Results became available in 2019 and based on this required sample number estimates to track changes in SOC stocks across all land-uses was revised (see 1.4.2.6 & 1.4.3).

In **1.4** the minimum detectable difference in SOC for given numbers of sampling locations are presented. An analysis was made of the achieved statistical power as well. Finally **scenarios for optimized distribution of sampling pairs across land-uses and strata** were developed.

In **1.5** we evaluated the potential for aligning the C-MON network with **existing environmental monitoring networks** (EMNs), considering the requirement of an unbiased sampling.

In **1.6** scenarios developed in 1.4 were used to **calculate the total cost** for deployment and execution of a first regional SOC survey in Flanders.

1.1 ASSESSMENT OF SOIL (CARBON) MONITORING NETWORKS AND CARBON STOCK INVENTORIES ACROSS AGRICULTURAL, FORESTRY AND NATURAL SOILS IN EUROPE

Previous research of Sleutel *et al.* (2011) has already reviewed existing soil monitoring networks (SMNs) in Europe for assessing soil organic carbon stock changes. In this report, we continued and updated the work of Sleutel *et al.* (2011) and added new initiatives which were started in the period 2011-2018. Further, the research of Sleutel *et al.* (2011) was limited to agricultural soils. In this report, we broadened the scope to forestry, natural and residential soils.

For a selection of EU-countries, a quick literature survey was performed and national experts were contacted to collect general information, scientific literature or research reports on existing national SMNs. As concluded by Morvan *et al.* (2008), a soil monitoring network is a set of sites/areas where a periodic assessment is carried out and documented. This requires site geo-referencing and at least two completed measuring campaigns. However, surveys or inventories that are measured only once can also provide valuable information and can also be taken as a starting point towards soil monitoring. Therefore, those surveys are also considered in this report and we differentiate between 'assessment' (measured only once), 'stock change' (measured at least twice to detect a change) and a SMN (a nationwide soil monitoring network).

For each survey, we collected information on sampling design, measured parameters, analytical methods, etc. If detailed information was missing, a request for information was sent to the national contact (Table 1). The surveys are described below.

Table 1. Contact persons.

Name	Country	Organization	E-mail
Peter Kuikman	The Netherlands	Wageningen Environmental Research	peter.kuikman@wur.nl
Dominique Arrouays	France	INRA	dominique.arrouays@inra.fr
Sigbert Huber	Austria	Umweltbundesamt GmbH	sigbert.huber@umweltbundesamt.at
Lilian O'Sullivan	Ireland	Teagasc	lilian.osullivan@teagasc.ie
Karl Vanderlinden	Spain		karl.vanderlinden@juntadeandalucia.es
Edoardo Costantini	Italy	CREA-AA	edoardo.costantini@crea.gov.it
Andrew Ross	United Kingdom	University of Leeds	a.b.ross@leeds.ac.uk
Anna Jacobs	Germany	Thünen Institute	anna.jacobs@thuenen.de

1.1.1 Italy

Currently, **no nationwide network for monitoring soil organic carbon stock changes exists in Italy** (Edoardo Costantini, personal communication, January 17, 2018). To estimate organic carbon stocks in Italian soils, Fantappiè *et al.* (2010) used data of the soil database of Italy in which information of 20.702 georeferenced observations of soil profile pits is stored (Costantini *et al.*, 2007). Data were collected during different surveys and completed in different time intervals: 1979-1988, 1989-1998 and 1999-2008. This resulted in a random sampling design with a great inhomogeneous spatial and temporal distribution of samples. Although the observations were collected from different sources, soil description and classification were similar while soil analyses always followed the Italian official methods. In particular, SOC content was determined using the Walkley & Black procedure (Walkley and Black, 1934).

Fantappiè *et al.* (2010) used the SOC and bulk density data of the first 50 cm, which contains the plough layer, in agricultural soils, and the organic-mineral horizon (A horizon), in forest soils. Information on rock fragments content and soil bulk density was also available. However, as in only 37.5% of the cases bulk density was actually measured, the authors used a pedotransfer function, which related bulk density to the amount of clay, silt, OC, and CEC (Pellegrini *et al.*, 2007).

Further, Fantappiè *et al.* (2010) stratified the data by using a geographical database of Italy which contains information about physiography, morphogenetic processes, river drainage network and lithology. Besides, the influence of climate was taken into account by classifying the data into different soil moisture and temperature regimes. Finally, land use was obtained by using the CORINE Land cover Maps of 1990 and 2000 which resulted in three land use classes: **arable land, forest and permanent meadow**.

1.1.2 Belgium

Existing soil monitoring networks in Belgium are discussed under 1.3.1 Soil survey campaigns.

De Vos (2009) investigates the uncertainty of SOC stocks at different levels (plot, stand, region). At the plot level, samples were collected at 7 experimental sites of both Ah and E layers at approximately 48 locations within the same plot. Distances between observations varied between 0.5 and 215 m. Coefficients of variation vary from 22 to 50% C in the Ah and from 22 to 92% C in the E horizon. In order to determine the plot mean C concentration with a precision of 10% (i.e. SOC levels varying from 0.27% to 0.79% in Ah and from 0.10 to 0.25% in the E horizon) between 20 and 100 samples are theoretically required of the Ah horizon and 18 to 334 samples in the E horizon. If a change in carbon concentration equal to this 10% of the mean has to be detected, about 4 times more samples are required (between 77 and 327 samples for Ah and 72 to 1311 for E).

Assuming a high small scale variability at all sites, a sampling scheme is proposed based on 4 or 16 samples each consisting of 16 bulked cores taken at short distance. Using this scheme, uncertainties on the determination of mean SOC concentrations and on the detection of SOC changes at stand level will be reduced to an acceptable level.

At the regional scale, different stratification schemes for upscaling plot based forest soil carbon stocks were compared. It was decided that the most useful stratifiers for carbon mapping were the combined texture-drainage class for predicting C stocks. Ecosystem based stratifiers, elevation and forest history are inadequate for representing the spatial distribution of mineral SOC pools.

Ottoy *et al.* (2017) estimated the soil organic carbon content in the upper 100 cm of soils in natural open habitats in Flanders. They collected soil data at 139 sites in nature reserves across different ecoregions. At each site, a plot of 10 × 10 m was positioned in a homogeneous vegetation patch. Therein three subplots of 0.5 × 0.5 m were randomly selected. In each subplot, the topsoil was sampled to a depth of 15 cm. Soil organic carbon was measured by the Walkey and Black method (Walkley and Black, 1934). The resulting data were used to develop a statistical model with different soil and vegetation variables as parameters

1.1.3 Denmark

In Denmark, studies on carbon stock dynamics and its quantification have started after the establishment of two nationwide soil databases between the years 1975-1987 (Adhikari *et al.*, 2014):

- The **Soil Profile Database** contains land use information and horizon-specific physico-chemical data for approximately 2000 soil profiles (**1m depth**) examined between 1987 and 1991. A sample of 0.5 dm^3 from the central part of **each horizon** was used for C analysis. Three metal core samples were used to determine bulk density of each horizon. The soil profile database also contains 837 profiles belonging to a nation-wide square grid monitoring net ('Kvadratnettet'; 7 km × 7 km), established in 1986 in order to improve fertiliser recommendations (Madsen *et al.*, 1992).
- The **Danish Soil Classification** system contains soil texture and carbon data from the 0-20 cm layer for 36,000 geo-referenced sites, which were sampled between 1975 and 1978. At each site a composite sample consisting of 25 subsamples was taken within a 70 m × 70 m square to determine soil texture and C concentration. Forest and urban areas were not included in this database.

Taghizadeh-Toosi *et al.* (2014) used and resampled the sampling areas under agricultural use (590 areas in 1986) of the 'Kvadratnettet' to detect changes in carbon stocks of Danish agricultural mineral soils between 1986 and 2009. The sampling areas under agricultural use are hosted by farmers and a given year's management is reported by the farmer in annual questionnaires. The sampling areas were sampled in 1986/87, 1997/98, and 2009/10 (referred to as 1986, 1997 and 2009, respectively).

In **1986**, soil was sampled all 590 (50 × 50m^2) grid areas under agricultural use (Figure 2). At each grid area, located by maps, 16 soil cores were taken along three parallel transects **at four depths; 0–25, 25–50, 50–75 and 75–100 cm**. These depths were selected to represent the plough layer (0–25 cm), the main rooting zone (0–50 cm), and drainage depth (75–100 cm). At each sampling area and at each soil depth, the 16 samples were mixed into one bulk sample. The soil was left to air-dry and stored. Soil texture was analyzed by standard sieving and sedimentation methods. In **1997**, soil samples were collected from **336 agricultural grid areas located <40m from those of the 1986 campaign**. The sampling protocol was the same as in 1986.

In **2009**, 504 sampling areas were again located by maps and then positioned with GPS technology (to facilitate future samplings). Each 50 × 50m^2 grid area was subdivided into 100 grid cells (each 5 × 5 m^2) and 16 of these (drawn randomly a priori) were sampled to 100 cm depth using three depth intervals: 0–25, 25–50 and 50–100 cm. Samples were air-dried, ball-milled and analyzed for C as in 1997 and 1986 by means of dry combustion.

Soil bulk density was not determined at each sampling area. Instead, guided by the soil texture data of the 0-25cm soil layer in 1986, representative soil bulk densities were established for each sampling area, soil depth, and sampling campaign by **retrieving average soil bulk densities from matching soil profiles in the soil profile database** (Krogh *et al.*, 2003). The sampling areas were grouped according to soil types in the Danish soil classification system whereby soil bulk density values were assigned to each soil type.

The calculation of the SOC stocks pointed out that the SOC in the 0-25cm accounts for less than half the quantity of the SOC stored in the entire soil profile. Consequently, Taghizadeh-Toosi *et al.* (2014) strongly advise the inclusion of deeper soil layers in national SOC inventories. After all, the SOC in deeper layers may also show long-term changes following the cultivation of soils as a substantial part of the rooting system of plants extends below the plough layer and because of vertical transport of SOC down the soil. Further, the authors observed substantially larger changes in the 25-50 cm than in the 0-25cm layer between the different sampling campaigns. Averaged across all soils, the amount of SOC in the 50-100cm soil layer remained almost constant between 1986 and 2009.

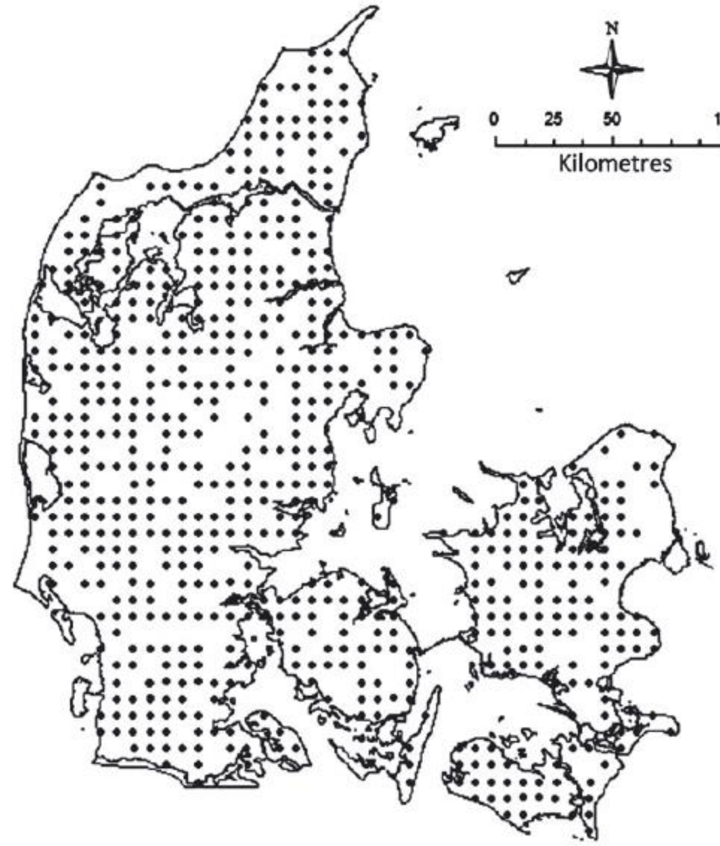


Figure 2. The location of the sampling areas under agricultural use in 1986 when the nation-wide monitoring network was established in Denmark

In 1990, a total of 119 sites were forest and could be re-sampled, of which 98 sites were under forest remaining forest (FRF) and 21 sites were afforested (AFF) since 1954. Around 1989, a soil profile was dug within the plot (Callesen *et al.*, 2015). Genetic soil horizons were sampled from mid-horizon material. Physical and chemical analyses were carried out enabling classification according to World Reference Base. The same sampling protocol was used for the second field campaign in 2007-2009, now also including forest floor sampling. Carbon content was determined by dry combustion and samples of the first campaign were retrieved from the archive and re-measured along with the new forest floor and mineral soil samples from 2007 to 2009. Bulk densities were not determined and stone content was not recorded. Stone contents in most topsoils are generally less than 5% of the soil volume of Danish soils that are of sedimentary origin and have been cultivated through time.

Therefore it was not accounted for in the calculation. Bulk density was estimated by two separate pedotransfer functions for soils with either more, or less than 10% C.

Average SOC stocks were computed per FAO soil group. Average SOC stock (and standard errors) in 0-100 cm for the three most common soil groups were 96 (15) t C ha−1 for Arenosols (N=15), 137 (15) t C ha−1 for Luvisols (N=17) and 150 (8) t C ha−1 t C ha for Podzols (N=59) (Callesen *et al.*, 2015). Further strata that were distinguished were drainage status and subsoil texture class. A power analysis was carried out to address the possibility of detecting national forest SOC stock changes. Following the design with paired sites and a standard deviation of 20 t C ha−1, this revealed that an MDD of 3 t C ha−1 equal to one standard error of the mean dSOC at the national scale would be detectable with 80% power and a correlation of 0.8 if 142 paired sampling sites were available. When increasing the correlation between paired observations to 0.9, the number of sampling sites required to detect a change of one standard error of the mean SOC decreased to 72 pairs. In contrast, with no stratification of the national grid data, a standard deviation of 90 t C ha−1 would require 438 and 1415 sites for the same MDD with correlation 0.9 and 0.8 between paired observations, respectively.

1.1.4 Finland

In Finland, a soil monitoring network consisting of agricultural fields on both mineral and organic soils was **established in 1974 and resampled in 1987, 1998, and 2009** (Heikkinen *et al.*, 2013). Due to regular tillage and involvement of annual crops, practically all actively used agricultural lands in Finland fall in the "**cropland**" category according to the definition by the IPCC (IPCC, 2006) while no large areas of grazing land or permanent grasslands exist.

The first nationwide survey was conducted in 1974 with the collection of soil samples from 2042 sampling plots. The location of those plots was determined regionally and adjusted in the field when needed (e.g. drainage ditches were avoided). Due to decreasing resources the number of sampling plots has decreased from the original 2042 plots to 611 in 2009. The number of plots was reduced without hampering the regional coverage of the network. In the first three surveys, detailed maps were drawn and the locations of the sampling plots were tied up with landmarks while in 2009 the coordinates of all sampling plots were determined with GPS. Further, the network was not originally formed randomly as all sampling plots were established on fields growing timothy (perennial cropland). The authors claim that due to land use changes, currently the number of sampling plots in different management classes correspond more closely to the current use of Finnish croplands.

The soil samples were taken from the topsoil (0-15cm) of a 10m x 10m sampling plot. The samples were pooled from 10 subsamples taken with an auger. The soil samples were air dried and passed through a 2 mm sieve before C concentration was determined by means of dry combustion. **All analyses were performed in the same laboratory (MTT Agrifood Research Finland, Jokioinen) to guarantee the consistency of methods.** Soil bulk density and texture were determined in 2009. Samples were taken from the 0–15 cm layer using 5 cm(V = 294 cm3) soil core samplers. The samplers covered the whole sampling depth. Each sample was pooled from three subsamples. Samples were oven dried in 105°C overnight and weighted. Bulk densities were corrected by removing the stone fraction/weight. Soil texture was determined using the sieve-pipette method. The C stocks of the sampling plots in all observation years were calculated as C concentration x bulk density x depth (15 cm), where the bulk density was estimated for all years by using a pedotransfer function (PTF). This PTF was determined on the basis of the measured bulk densities in 2009. For statistical analysis, the authors the authors grouped the data based on the **region** (North, South, East, West), **soil class** (mineral and organic soils) and **management** (annual and perennial cropland, crop rotation).

1.1.5 France

In France, a nationwide soil monitoring network (**R**éseau de **M**esures de la **Q**ualité des **S**ols) was first surveyed between 2001 and 2008. From 2009 onwards, 10% of the sampling sites is sampled every year (Jolivet *et al.*, 2006; Martin *et al.*, 2011). The network is based on a **16 km×16 km square grid** and the sites are selected at the **centre of each grid cell** resulting in about 2200 soil sampling sites covering all land use types. This network comprises the 600 ICP-Forest level 1 sites of the International Cooperative Program on Assessment and Monitoring of Air Pollution Effects on Forests which were installed and monitored since 1995 (Figure 3). In the case of soil being inaccessible at the centre of the cell (i.e. urban area, road, river, etc.), an alternative location with a natural (undisturbed or cultivated) soil is selected as close as possible, but within 1 km from the centre of the cell.

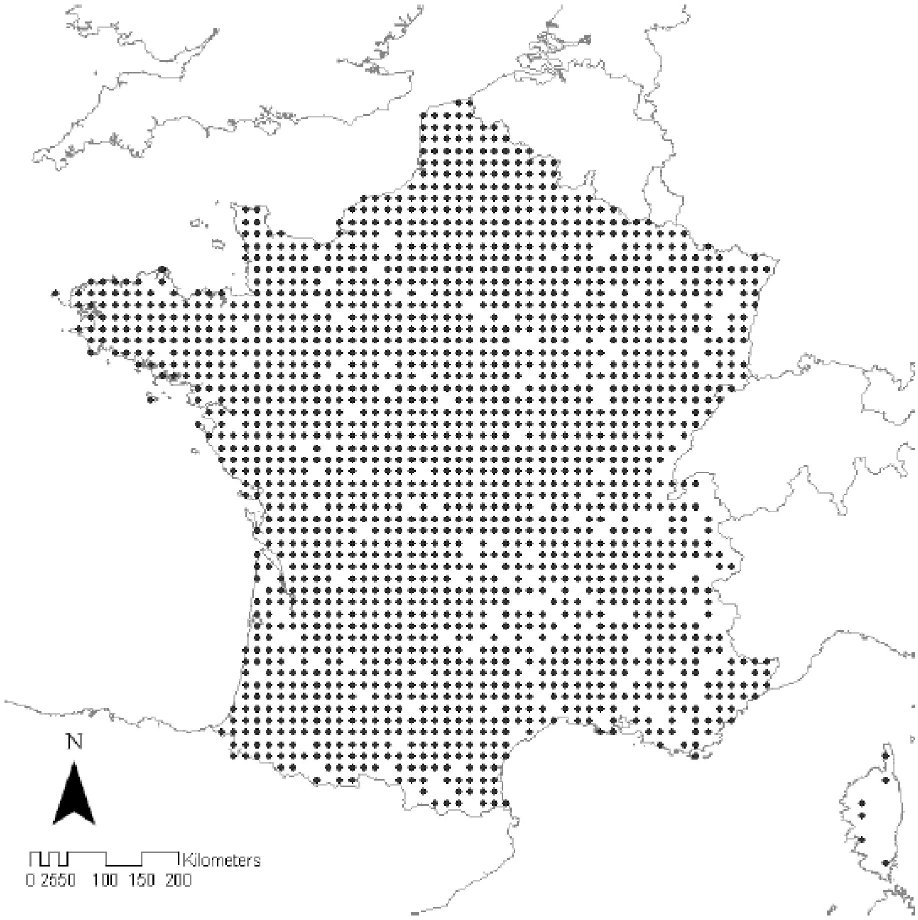


Figure 3. Distribution of the 1974 sites within the French monitoring network which were used in the study of (Martin et al., 2011)

At each site, 25 individual core samples were taken from the **topsoil (0–50 cm)** using a hand auger according to a stratified random sampling design within a 20m×20m quadrant. The quadrant was installed by a north-south direction and divided into 100 smaller quadrants of 2m x 2m (Figure 4). Afterwards, a number from 1 till 4 is randomly attributed to each smaller quadrant after which each quadrant with number 1 was sampled during the first sampling campaign. The numbers 2-4 will be sampled during future campaigns (Jolivet *et al.*, 2006). Apart from composite sampling, at 5m from the south border of the 20m×20m area, a soil pit was dug (>1m depth), from which the soil profile was described and 6 bulk density measurements were done, as shown in Figure 5. In each soil layer/horizon, 3 metal rings were sampled, each at a different depth. Bulk density samples are taken when soil moisture content is close to field capacity and after the soil has remained undisturbed for a longer period.

Individual samples at the 20mx20m quadrant were obtained at two different depths depending on the presence and the depth of a plough pan which was derived from the profile pit. **If a plough pan was detected, the soil was sampled by horizon** whereby the first horizon was sampled above the plough pan while the second horizon was sampled below the plough pan till a depth of 50cm. If **no plough pan was observed (e.g. grassland and forest soils), the soil was sampled at fixed depths (0-30, 30-50cm).** If a O horizon was present, this layer was sampled separately also. Afterward, the individual samples of the 25 2x2m quadrants were mixed to obtain a composite sample for each soil layer and analyzed in the lab for total organic carbon. From these data, the bulk density data and the percentage of rock fragments, SOC stocks were computed for the 0–50 cm soil layer.

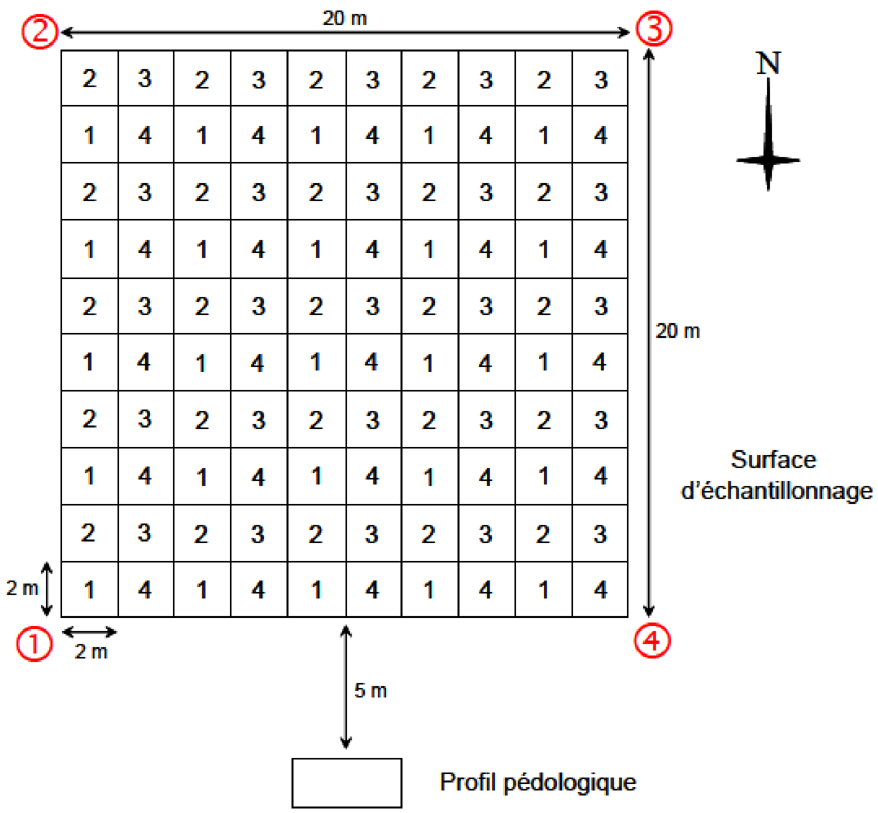


Figure 4. Sampling quadrant at each location of the French soil monitoring network (RMQS) (Jolivet et al., 2006).

After sampling, the positions of the four corners have been exactly measured and their coordinates determined with GPS (Figure 4).

Besides soil sampling, field observations were used to assign land use category values to the RMQS sites. **Land cover** was described using a 3 level classification, similar to the procedure used for the Corine Land Cover maps. Level 1 land covers include various crops (1), permanent grasslands (2), woodlands (3) orchards and vineyards, shrubby perennial crops (4), wasteland (5), specific natural systems (6) and **parks and gardens (7)**. Levels 2 and 3 refine level 1 (e.g. woodlands (L1), forest (L2) and coniferous forest (L3)). Soil moisture regime was also described using two variables waterlogging and water regime.

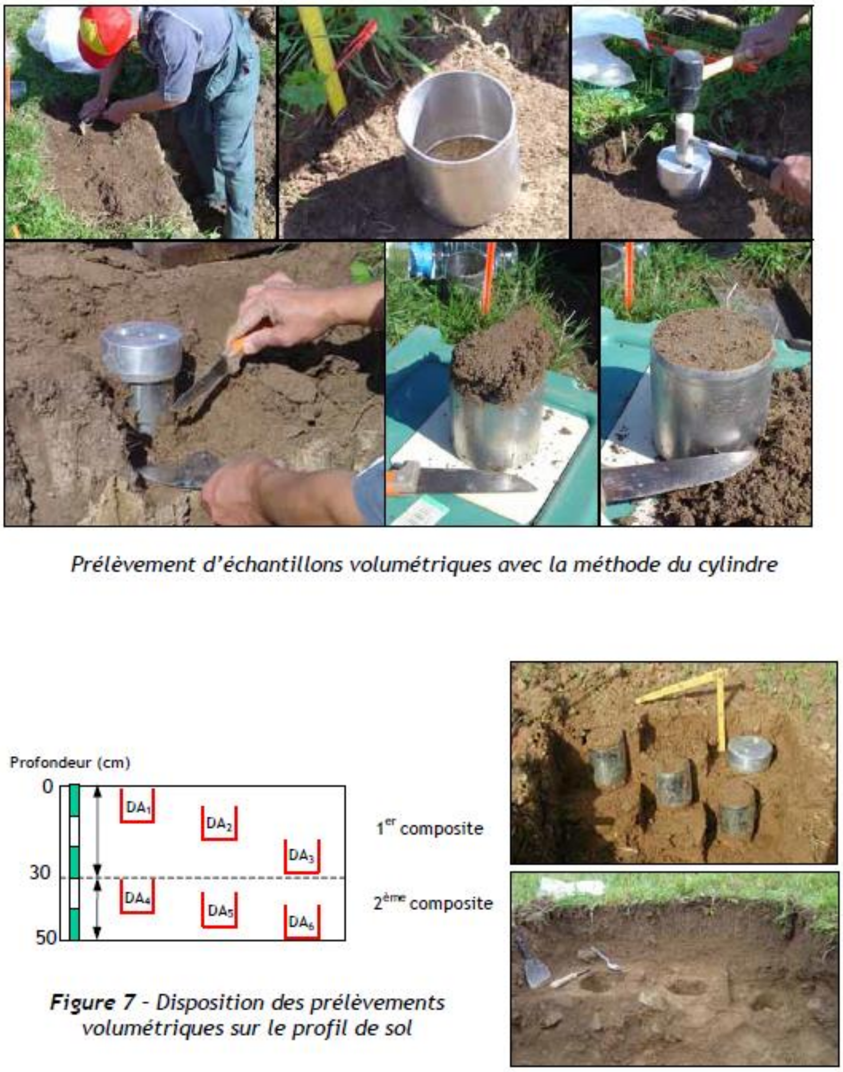


Figure 5. Sampling method for measuring bulk density in the French monitoring network (RMQS) (Jolivet et al., 2006).

The same locations as in the first campaign are being sampled unless the soil has become inaccessible (i.e. urban area, road, river, etc.). In that case, an alternative location with the same soil type and land use is selected as close as possible to the previous location. Changes in land-use are being monitored.

Apart from the French soil monitoring network RMQS, a study was carried out to study SOC stocks in forests (Jonard *et al.*, 2017). French level II forest monitoring plots (RENECOFOR) in 1993–1995 and in 2007–2012. The 102 plots are distributed throughout France and comprise a wide range of ecological conditions. Two surveys have taken place (1993-1995 and 2007-2012), following exactly the same sampling protocol. Within the central zone of each 0.5 ha plot, sampling was carried out on five 13.5 m × 13.5 m subplots. In each subplot, five sampling points were selected from the 16 intersections of a systematic grid (4.5 × 4.5 m) so as to have good spatial distribution and to avoid disturbed areas and proximity to living trees. At each sampling point, the forest floor was collected by horizon and a small soil pit was dug in order to sample the underlying mineral soil by fixed depth layers down to 40 cm depth (0–10 cm, 10–20 cm, 20–40 cm). For each mineral layer, an undisturbed soil sample was taken with a Kopecky cylinder to measure bulk density. The volumetric stoniness was determined by visual inspection of the soil pits. In the first soil survey, two additional layers (40–80 cm, 80–100 cm) were sampled were sampled from the soil pits, also for both bulk density and chemical measurements. Standard deviations in the upper soil layer vary from 7.7 to 15.2 t C ha^{-1}, depending on tree species.

1.1.6 Germany

Wiesmeier *et al.* (2012) calculated representative SOC stocks to a depth of 1m for the main land use types in southeast Germany (Bavaria). Available data from different soil surveys and permanent soil observation sites in Bavaria (Bavarian Environment Agency (LfU) and Bavarian State Institute for Forestry (LWF)) were screened in order to compile a representative SOC data set. Sampling locations were incorporated only where soil profiles were sampled by horizon down to the parent material or to least 1 m depth and then analyzed for SOC (by means of dry combustion), bulk density and stone content. The selected sampling locations comprised a data set of 1460 soil profiles. The main land uses were adequately represented, with 384 locations (26% of the data) as cropland (34% of the total area), 333 locations (23%) as grassland (16%) and 596 locations (41%) as forest (35%). The remaining locations were composed of 68 and 79 sites (10%) for bogs and other land uses (15%), respectively.

The main part of the data constituted a **grid sampling (8 x 8 km**) with 1077 sites that were sampled between 2000 and 2004. At each grid node, a representative (in terms of vegetation, relief, soil type and parent material and land use type) location was selected within a radius of 1500 m and a soil profile was sampled to at least 1m depth. Anthropogenic disturbances in the subsoil were excluded in a pre-exploratory survey using a soil auger. For top- and subsoil horizons down **to a depth of about 35cm, a composite sample** from eight sub-locations around the main soil profile was collected. Samples below 35cm were taken from main soil profile only. The remaining 383 soil profiles were from permanent soil monitoring sites and other regional soil surveys. Overall, a sampling density of one location per 48 km² was obtained.

To calculate SOC stocks, the bulk density of the different soil horizons was quantified by means of soil cores with a fixed volume. If the **bulk density could not be analyzed directly** due to high amounts of stones or low thickness, bulk density was estimated **based on values from adjacent sites with similar land use, soil type and parent material.** Stone contents were estimated visually in the soil profiles.

The incorporation of subsoil SOC stocks revealed that land use may not be the main controlling factor for SOC storage and highlighted **the importance of pedogenetic properties**, particularly in grassland soils. Consequently, Wiesmeier *et al.* (2012) recommended that pedogenetic soil information (soil classes, for example) should be included in SOC stock estimations. Further, the authors proposed that in future SOC inventories, SOC stocks should be determined by horizon for the entire soil profile in order to estimate the impact of land use changes precisely and to evaluate C sequestration potentials more accurately. Finally, they questioned the application of modelled parameters in SOC inventories as a calculation of SOC stocks using different pedotransfer functions revealed considerably biased results.

Capriel (2013) reported the results of a Bavarian monitoring programme which was initiated in 1986. The network consists of 92 locations on cropland and 21 on managed permanent grassland. They are evenly distributed across the study area and have been chosen so as to cover the diversity of agricultural soils in Bavaria with regard to land use, soil type, texture, geology and climate. Since 1986 the plots have been sampled four times: 1986–1987, 1989–1993, 1996–1999 and 2005–2007. Sampling was always carried out in spring (March–April). The land use of the different sites has not changed for many decades. For each monitoring plot there is a database with detailed information comprising crops, intermediate crops, amount and kind of mineral and organic fertilizers and tillage.

Each monitoring plot is a square of about 1000m² and the positions of the corners have been exactly measured and their coordinates determined with GPS. In addition, **a magnet was buried at about 60 cm depth at each corner** in order to locate the plot more precisely for resampling using a magnet detector. About 25 soil cores were taken at random from each monitoring plot to a depth of 15 cm (cropland) and 10 cm (grassland) and pooled together, giving a bulk sample. At each sampling campaign 4 bulk samples were taken from each monitoring plot. Total carbon and nitrogen were simultaneously determined by dry combustion (ISO 10694 and ISO 13878). Bulk density was not determined which prevented the calculation of soil organic carbon stocks.

Besides regional carbon inventories in Germany, a national, consistent soil inventory for agricultural soils was set up in 2011. With the **German Agriculture Soil Inventory**, a consistent and representative inventory of the organic carbon stocks in the top 100 cm of agricultural soils is conducted for the first time. This inventory will deliver an important database for Germany's engagement in terms of the United Nations Framework Convention on Climate Change and the Kyoto Protocol (https://www.thuenen.de/en/ak/projects/agricultural-soil-inventory-bze-lw/). Based on a **systematic grid of 8 x 8 km**, more than 3000 sampling sites on agricultural soils are examined all over Germany. The sampling sites are identified in a coincidence-based procedure, which is based on the distance between the points as well as on the land use (arable land, grassland, garden, special crop) identified by the basis digital landscape model. According to several tests, the sampling-grid produced is representative for the distribution of agricultural fields in Germany and in the Bundesländer as well as for the respective soil-climate-regions (Figure 6).

Figure 6. Progress of the Agriculture Soil Inventory in terms of sampling, quality management, and evaluation of data (02/02/2018; © Thünen-Institut/AK)

If one point of this grid is located on an arable field or a grassland, the owner or manager of this field is contacted. Only when the owner of the field agrees, the sampling takes place. On each sampling site, soil samples are taken from a pit down **to a depth of 100cm** (five different depth increments: 0–10, 10–30, 30–50, 50–70 and 70–100 cm) following standardized procedures. In accordance with the sampling procedure of the German Forest Soil Inventory (Grüneberg *et al.*, 2014), the small scale variability in **a radius of 10m around the pit is recorded via 8 satellite samples** (Figure 7). To determine soil organic carbon stocks all relevant parameters (rock fragments content, fine soil mass, carbon content of the fine soil) were analyzed (Poeplau *et al.*, 2017). Volume-based samples were taken by volume replacement or with a cylindrical core or a cap cutter, an AMS Core sampler or a motor driven auger. If soil sampling was not practical or feasible due to a high stoniness, onsite estimates of the bulk density were permitted. In addition to soil sampling, a questionnaire on the agronomic management and the land use history of the sampling site is completed by the farmer/field manager. The first sampling campaign started in 2011 and was finished by the end of 2017.

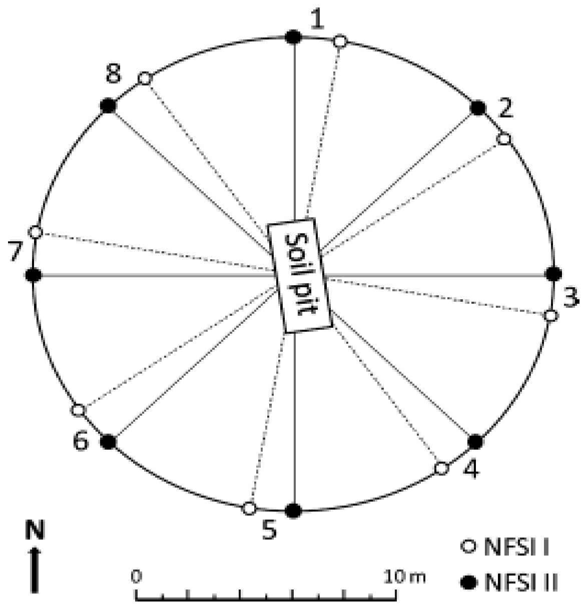


Figure 7. Schematic presentation of the sampling design used for each sampling site of the Agricultural Soil Inventory (Grüneberg et al., 2014)

Germany started in 1987 with its first **National Forest Soil Inventory** (NSFI) on a 8 x 8 km² grid that was made denser up to 4 x 2 km² if required for sufficient representativeness. Two field campaigns have taken place in 1987-1993 and 2006-2008, during which over 1800 plots were visited and sampled at fixed depth, with 8 subsamples pooled at 0-5 cm, 5-10 cm and 10-30 cm and 4 samples at 30-60 cm and 60-90 cm (Grüneberg *et al.*, 2014; Wellbrock *et al.*, 2017). Approximately two thirds of the sampling plots were resampled during the second inventory. The other third were new sites. Coarse fraction and bulk density were measured in the pooled samples. Average SOC stocks of the mineral soil is computed per soil type (i.e. combinations of soil group and parent material according to FAO legend), average SOC stocks of the organic layer per stand type (coniferous, deciduous, mixed) (Grüneberg *et al.*, 2014). The uncertainty of SOC stocks and SOC stock changes is computed as a combination of the uncertainty due to sample variance, uncertainties obtained by single measurement techniques (interlaboratory standard deviation and the standard deviation of repeatability or intra-laboratory standard deviation) and uncertainties which derived from methodological changes in analysis techniques between both inventories. Values for the interlaboratory standard deviation ranged from 0.9 mg g-1 for non-calcareous soils to 2.9 mg g^{-1} for calcareous soils. A standard deviation of reproducibility of 20.2 mg g^{-1} was estimated for the organic layer. The coefficient of variation ranged between 5 and 20% for the mineral soil and between 5 and 10% for the organic layer. Standard errors of the mean per soil group varied between 0.5 and 6.8 t C ha^{-1}.

1.1.7 Sweden

Similar to the United Kingdom, Sweden has a long tradition of soil monitoring with the Swedish Forest Soil Inventory (SFSI) (Ortiz *et al.*, 2013). The first inventory took place in 1983-1987 and currently the fourth inventory is ongoing (2013-2022). Samples of mineral soil are collected every 10 years at 4500 plots. Sampling is done by horizon (O, A, B, B/C and C horizon, up till 65 cm depth) and 2 soil profiles are sampled per plot during each campaign. Bulk density is estimated by a PTF that was developed specifically for Swedish forest mineral soils and humus layers. Stoniness is estimated based on the surface boulder frequency (Stendahl *et al.*, 2009). The total SOC stock up to 50 cm depth in 2000 was estimated 73 ± 10 t C ha^{-1} (Ortiz *et al.*, 2013). Important differences in estimates of SOC stocks were discovered between counties (north-south gradient), between soil types and between dominant tree species and soil moisture classes (SLU, 2017). In order to estimate changes in soil organic carbon stocks under forest, Sweden usually applies process-based models that require litter quantity and climate variables as input data (Ågren *et al.*, 2008; Ortiz *et al.*, 2013).

1.1.8 United Kingdom

Chapman *et al.* (2013) compared soil organic carbon stocks in Scottish soils between 1978 and 2009. The authors used the results of the National Soil Survey of Scotland which sampled 721 soils on a 10-km grid throughout Scotland between 1978 and 1988 and resampled 25% of the locations between 2007 and 2009. This survey considered not only agricultural and forest soils, but also distinguished between several natural open vegetation types, namely moorland, semi-natural grassland and bog. The scale of the resampling was adequate for covering the most common land-use/soil-type combinations and was designed to give sufficient locations to detect the degree of change in soil C suggested by Bellamy *et al.* (2005). The resampling scheme was based on a 20-km grid pattern which means that one in four of the original sites was revisited so there were four possible grid options. The authors tested whether any of these grids would bias the results by examining specific soil and environmental attributes such as carbon content, base status and slope for each of the four potential grids using data from the original 10km grid and detected no significant bias.

Before the start of the sampling campaign, protocols for recording site and morphological characteristics and sampling protocols were designed and described in Lilly *et al.* (2010). The vegetation at each site was recorded according to the classification scheme of Robertson (1984) and aggregated into six land use types: arable, improved grassland, semi-natural grassland, woodland, moorland and bog. **Ley-arable rotations were assigned to arable or improved grassland depending on the vegetation type at the moment of sampling**. The major soil group and major soil subgroup were also recorded at each site using the Scottish soil classification system.

At each location a pit was excavated to reveal the soil profile and soil samples were **sampled by horizon** (from a 10 cm depth band, approximately in the middle of the horizon) to at least 75cm (100cm in peat soils). Samples were taken according to set protocols and the national grid reference, as indicated by a GPS, was recorded. During the second survey, the **soil bulk density** was determined in the middle of each major horizon in the profile, using up to **three replicates per horizon**. Steel cylinders, internal diameter 7.3 cm and height 5 cm, were pushed vertically or horizontally into the soil. The position of the replicates was not specified. **Stone content** was estimated visually on a six-point scale of stoniness in two size categories (Lilly *et al.*, 2010). To determine **topsoil variability**, **four additional satellite pits**, aligned to each of the 4 cardinal points and at a distance of 4, 8 or 16 m from the centre of the central soil pit, were dug at the same depth as the central pit. The distances and directions were randomized for each location and two samples at the 16m distance were taken at different orientations. At the satellite pits, only the same near surface pedological horizon as the central pit was sampled (at the same depth if possible). Also, one bulk density core was taken from the sampled near surface horizon at the four satellite pits. The bulk density samples were then air-dried at 30◦C, sieved (<2 mm) to remove stones and any roots, dried at 105◦C and weighed. The bulk density of the fine fraction was obtained after making a correction for the volume of stones and roots. Samples for carbon analyses were air-dried at 30◦C and sieved (<2 mm) and further dried at 50◦C for C content (Elemental analyzer) and at 105◦C for loss on ignition.

As bulk density values were missing for the first sampling period (1978-1988), Chapman *et al.* (2013) used the measured bulk densities of the second sampling period (2007-2009) for the calibration of a

NIR spectroscopic method by which **predicted bulk density values** for both periods (original samples of the first sampling round were still available) were obtained and carbon stocks were calculated. This approach was evaluated thoroughly and was identified as utile when measured values for soil bulk density were not available for the initial sampling time.

Average soil C stocks were reported per broad vegetation type, with averages between 37.3 t C ha^{-1} (arable) and 90.7 t C ha^{-1} (bog) in the first sampling period. Standard errors varied between 2.5 and 6.8 t C ha^{-1}.The authors reported no detectable change in overall total soil C stock (to a depth of 100 cm) between the two sampling periods or generally in C stock within specific vegetation or soil (except for soils under woodland, excluding those on deep peat). Recalculating the C stock to a depth of 15 cm showed a significant increase in overall C stock (when deep peat sites were excluded) as well as specifically in moorland and woodland soils, suggesting that **changes in C stocks in the top soil (0-15cm) were more pronounced**.

Between the two sampling periods, 29 sites recorded **a change in broad vegetation type/land use**. Ten of these were changes between arable and improved grassland and were attributed to different points in a ley-arable rotation by the authors. Omitting those sites were a land-use change occurred, resulted in a significant decrease in C content in grassland soils and a significant increase in woodland soils between the two sampling periods while no overall change in C content was observed when those sites were included in the analysis. Further, the number of sites where there was a land-use change was too small to test any effect of land use changes on carbon stocks. Consequently, Chapman *et al.* (2013) suggested that future monitoring initiatives should focus on increasing the number of sites sampled where a land-use change has occurred.

Reynolds *et al.* (2013) reported the results of the Countryside Survey for the period 1978-2007. The Countryside Survey is an integrated national monitoring program that measures vegetation, physical, chemical and biological soil quality (0-15cm), water quality and land use across the United Kingdom. The United kingdom was stratified first into land classes based on the major environmental gradients across the countryside such as altitude, average annual temperature and average rainfall. That way, the sample could be considered as representative of the range of different environments found in the United Kingdom. Subsequently, within each land class, a set of 'sample squares' measuring 1km x 1km, were selected randomly from the Ordnance Survey grid (Carey *et al.*, 2008). As far as possible, the same sample squares are sampled each time the Countryside survey is repeated. The first survey was conducted in 1978 and consisted of 256 1 by 1 km squares. The vast majority of those squares were also visited in 1984, 1990, 1998 (CS 2000) and 2007 by which each sampling round included a greater number of sample squares. The authors performed power analysis of the existing CS dataset (1978 & CS2000) to determine the number of squares needed in CS2007 to give adequate reporting power for detecting C-changes in soils in Wales, and greater power for soils in Scotland and England. This resulted in 591 sample squares by which a 64.6%; 90.1% and 72.5% chance of observing a 10% change in C-content with a significance of 5% was obtained for England, Scotland and Wales, respectively (Emmett *et al.*, 2008).

Within each sample square, **five randomly placed plots** (200 m^2; Figure 8) are used for soil sampling. In summary, the sampling strategy is hierarchical, with random placing of plots within randomly chosen 1 km squares within the different land classes by which the same plots are revisited for each successive survey augmented with additional 1 km squares.

In 1978 soil samples were collected from a soil pit in the center of each of the five main survey plots. During the 1999 sampling campaign, soil samples were collected from a point 15cm to the north of the inner 2 by 2m plot at the center of the same main survey plots as in 1978. In 2007 soil samples were collected from a point 15cm to the south of the inner 2 by 2m plot, resulting in soil sample locations approximately 2 to 3m apart between Countryside Surveys. Plots were relocated using maps and/or permanent metal markers placed in previous surveys. If resampling of plots was not possible due to access restrictions or loss to urbanization, a new survey plot was randomly located within the sample square using rigid statistical design criteria (Reynolds *et al.*, 2013).

In 1998 and 2007 one plastic core (**15cm deep by 5cm diameter**) per survey plot was hammered into the soil after removal of loose vegetation and plant litter to obtain a core with a known volume. This core was used for the determination of **stone volume**, **bulk density, soil C and N and pH**. Using the ISO standard method for measuring the bulk density (ISO ISO 11272:2017) requires drying all the soil in a core at 105°C, which would change the soil to such an extent that no other analyses (e.g. pH, carbon content) would be possible. Hence, Emmett *et al.* (2008) suggested an alternative method which implies the use of one core sample and subsampling for pH and air-drying. Further, soil C concentration (in grams per kilogram) was estimated for every soil sample from loss on ignition (LOI; 16h at 375°C).

When conducting soil surveys, there is the inevitable occurrence of missing values, for example, when plots can no longer be used in the survey or cannot be relocated. To cope with incomplete observations, the data of the countryside survey were analyzed using a repeated measures mixed – effect model containing random square and plot effects and an autocorrelation parameter of order one to allow for correlation between successive measurements of the same plot (Scott, 2008). The model makes maximum use of the data (it utilizes all the available data in each survey year), especially the power obtained from resampling of plots over time. The magnitude of the power was not specified.

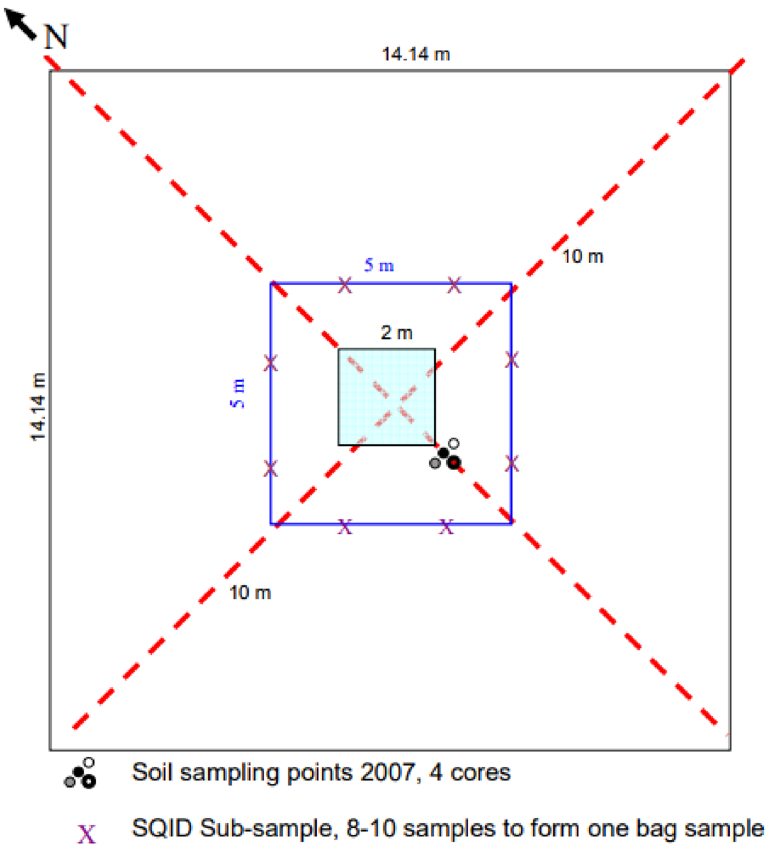


Figure 8. Schematic presentation of the sampling design used for each sampling plot of the Countryside Survey (Emmett et al. 2008)

1.1.9 Ireland

In **Ireland**, a consistent **national-level soil monitoring network (SMN) is still lacking** (O'Sullivan *et al.*, 2017). Therefore, O'Sullivan *et al.* (2017) investigated the development of a SMN for Ireland using existing Irish soil projects and data while also considering the costs of implementation. To do so, existing data were intersected with variable spatial grid intervals based upon SMN approaches utilized outside of Ireland. Following the guidelines of Morvan *et al.* (2008), who stated that existing sites must have GPS locational accuracy and that on those sites at least one or more measuring campaigns have already been conducted, three existing Irish national data sets were considered. The National Soils Database (NSDB), the Irish Soil Information System (SIS) and the Tellus-Project.

The **National Soils Database** (NSDB) is a national database of soil geochemistry for Ireland of major nutrients and trace elements. A total of 1015 soil samples were collected between 2003 and 2005 from predetermined positions on the national systematic grid (two samples per 100 km^2, no stratification was used) excluding the southeast of the country (n = 295), which was previously surveyed in 1995–1996. At the 1310 sampling locations, **25 soil cores were sampled from a 20 by 20 m square, at 5 m intervals to a depth of 10 cm** and combined to form a composite sample (Fay et al., 2007). All 1310 samples were sub-sampled and these were analysed for a number of chemical parameters (e.g**. Soil organic carbon, pH**, available P).

A **subset** of these sampling sites (n = 71) was sampled more intensively in the period 2005-2007 to measure **soil carbon stocks** in a representative number of Irish soils (Kiely *et al.*, 2009). The 71 sites represent **five land-cover types** (arable, grassland, peatland, rough grazing and forest) and nine soil types and were considered representative of the major land uses and soil types throughout Ireland. At each site, which was located in the field using the GPS coordinates given by the NSD, a 20 m × 20 m sampling quadrat was laid out on a north– south central axis. Photographs, elevation, land cover, land-use history, vegetation and soil profiles were recorded at each site. At each site, **bulk density and soil samples** were collected. At each sampling point, surface litter was removed prior to sampling, but no attempt was made at removing the O horizon. This was an a priori decision for ease of sampling across dissimilar soil types and land uses. Bulk density samples were taken using the **core method** at five points: the corners and centre of the square plot. A fixed volume bulk density sampling ring (5cm deep and 8 cm diameter) was used and core samples were taken at six depths: **0–5 cm, 5–10 cm, 15–20 cm, 20–25 cm, 40–45 cm and 45–50 cm**. Soil samples for **elemental analyses** were collected at nine points on the quadrat. Soils were collected for a continuous profile from the surface to 50 cm deep, broken into the following sections: **0–10 cm, 10–25 cm and 25–50 cm** deep. Kiely *et al.* (2009) also conducted a small-scale soil sampling study on a 50 m × 50 m plot in a grass field of know land-use history to determine the number of samples and the time period needed to detect changes in SOC and to quantify what level of change could be detected. Therefore, the authors set the probability for falsely rejecting the null hypothesis at 5% (α = 0.05) and the probability for falsely accepting the null hypothesis at 10% (β = 0.10 , **i.e. statistical power = 0.9**).

The **Irish Soil Information System** (SIS) includes a soil survey to produce the 3rd Edition National Soils Map of Ireland (Creamer *et al.*, 2014) and an associated database describing 807 sites. 228 of those sites, which were selected at representative locations across the country, were characterized between 2012 and 2013. At each site the principal landscape features (relief, topography and land use) were described and a profile pit was excavated to a depth of approximately 1.2 m. After an extensive description of the soil profile (e.g. structure, colour, stone content), each horizon was sampled for laboratory analysis, which assessed pH, total organic carbon content and total nitrogen. **Bulk density** was sampled with fixed volume stainless steel rings (98 cm^3). **Three rings were taken per horizon** to determine the degree of variation of bulk density within a given soil profile and horizon. Data for bulk density are reported as the average value for each horizon.

The **Tellus Project** contains a national-scale geochemical and geophysical survey conducted by the Geological Survey of Ireland. The survey was conducted at high density collecting data using ground sampling and airborne geophysical techniques. This resulted in regional baseline data which describe the inorganic chemical distribution in shallow (**5–20 cm**) soil. The survey of the Northern part of Ireland was conducted in 2011–2012 and collected 7000 samples. Sampling points **were randomly distributed based on an ad hoc gridded survey design** at a density of 1 per 4 square km. The national survey is expected to be completed around 2025 (http://www.tellusborder.eu/Home.htm).

In a first step, O'Sullivan *et al.* (2017) intersected different grid layers and the existing data points of the national datasets described above. **10 or 16km grid intervals** were found as the best option for geographic coverage and grid capture of the existing data points (Figure 9).

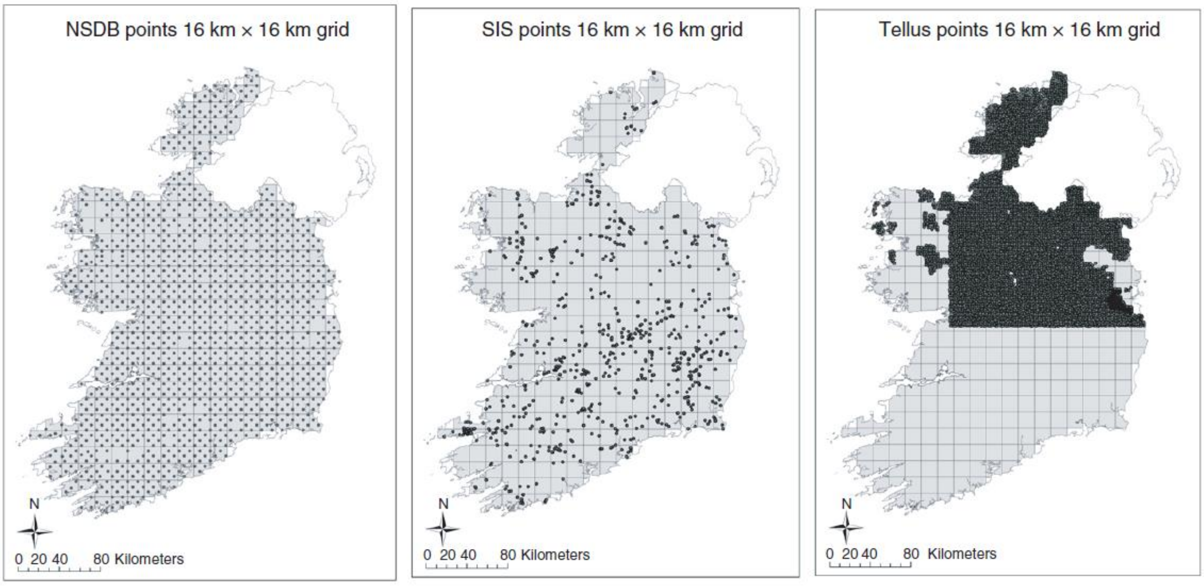


Figure 9. Spatial distribution of the sites of the three Irish databases applied to a 16 km² grid interval (O'Sullivan et al., 2017)

According to the authors, an optimized grid design (**a combination of stratification and grid interval spacing**) offered a better scope for achieving broad geographic coverage while responding to questions posed to the SMN**. Land use data** (i.e. arable, bioenergy, broad/mixed and coniferous forestry, managed grass, unimproved grass and Natura 2000) and **soil drainage categories,** which were considered as the main drivers that govern soil quality, were used as stratification factors. In a second step, O'Sullivan *et al.* (2017) performed an economic analyses and identified the 16 km² resolution in combination with the SIS data with land use by drainage stratifications (628 sampling sites) as the option with the best value for money. Baseline analysis costs were estimated between 706.481 euro and 2.769.888 euro, depending on the selected soil parameters (e.g. with or without a biodiversity assessment). Field costs were estimated at another 25%.

1.1.10 Spain

Currently, no nationwide network for monitoring soil organic carbon stock changes does exist in Spain (Karl Vanderlinden, personal communication, January 16, 2018).

A study by (Rodríguez Martín *et al.*, 2016) was the first assessment of the SOC stored in entire Spanish surface soils (arable land, grassland, forest, other) obtained from one sampling protocol within a regular sampling framework (8x8 km) in a short time. The authors analysed topsoil samples (0–30 cm) from 4401 locations. At each location 4–20 individual soil cores were collected from the upper 20–30 cm of soil and mixed to form a composite sample. Soil organic carbon content, soil bulk density and stoniness were measured to estimate the soil organic carbon stocks. The results showed that there is inherently wide spatial variability in SOC contents in Spain with low SOC concentration levels located in southern areas. The lowest SOC levels were associated with agricultural soils. However, no statistically significant differences were found between forestlands and grasslands. Further, spatial variability of SOC, BD and stoniness to determine carbon stock was determined. Spatial correlation range was significantly wider for BD than for SOC and rock stoniness.

1.1.11 The Netherlands

Despite the fact that guidelines to develop a monitoring system for soil organic carbon stocks in the Netherlands were already provided in 2006 (Hoogland *et al.*, 2006), currently, **no nationwide network for monitoring soil organic carbon stock changes does exist in the Netherlands** (Peter Kuikman, personal communication, January 12, 2018).

A nationwide network for the monitoring of soil quality in general does exist (‘Landelijk Meetnet Bodemkwaliteit’) (Wattel-Koekkoek *et al.*, 2013). The network was initiated in 1993-1997 and resampled in 2006-2010. For this purpose, 200 locations were sampled. Soil quality is determined at the farm level. The network uses a stratified, random sampling by which land use and soil type are regarded as the main determining factors for variations in soil quality. This resulted in 10 combinations and within each combination 20 locations were selected (= 200 locations). With these combinations, the greater part of the rural area of the Netherlands was covered and each location consisted of several parcels of one farm or natural area.

At each farm, 320 core samples of the topsoil (**0-10cm**) were taken from different parcels and mixed (composite sample). Further, 16 soil cores were taken from the **30-50cm soil layer** and mixed, also at different parcels. At **the forest plots**, 40 individual 20x20cm samples are taken of the litter layer and mixed to form a composite sample. Further, the soil is sampled to a **depth of 10cm** on those 40 locations and 16 of those locations are sampled at the **30-50cm** depth. A total of 20 forest locations were sampled, belonging to the category “Forest on sand soil”.

The majority of the farms (80-90%) that were sampled during the first sampling campaign (1993-1997) were resampled in 2006-2010. A wide array of soil properties was determined (e.g. SOC, pH, Total N, plant-available nutrients).

1.1.12 Switzerland

Switzerland has a **non-systematic monitoring network** (Réseau de mesure NABO) that covers the land use types forest, cropland, nature and parks (Gubler *et al.*, 2015). The 102 sampling sites are stratified by land use, soil type and geology (Figure 10). Sampling started in 1985 and approximately one fifth of the sampling sites is sampled every year. Plots are 10 x 10 m^2 squares and per plot 4 samples are collected, each consisting of 25 subsamples (0-20 cm). Since 2005, 4 subsamples of 20-40 cm were added and since 2010 4 subsamples up to 1 m were collected (sampled by horizon). Bulk density was measured in the upper 20 cm. For 48 agricultural sites, a detailed inventory of the management is done by quantifying all agricultural inputs (such as manure, herbicide use, etc.) and harvested products.

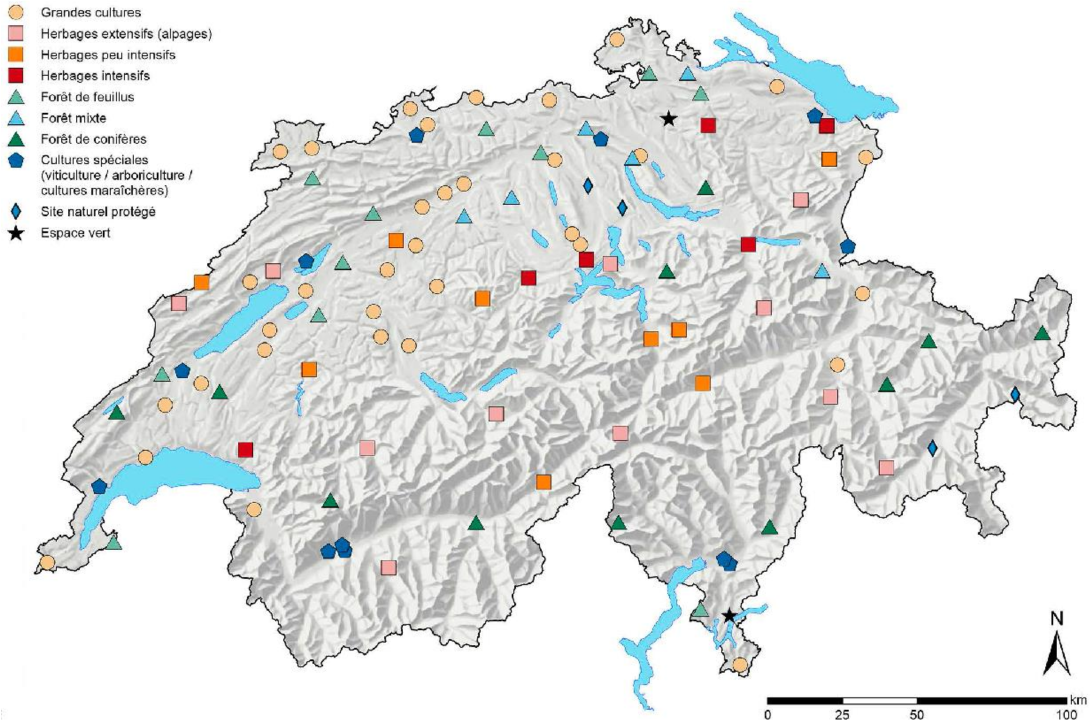


Figure 10. NABO reference sites by land use class (Gubler et al., 2015).

1.1.13 European soil monitoring networks

1.1.13.1 GEMAS

GEMAS stands for Geochemical Mapping of Agricultural and Grazing Land Soil over agricultural soil (0–20 cm) and grazing land (0–10 cm) spans across 33 European countries (Reimann *et al.*, 2014). During 2008 and until early 2009, a total of 2108 samples of agricultural (0–20 cm) and 2023 samples of grazing land (0–10 cm) soil were collected at a density of 1 site/2500 km² each from 33 European countries, covering an area of 5.600.000 km². All samples were analysed for 52 chemical elements and soil properties, like CEC, TOC, pH (CaCl2), following external quality control procedures. In addition, the agricultural soil samples were analysed for 57 elements in a mobile metal ion (MMI®) extraction, lead isotopes and magnetic susceptibility. The GEMAS project thus provides for the first time fully harmonised data for element concentrations and soil properties known to influence the bioavailability and toxicity of the elements at the continental (European) scale. The provided database is fully in compliance with the requirements of the European REACH Regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals).

1.1.13.2 LUCAS

The LUCAS (Land Use/Cover Area frame statistical Survey) soil survey collects information from EU Member States (MS) on land cover and land use (Tóth *et al.*, 2013). Using the intersection points of 2 x 2 km^2 sampling grid resulted in around 1 000 000 georeferenced points. Each point was classified according to seven land cover classes using orthophotographs or satellite images (Eurostat 2012). A subsample of around 200 000 points was selected for 23 MS as a representative sample for the LUCAS 2009 survey as control points for the survey. The total number of soil samples collected in the frame for 25 MS (EU-27 except Bulgaria and Romania) with exact geographic coordinates is 19 967.

1.1.13.3 ICP Forest level I plots

Baritz *et al.* (2010) estimated SOC stocks in European forest soils (0-20 cm) based on data from the 4279 ICP Forest Level I plots for the period 1985-1996 (Figure 11). Carbon concentration (%) was measured and stoniness was estimated visually from a soil profile at 73% of the profiles, and average values per soil type were assumed at the remaining locations. Bulk density was measured at approximately half of the locations and estimated by pedotransfer function in the remaining half. In 80% of the cases, the litter weight (kg m^{-2}) was measured. However, between-country differences in sampling and analysis introduced a substantial error in the study results. De Vos *et al.* (2015) harmonized sampling and analysis protocols between countries for the second inventory in 2004-2009 and updated the estimates of Baritz *et al.* (2010). This survey was carried out within the large-scale European BioSoil project that investigated the feasibility of providing harmonized soil and biodiversity data under a forest monitoring scheme. Soils were now measured up to 80 cm depth and bulk density was measured in all plots. Special attention was given to the peat soils.

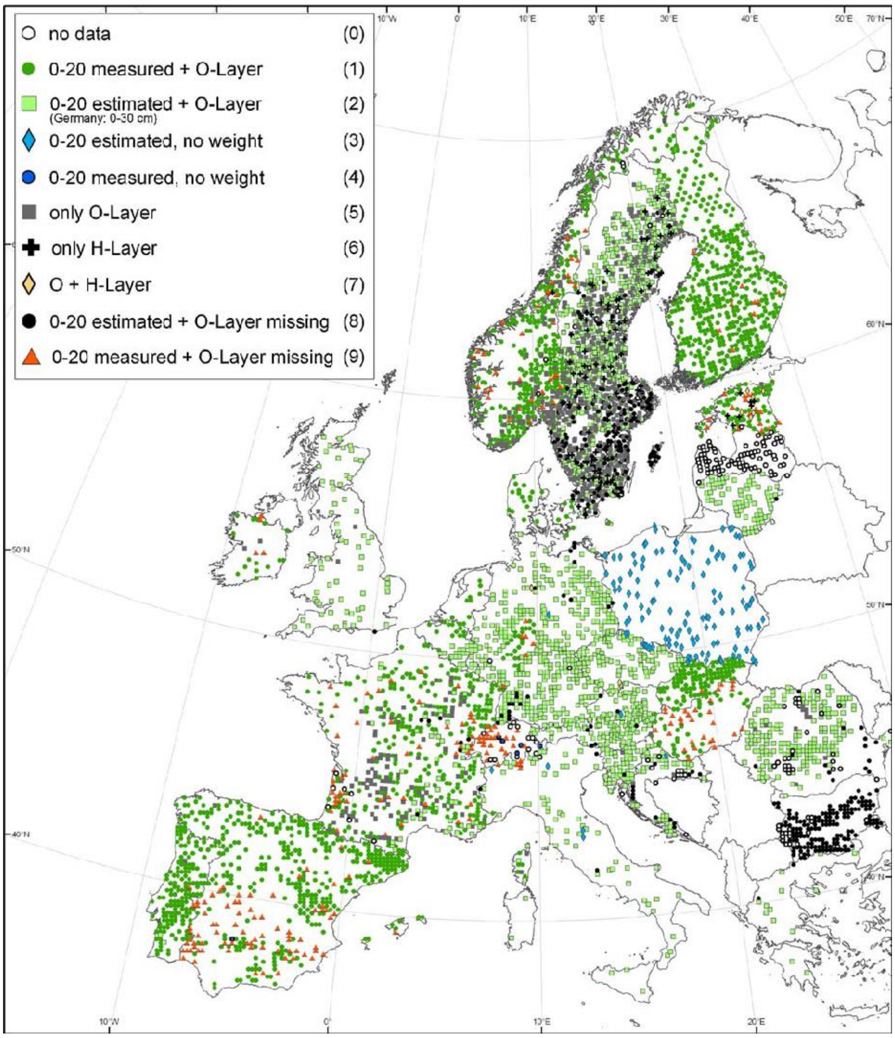


Figure 11. Map of the EU/ICP Forests LevelI plots (Baritz et al., 2010)

The main environmental factors controlling SOC stocks were investigated by boosted regression trees and it was revealed that forest floor C stocks were mainly predicted by humus form or tree species, while the 1-m SOC stock in mineral soils was best predicted by the reference soil group of WRB, but ecoregion, mean annual precipitation (MAP) and humus form were potentially important predictors as well. Forest characteristics, such as tree species, forest type or stand type, were not retained as predictors and neither were the soil characteristics parent material or soil depth. The parent material had the largest influence on the peat SOC stocks though.

1.1.14 Conclusions

Which land use types have been included in the surveys?

Depending on the country, several land use types are included in the surveys: arable land, (permanent) grasslands, forest, bogs, orchards and vineyards, parks and gardens, etc. In most surveys, the three main land use types (arable land, grassland and forest) were included while only two surveys (i.e. SMN's in France and Germany) included private gardens as well. Natural vegetation was included as a separate land use class only in Spain, Scotland and United Kingdom.

What sampling depth was used and which sampling protocols were used at the sampling site?

Different opinions are expressed concerning the appropriate soil sampling depth. When the sampling is limited at shallow depths the field work is less time-consuming. Moreover, a shallow sampling depth is often chosen for reasons of efficiency, as soil organic carbon predominantly accumulates at the topsoil (0-30cm). In our report, in approximately one third of the surveys soil sampling was limited to the topsoil (0-30 or 0-15cm). In those surveys, no extrapolation was performed to estimate soil organic carbon stocks below 30cm.

It has been shown that the SOC pool in the upper mineral soil is not a useful estimator of the total soil C pool as a substantial fraction of this pool can be stored in the subsoil. Although the SOC pool in the subsoil is less dynamic over time it may contribute to changes in the total soil C pool (Lorenz *et al.*, 2011). In the remaining two third of the surveys, soil was sampled to 50-100cm. In some cases, sampling depth differed between sampling campaigns. E.g. in Germany the first sampling campaign measured soil organic carbon stocks at 1m deep while future samplings will most likely not include all depths. In France, the initial sampling was limited to 50cm deep while deeper soil layers were incorporated in the consecutive sampling campaign.

Avoiding subjectivity and allowing comparison between different sites are among the most important reasons for adopting fixed increments rather than pedogenetic horizons. Consequently, in the greater part of the surveys in our report, the soil was sampled at fixed depths. In one case (i.e. SMN of France) the presence of a plough pan was the determining factor in sampling by horizon or by a fixed depth. If a plough pan was detected, the soil was sampled by horizon whereby the first horizon was sampled above the plough pan while the second horizon was sampled below the plough pan till a depth of 50cm. If no plough pan was observed (e.g. grassland and forest soils), the soil was sampled at fixed depths (0-30, 30-50cm).

In most surveys, the sampling at the sampling site was executed following the same procedure. First, at each site a soil pit was dug from which the soil profile was described and samples were taken to determine bulk density and soil organic carbon content. In most surveys, volume-based samples were taken by means of metal rings at different depths in the soil profile. The metal rings were either samples at the middle of each soil layer or several metal rings were sampled in a soil layer, each at a different depth interval within that soil layer.

Afterwards, individual soil cores were taken in a radius around the central sampling point. Those individual soil cores were either pooled to form a composite sample (in most cases) or treated as individual samples to investigate small-scale variability. In some surveys, the deeper soil layers are only sampled at the central sampling location.

In order to create the composite sample, between 5 and 25 subsamples were pooled. Kirwan *et al.* (2005) investigated spatial variability of forest plots at three forest monitoring plot3 Level II sites in the UK. Detailed soil sampling was carried out and based on the multivariate variogram for each site the authors suggest that a bulked sample from 36 cores would reduce error to an acceptable level. Furthermore it was concluded that sampling should be designed so that it neither targets nor avoids trees and disturbed ground and that a stratified random sampling design was most suitable for this purpose.

The sampling grid which was installed to collect the subsamples on each sampling location differed between the different surveys:

The subsamples are located on a radius of e.g. 10m around the central sampling point. The location slightly differs between different monitoring campaigns

A square-shaped sampling plot (e.g. 10 x 10m²) in which subsamples were taken randomly

A square-shaped grid area (e.g. 50 x 50 m², 20 x 20 m²) divided into a number of smaller grid cells (e.g. 2 x 2m²) by which a fixed amount is sampled. The sampled grid cells differ between different sampling campaigns.

Which method was used to locate and relocate the sampling locations?

In former monitoring surveys, relocation of the sites was carried out using the original aerial photographs on which the sites were marked and/or permanent metal markers which were placed in previous surveys. In more recent surveys, coordinates of the sampling location and the sampling grid are determined by means of GPS.

Which soil parameters are included in the monitoring and which analysis protocols are used?

To determine soil organic carbon stocks both soil organic carbon content as soil bulk density have to be determined. Consequently, in most surveys both parameters were included. In most cases the soil organic carbon content was determined by means of dry combustion while metal rings were used to determine bulk density (as described above). If bulk density values were not available for every sampling location, a pedotransfer function was used or soil bulk densities were retrieved from matching soil profiles in existing soil profile databases.

Besides soil organic carbon content and bulk density, total N (by means of dry combustion) and soil texture (wet sieving and sedimentation) are soil parameters which are frequently measured.

Which method was used to select the sampling locations? If stratification was used, which strata were included in the analysis?

In the greater part of the surveys no stratification was performed to select the sampling locations. Instead, an unstratified, systematic sampling grid was installed (e.g. 8 x 8 km, 16 x 16 km). After, sites are selected at the centre of each grid cell or at a point of the grid which is located on the land use of interest.

A systematic sampling grid can deliver a good resolution to be representative for soil type/land cover combinations when the area is covered by a homogenous land use and soil type. In the French SMN (RMQS), this problem was circumvented by only sampling sites representative for the dominant soil type/land use combination for the specific grid cell but this is not representative for the variation within the grid cells. Therefore, stratification seems the better option, like the stratified Dutch SMN in which only farms were included that covered a single soil type, thereby covering all dominant soil type/land use combinations. Or the Countryside survey (UK) that used land classes based on the major environmental gradients across the countryside such as altitude, average annual temperature and average rainfall. The Swiss monitoring network stratified by land use and management intensity (for agricultural land) or tree species (for forest).

Besides, when presenting the results, most countries evaluate different stratifiers. For the nation-wide networks, results are most often presented by land use type (Scotland, UK, Switzerland), while other countries further distinguish per soil type (Bavaria). The countries that have a network limited to forest distinguish between tree species (France-RENECOFOR) or between soil types (Germany, Denmark). For the organic layer (litter), total carbon stocks are presented by tree species. De Vos *et al.* (2015) decided that for the European forests, soil type was the main determining factor for the C stocks of the top soil.

What is the sampling frequency?

A study by Saby *et al.* (2008) pointed out that a time interval of about 10 years would enable the detection of some simulated large changes in soil organic carbon stocks in most European countries.

Most of the SMNs in this report make use of this time interval (e.g. Denmark and France). The SMN in Germany (the first sampling campaign was finished in 2017) is also aiming for this time interval. Very often, the countries survey a fixed part (mostly 10%) of the sampling locations every year.

Did the monitoring network include the monitoring of land use and land management as well?

Different approaches were used to collect information about land use and land management. Information can be collected by a comprehensive questionnaire as is the case in the SMN of Germany. In addition to the soil sampling, a questionnaire on the agronomic management and the land use history of the sampling site is completed by the farmer/field manager. Afterwards, the data is stored within a comprehensive, geo-coded information system. In Denmark, farmers hosting sampling areas are asked every year to submit reports with information on the previous year's land use (e.g. grass leys, spring sown row crops) and management (e.g. cattle manure applied, soil ploughed). Other surveys use field observations to assign land use category to the sampling sites.

Did the surveys make use of soil carbon data from existing databases or monitoring networks?

If the assessment of soil organic carbon stocks at a given point in time or if the detection of stock changes over a specific time period were the main interest, most surveys made use of data from existing databases such as permanent soil observation sites (Germany - Bavaria), national soil surveys (e.g. Scotland, Ireland), the national soil database (e.g. Italy), etc. Few SMNs made use of existing data except for the Danish SMN which contains profiles belonging to a nation-wide square grid monitoring net ('Kvadratnettet') in order to improve fertiliser recommendations.

How did foreign monitoring networks cope with a change in land use between two sampling campaigns?

In most surveys, a change in land use was indicated as one of the main interests of the soil monitoring network. Consequently, a change in land use was recorded and the sampling location was retained in the network. However, if testing any effect of land use changes on carbon stocks is the aim, the number of sites where a land-use change occurs should be significant.

Did they set goals for the minimum detectable difference and the type II error? The use of carbon modelling to e.g. detect temporal variability?

The greater part of the surveys did not include goals for minimum detectable difference and the type II error or made use of carbon modelling to e.g. detect temporal variability. Kiely *et al.* (2009) conducted a small-scale soil sampling study on a 50 m × 50 m plot in a grass field of know land-use history in Ireland to determine the number of samples and the time period needed to detect changes in SOC and to quantify what level of change could be detected. Therefore, the authors set the probability for falsely rejecting the null hypothesis at 5% (α = 0.05) and the probability for falsely accepting the null hypothesis at 10% (β = 0.10 , **i.e. statistical power = 0.9**).

1.2 LAND-USE MAPPING TO ENABLE FUTURE REPORTING OF SOC STOCK CHANGES IN THE FRAME OF LULUCF-ENGAGEMENTS

1.2.1 Introduction

As Belgium ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1996, it is committed to develop, publish and regularly update national emission inventories of greenhouse gases (GHGs). For the second commitment period of the Kyoto Protocol (2013-2020), Belgium communicated an independent quantified economy-wide emission reduction target of a 20 percent emission reduction by 2020 compared with 1990 levels (base year). In Belgium, the 3 regions are responsible for delivering their greenhouse gas inventories, which are later compiled to produce the Belgian GHG inventory. For Flanders, the main regional institution involved is the Department Air, Environment and Communication of the Flemish Environment Agency (VMM).

LULUCF is a part of the inventory and comprises the greenhouse gas emissions and removals from land use, land use change and forestry. Belgium follows the methodology described in IPCC 2006 Guidelines and 2013 KP supplement to establish the LULUCF inventory. One of the basic activity data in the LULUCF-inventory is the land-use change matrix (Bauwens *et al.*, 2010). The LUC matrix was determined by the Gembloux University (Gembloux Agro Bio Tech). The method adopted for monitoring of the land-use for Belgium is a grid of points (1 X 1 km²; 6799 point for Flanders) on which a diagnosis of occupation/land use is carried out for the various dates of reference. With each point of the grid of reference is allocated one of the 6 categories of land use proposed by the IPCC: forest land, cropland, grassland, wetlands, settlements and other land. A method of estimate of surface, by counting of points is then possible.

The diagnoses of occupation/land use are carried out following two types of information: vectorial cartographic layers related to the land use (example: Forest reference layer in Flanders, agricultural area data collected in the framework of the Common Agricultural Policy of the EU 'landbouwgebruikspercelen); or image layers (orthophoto plans or satellite images with very high-resolution). The attribution of a category of land use on the points not classified following geoprocessing is ensured by photograph interpretation of orthophoto plans. By means of this study the land-use matrix for Belgium was determined for 1989/90, 2009 en 2012. Currently, the land-use matrix of 2015 is being developed and will be further updated for the National Inventory Report in 2019.

1.2.2 Forest land

This category includes all land with woody vegetation consistent with thresholds used to define forest land as described above (0.5 ha). It also includes systems with vegetation that currently fall below, but are expected to exceed, the threshold of the forest land category. Forest inventories were conducted both in the Flemish and the Walloon regions to determine the surfaces by categories of property (Private or Public: State, Province, Community), type of forest, species, age, size and quality. The sampling points of the regional forest inventories were selected according to a 1.0 km x 0.5 km grid oriented from the east to the west on the National Geographic Institute (NGI) maps at a scale of 1/25000. In Flanders, 2665 plots were sampled in the framework of the first forest inventory, which was constituted in the period 1997-1999 (Ministerie van de Vlaamse Gemeenschap, Afdeling Bos & Groen, 2001). This regional inventory is intended to be repeated every 10 years, to allow e.g. the calculation of growth rates in the Flemish forests. In 2009 measurements started for the second permanent forest inventory in the Flemish region.

Lettens *et al.* (2005) estimated the soil organic carbon stocks in Flemish forest soils (0-30cm) at 79 t C ha^{-1} in 2000 in Flanders in the 0-30cm soil layer. The authors quantified changes in SOC stocks in Belgium (Flanders) between 1960, 1990 and 2000 for 289 spatially explicit land units with unique soil association and land-use type, termed landscape units. The SOC stocks were derived from multiple non-standardized sets of field measurements up to a depth of 30 cm. The SOC evolution between 1990 and 2000 was estimated at 0.425 t C $ha^{-1}yr^{-1}$ in Flanders.

1.2.3 Cropland and grassland

'Croplands' include arable and tillage land, and agro-forestry systems where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions. The carbon stocks of perennial woody crops such as orchards are also estimated. Grasslands includes rangelands and pasture land that is not considered as cropland. It also includes systems with vegetation that fall below the threshold of forest definition and are not expected to exceed, without human intervention, the threshold used in the forest land category.

The soil C stock values in mineral soils (0-30cm) for cropland and grassland have been updated in 2015, through a new study by Meersmans *et al.* (2011) who used a modeling approach to analyze the spatial patterns and temporal evolution (1960-2006) of organic carbon in mineral soils under agricultural land use in Belgium. Data corresponding to the 1960s were selected from the Aardewerk database (7200 locations) after which 629 profiles under grassland and cropland, over a wide range of soil types over the entire country, were resampled during field campaigns in the period 2004-2008. The resulting SOC stocks and carbon stock evolution are given in Table 2.

Table 2. Soil organic carbon stocks (t ha^{-1}) and evolution in carbon stocks (t $ha^{-1}yr^{-1}$) in mineral arable and grassland soils (0-30cm) in Flanders for the period 1960-2006 (Meersmans et al., 2011).

Land use	SOC stock (t/ha^{-1})		SOC stock change (t $ha^{-1}yr^{-1}$)
	1960	2006	
Cropland	54.6	54.9	-0.016
Grassland	74.6	73.7	-0.019

1.2.4 Wetland, settlement and other land

Wetlands include land that is covered or saturated by water for all or part of the year (e.g. peat land) and that does not fall into the forest land, cropland, grassland or settlements categories. It includes reservoirs as a managed subdivision and natural rivers and lakes as unmanaged subdivisions, in line with IPCC 2006 Guidelines. **Settlements** include all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. **Other lands** include bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

The SOC of wetland was estimated at 100 t C ha^{-1} by VMM *et al.* (2017). This value is used for calculation of C stock change in soils. It is considered as provisional as a clear distinction of wetland and reservoirs is still lacking. However, it should be noted that the areas subjects to land use from and to wetlands are very limited compared to other subcategories. In this sense, the impact of this subcategory on the emissions/sinks should also be limited. For wetlands remaining wetlands, emissions are reported as 'not occurring'. No data are available on an evolution of the C stock, which is assumed stable.

In absence of default values in the IPCC guidelines, average soil carbon content under settlements was estimated based on the SOC under cropland. Although many settlement were likely built on former grasslands, the SOC from cropland is used as an average value, as this approach is deemed more conservative and should reflect possible carbon losses during construction. For settlements remaining settlements, after consulting soil experts, it was assumed that no changes in soil C occur as these soils are mainly covered by concrete. **Finally, no more areas are reported under "other lands", for Belgium as these were reclassified.**

In summary, the carbon stocks and stock changes (0-30cm) under different land use types in Flanders as used in the LULUCF inventory of 2014 are given in Table 3.

Table 3. Carbon stocks and stock changes (0-30cm) under different land use types in Flanders as used in the LULUCF inventory of 2014 (VMM)

Land use	SOC stock (t ha^{-1})	SOC stock change (t ha^{-1} yr^{-1})
Forest land	95.5	0.425
Cropland	53.8	-0.016
Grassland	73.6	-0.019
Wetland	100	0.0
Settlements	48.2	0.0

The estimates of the soil C stock changes of land use change is calculated according to to the IPCC 2006 guidelines, assuming a 20 years duration of the transition from one land use type to another. For example, SOC stocks are assumed to increase for 20 years after conversion to Forest Land. After 20 years, the area converted enters the category Forest Land Remaining Forest Land, and no further SOC changes are assumed.

1.2.5 New LULUCF-regulation for the periods 2021-2025 and 2026-2030

Up till now, the emissions which were reported in the framework of LULUCF were not included in the EU effort to fight greenhouse gas emissions. However, from 2021 on, the regulation on land use, land use change and forestry will incorporate greenhouse gas emissions and removals related to agricultural land and forestry into the EU's climate framework. The new rules will enhance the role of land and forests as sinks of carbon and will incentivize their productive and sustainable use, enhancing the bio-based economy and climate-smart agriculture.

To ensure the contribution of the LULUCF sector to the achievement of the Union's emission reduction target of at least 40 % and to the long-term goal of the Paris Agreement, a robust accounting system is needed. In order to obtain accurate accounts of emissions and removals in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories ('IPCC Guidelines'), the annually reported values under Regulation (EU) No 525/2013 of the European Parliament and of the Council (

2) for land use categories and the conversion between land use categories should be utilized, thereby streamlining the approaches used under the UNFCCC and the Kyoto Protocol.

The new rules for the accounting of emissions and removals from LULUCF have been laid down by the European Parliament and the council of the European Union in REGULATION (EU) 2018/841. In this regulation the following the following land accounting categories are listed for the periods from 2021 to 2025 and from 2026 to 2030:

- '**afforested land**': land use reported as cropland, grassland, wetlands, settlements or other land, converted to forest land;
- '**deforested land**': land use reported as forest land converted to cropland, grassland, wetlands, settlements or other land;
- '**managed cropland**': land use reported as:
  - cropland remaining cropland,
  - grassland, wetland, settlement or other land, converted to cropland, or
  - cropland converted to wetland, settlement or other land;
- '**managed grassland**': land use reported as:
  - grassland remaining grassland,
  - cropland, wetland, settlement or other land, converted to grassland, or
  - converted to wetland, settlement or other land;
- '**managed forest land**': land use reported as forest land remaining forest land.

As of 2026:

- '**managed wetland**': land use reported as:
  - wetland remaining wetland,
  - settlement or other land, converted to wetland, or
  - wetland converted to settlement or other land.

The accounting method differs between the different accounting categories.

For afforested land and deforested land, the total emissions and total removals (i.e. gross-net) for each of the years in the periods from 2021 to 2025 and from 2026 to 2030 will be accounted.

Emissions and removals resulting from managed cropland, grassland and wetland will be calculated as emissions and removals in the periods from 2021 to 2025 and from 2026 to 2030 minus the value obtained by multiplying by five the Member State's average annual emissions and removals resulting from managed cropland, grassland and wetland in its base period from 2005 to 2009 (net-net).

Finally, emissions and removals resulting from managed forest land, calculated as emissions and removals in the periods from 2021 to 2025 and from 2026 to 2030 minus the value obtained by multiplying by five the forest reference level of the Member State concerned.

Belgium (Flanders) has committed to comply with the 'no-debit' rule by ensuring that for each 5-year compliance period (2021-25, 2026-30), the amount of carbon absorbed in the LULUCF sector is at least equivalent to that emitted, in accordance with the accounting rules.

1.2.6 The use of a regional wide monitoring network for improving the LULUCF-inventory

Currently, Belgium (Flanders) is using the Tier II approach to estimate GHG emissions from the LULUCF sector. This implies that emission and stock change factors are based on country- or region-specific data (described in 1.1.2, 1.1.3 and 1.1.4) for the major land-use categories. The use of a regional wide monitoring network would enable to adopt a Tier III approach, with estimates of greater certainty. A monitoring network could improve the LULUCF-inventory by:

1. Providing recent and accurate estimates of carbon stocks and carbon stock changes under different types of land use

   Current carbon stock estimates for different land use types are based on studies by VMM *et al.* (2017), Lettens *et al.* (2005) and Meersmans *et al.* (2011), who all quantified changes in Belgian or Flemish SOC stocks for various time periods. These studies adopted sound statistical approaches but date back to the early 2000s and so, calculated SOC stock change rates are outdated (viz. 1960-2006, 1990-2000) and not representative for the current land use and management. Therefore, implementing a carbon monitoring network across the different land use types of Flanders would provide us with accurate and up to date estimates of carbon stocks (first measuring round). Furthermore, the field sampling will be repeated in time by which results of the second survey (after 5 or 10 years) would provide insight into up to date SOC stock changes under the different land use types.

2. Providing insight into carbon stock changes when land-use changes occur

   Currently, estimates of the SOC stock changes following a change in land use assume a 20 years period during which SOC stocks alter from one land use's mean to another, at a constant rate. Mean SOC stocks for each of both land-use types are used to calculate the carbon stock rate of change. Implementing a carbon monitoring network, with accurate information on timing of land-use change of individual measurements would permit to more realistically track mean rates of SOC stock change due to land-use change. A large number of monitoring points would allow for to derive representative statistics on SOC stock rates of change for the entire population of parcels in Flanders. Regardless, additional points are probably needed to ensure that any relevant land-use changes are sufficiently covered.

3. Providing insight into the effect of land management on carbon stocks

   In the current LULUCF-inventory, constant carbon stock changes are used for the different types of land use, irrespective of the management. E.g. the SOC stock and rates of change are considered to be the same for 'old' and 'young' grasslands, though ample studies contradict this simplistic assumption. Insight into the average grassland age followed by a proportional allocation of the monitoring points to different age categories would allow for accurate estimates of SOC stocks and changes therein following establishment of grassland. Similarly, by aligning the C-MON monitoring network with the Flemish Forest Inventory, more insight will be gained in the effects of forest management on soil carbon stocks.

4. Providing insight into the carbon sequestration potential of wetlands

   Presently, the LULUCF-category 'wetlands' in Flanders consists mainly of open waters. Due to a lack of data, the evolution of the C stock is assumed stable (i.e. 0 t C $ha^{-1}yr^{-1}$). A clear definition of the category 'wetlands' for Flanders followed by the allocation of a number of monitoring points in wetlands would allow for an accurate estimate of carbon stocks and carbon stocks changes under wetlands.

Finally, it is not only the methodology tier, and/or the availability and accuracy of emission factors that influence the LULUCF-inventory but also the availability and accuracy of land use data. At present, the land-use change matrix of (Bauwens *et al.*, 2010) is being used. This method uses a grid of points (1 X 1 km) based on which a diagnosis of occupation/land use is carried out for the various dates of reference. Implementing a land use map with finer resolution (e.g. VITO-Ruimtemodel, 10x10m) could improve the translation of the land-use categories into the LULUCF-categories. This could result in a more accurate determination of land use in Flanders. Obviously, this is only possible if this new land use map is regularly updated during the reporting period (2021-2030).

1.2.7 Land-use derived from the VITO Ruimtemodel2013

For the present research we used the VITO-Ruimtemodel version 2013 to estimate areas of land-uses, both globally and per defined stratum (https://ruimtemodel.vlaanderen/). The VITO-Ruimtemodel 2013 subdivides the entire surface of Flanders over different land-uses at a 10x10m ground-resolution. Subcategories defined at level 1 (Niv_1) were relevant for the present project. In Table 4 Niv_1 levels are assigned to overall land-use categories Nature in orange, Forest in green, Grassland in blue, Cropland in yellow and Residential usage in grey. Acreages were then deduced from cell counts.

Table 4. Counts of 10x10m grid cells assigned to different land-uses in the VITO 2013 'Ruimtemodel'. Total surface of 'nature' is summed from orange marked land-use forms, likewise surfaces of grey-colored land-uses sums up to non-covered residential land.

Niv1_nr	Niv1_name	counts
0	-	80129719
1	Ruigte en struweel	2327792
2	Loofbos	4852116
3	Populieren	1743705
4	Naaldbos	5609144
5	Alluviaal bos	1054507
6	Halfnatuurlijk grasland	2856492
7	Heide	1028647
8	Kustduin	430576
9	Moeras	226885
10	Slik en schorre	9754
11	Akker	49311136
12	Niet geregistreerde landbouw	2707462
13	Hoogstam boomgaard	426076
14	Laagstam boomgaard	1576687
15	Cultuurgrasland permanent	14985888
19	Gebouw	8012444
20	Overig laag groen	13272066
21	Overig hoog groen	7029340
22	Weg	7892213
23	Spoorweg	490963
24	Water	3921980
25	Overig	8144408

1.3 USEFULNESS OF PAST SURVEYS SOIL ORGANIC CARBON TO START MONITORING IN FLANDERS

A policy oriented survey grid should firstly monitor the current condition and evolution of a target population, whether or not influenced by specified policy or management. Measurement locations used in previous soil sampling campaigns might be of use for design of the current monitoring initiative. In 1.3.1 an overview is given of past initiatives within the study area, Flanders, Belgium. However, a **first** chief precondition when designing any monitoring grid is that the sample should be non-selective. Only then could the target population (e.g. grassland on wet loamy soils) be described representatively by derived statistics. This is further investigated in 1.3.2. **Second**, methodologies of the past soil survey and the future SOC monitoring initiative need to be compatible (1.3.3). Finally, we explore if past surveys in Flanders might be of alternative use when designing a future monitoring grid in Flanders (1.3.4).

1.3.1 Former Soil Sampling campaigns

1.3.1.1 Cropland and Grassland

Since the beginning of the 21st century, several projects attempted to quantify stocks and stock changes terrestrial carbon stocks in Flanders or Belgium under forest, grassland and crops. The CASTEC project (Carbon Sequestration potential in different Belgian Terrestrial Ecosystems: quantification and strategic exploration) reported SOC stocks for 1990 and 2000. In Wallonia the SOC monitoring network CARBIOSOL was set up during the past decade. These and other studies usually (re)sampled soil carbon stocks in agricultural or (semi-)natural soils:

Sleutel *et al.* (2007) selected 116 locations in West-Vlaanderen that were originally sampled in 1947-1962 en 1989-1994 (Van Meirvenne *et al.*, 1996) for resampling in 2003-2004. These sites had been under agriculture since 1947. The C content and the bulk density of the topsoil were determined at each location.

Meersmans *et al.* (2011) developed a model that predicts carbon stocks for distinct classes of land use, soil type and drainage. The model was originally developed for Flanders (Meersmans *et al.*, 2008). In a subsequent study, it was extended to Belgium in order to investigate changes between 1960 and 2006. In order to calibrate and validate the model for 1960, **the Aardewerk database** was used. This database contains soil profile descriptions up to 1-1.5m depth and reports carbon concentration, land use, drainage class and soil texture data per horizon. For 2006, **629 of the profiles under cropland and grassland in varying texture classes were resampled (2004-2006) in the whole of Belgium, up to a depth of 30cm.**

Goidts and van Wesemael (2007) computed soil carbon stocks under permanent grassland and cropland in Wallonia for the period 1955-2005. For 1955, the authors used the **Aardewerk database**. Profiles were grouped into 'landscape units' (LSUs) according to soil type (soil texture and drainage), land use (derived from the Aardewerk database), climate and carbon input from crop residue and animal manure. Average values per agricultural zone were used to derive climate and manure values. Each LSU consisted of a unique combination of agricultural zone, land use (cropland or permanent grassland) and soil type. **The 9 landscape units where the largest changes in carbon stock (1955 versus 2005) were expected, were resampled in 2004-2005.** Carbon concentration and bulk density of the upper 30cm were measured. In order to initiate a SOC stock monitoring network of agricultural soils (so called '**CARBIOSOL**'), 6 additional landscape units were resampled in 2006 and 2007 (Goidts *et al.*, 2009). In the 15 LSUs **434 profiles** were resampled. These 15 LSUs covered about 54% of the agricultural area (Figure 12). Theses soil profiles have not undergone any land use change since the National Soil Survey, and the SOC stock in **the soil surface (i.e. the plough layer for cropland and the 0–30cm layer for grassland)** was estimated for each one based on equivalent mass to correct for changes in the soil bulk density or in the rock fragment content.

This dataset was completed in 2012–2014 by 158 locations sampled within 30 additional LSUs to improve the spatial coverage of the network. To quantify SOC budgets and spatialize SOC stocks at regional scale (Wallonia), **Chartin *et al.* (2017)** developed a computation procedure based on Digital Soil Mapping techniques and stochastic simulations (Monte-Carlo). Based on 529 soil profiles from CARBIOSOL, this procedure resulted in the computation of mean SOC stocks and confidence intervals at the pixel scale, for selected sub-areas and for the entire study area.

Moreover, two LSU situated in the Loam region (one under cropland and one under grassland) were further investigated in order **to collect more information on the agricultural management at the farm level** in an attempt to link such detailed data to regional SOC stock changes. Therefore questionnaires were filled in together with the farmer for each of the fields in which the soil profiles had been (re)sampled. Questions were related to the type of farm surveyed and to various characteristics that were expected to have an impact on the C input in soils: farm size, proportion of the area under cropland and grassland, quantity and type of organic amendment spread per hectare of cropland and grassland, type of animal husbandry, straw management, tillage depth, etc.

The SMN CARBIOSOL is based on a legacy database following a convenience scheme sampling strategy rather than a statistical scheme defined by design-based or model-based strategies. Further, the 592 points of the CARBIOSOL network do not allow a representative and a sound estimation of SOC stocks and its uncertainties for all combinations of land use/agricultural regions.

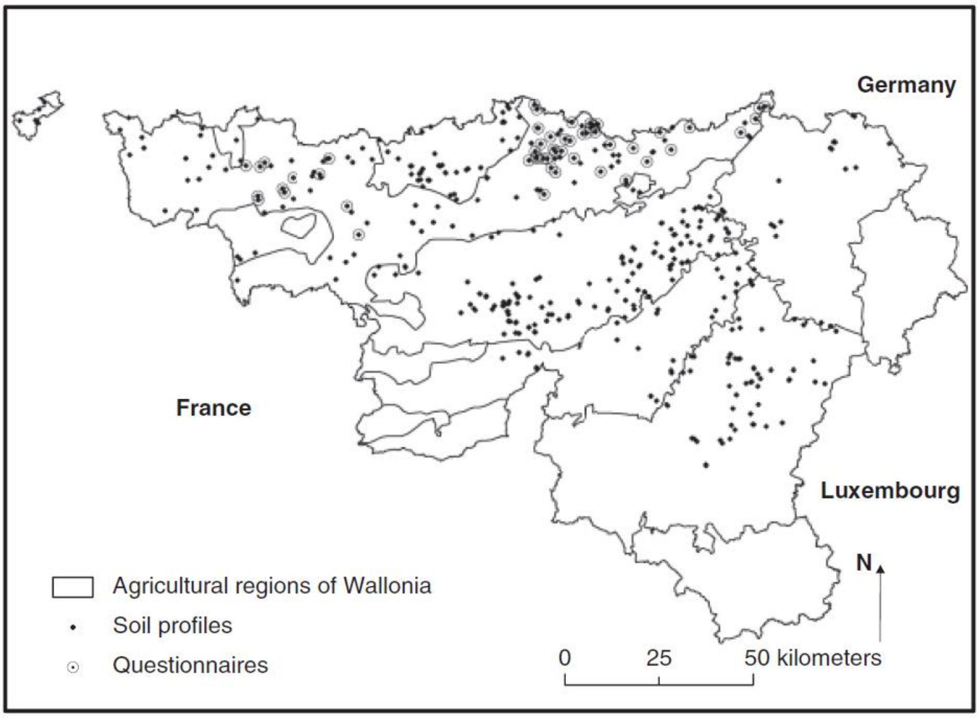


Figure 12. Study area and soil profiles of the network ‘CARBIOSOL’ implemented on agricultural soils (covering about 54% of the total agricultural area of Wallonia). Soil profiles for which questionnaires were undertaken are also shown (Goidts et al. 2009).

Mestdagh *et al.* (2009) collected data on carbon stocks up to 1m of depth under grassland in Flanders for 1990 and 2000. They combined available numbers on grassland area in Flanders (Algemene Directie Statistiek, landbouwtelling 1990 en 2000) with carbon measurements under grassland of the Bodemkundige Dienst van België vzw (carbon concentration 0-6cm, aggregated per municipality) and additional measurements of soil bulk density and the distribution of the carbon within the soil profile (0-60 cm). The carbon concentrations of the topsoil (0-6 cm) were extrapolated to a depth of 1m based on the Hillinski model. In order to increase the accuracy of the carbon distribution within the soil profile, a large number of soil samples were collected and the carbon concentration was analysed at different depths (0-10, 10-30 en 30-60cm) (Mestdagh *et al.*, 2009). The sampling locations were visited **between 2001 and 2004** and were situated in different grassland types in the **different agricultural zones of Flanders**.

At the request of individual farmers, the **Bodemkundige Dienst van België vzw** carries out a large number of standard soil analyses, including carbon concentration, of samples from cropland and grassland, in order to advise farmers on when and how much to fertilize their crops. Sampling is carried out on the level of the parcel up to a depth of 23cm in cropland and 6cm in grassland. The results are considered confidential and are therefore reported at an aggregated level (municipality and agricultural zone). Every 4 years the results are published in the report 'Wegwijs in de bodemvruchtbaarheid van de Belgische akkerbouw- en weilandpercelen'. Although these reports are based on a very large amount of data, the selection of the sampling locations is biased, since soil samples are presented by individual farmers to the Bodemkundige Dienst van België vzw.

On the **European level**, large-scale soil surveys were carried out in order to estimate the soil carbon stocks in European soils. This is discussed under 1.1.13 European soil monitoring networks.

1.3.1.2 Specific initiatives for forests, nature and residential land-use

Forest SOC stocks and the associated uncertainties were computed by averaging forest soil inventory data (De Vos, 2009). In this approach, historical (1949 – 1965) forest soil dataset HIBBOD (Leroy *et al.*, 2000) and the more recent dataset ForSite (1997 – 2002) were combined. The former contains 669 georeferenced forest soil profiles (0-125 cm) from the Aardewerk dataset (Van Orshoven *et al.*, 1988; Beckers *et al.*, 2011). Bulk density was estimated (De Vos *et al.*, 2005) and spatial coordinates were verified (Leroy *et al.*, 2000). During the ForSite inventory, 864 georeferenced soil profiles were sampled up to 120 cm depth, including humus layers, in 306 forest plots. The plots were selected as a subset of the national forest inventory (NFI) (Wouters *et al.*, 2008b). Whereas the NFI follows a 1 x 0.5 km² grid, the ForSite inventory followed a 2 x 2 km² grid. This study contains several key values of spatial variation of SOC stocks, both lateral (plot scale, stand scale, Flanders) as with depth (depth functions). Van Meirvenne *et al.* (2001) also collected geostatistical knowledge necessary SOC stock computation of forest soils. The ForSite stocks have been used for the calibration and validation of spatial SOC models (Ottoy *et al.*, 2017).

In Wallonia, forest soils were sampled on 10% of the grid points of the regional forest inventory ('Inventaire Permanent des Ressources Forestières de Wallonie' or IPRF), that follows a regular non-stratified grid of 1 x 0.5 km². Latte *et al.* (2013) computed the soil organic carbon stock in the upper 20 cm based on 566 locations that were sampled between 2001 and 2010. At each location, 21 soil cores of the 0-20 cm fixed depth layer were bulked. Stoniness was not measured. Bulk density was estimated in this study. Litter was weighed (kg m^{-2}) at 120 location and averaged over 6 humus types (calcic mull, mull, moder–mull, moder, dysmoder and mor).

No systematic survey has been carried out of soil organic carbon stocks in **natural open areas** of Flanders. Within the framework of the current HabNorm project of INBO, dominant Natura 2000 habitats in Flanders are sampled systematically since 2015. Around 200 soil surface samples (0-10 cm) are collected every year, together with deeper (0-120 cm) soil samples at ca. 30 locations in dunes, natural grassland, peat soils, heath and forest.

Leroy *et al.* (2002) brought all historical Aardewerk data together in HINBOD, the historical natural soils database. This database contains 846 profiles (530 are situated in Bird and Habitat Directive areas, 30 profiles lie within nature reserves, around 80 profiles are situated in 'very valuable' nature area) and 571 top soil samples. Historical SOC stocks can be computed for these profiles if accurate pedotransfer functions can be derived to estimate bulk density, calibrated based upon bulk density values of the HabNorm project.

Ottoy *et al.* (2017) estimated the soil organic carbon content in the upper 100 cm of soils in natural open habitats in Flanders. They collected soil data at 139 sites in nature reserves across different ecoregions. The resulting data were used to develop a statistical model with different soil and vegetation variables as parameters.

Systematic surveys in forests at the European level are discussed under 1.1.13 European soil monitoring networks.

1.3.2 Non-selective sampling to obtain unbiased statistics

A first pertinent question when considering making use of past monitoring initiatives is whether or not sampling locations were in fact chosen randomly or at least unbiased (Rawlins *et al.*, 2017) and (Arrouays *et al.*, 2012) already noted that any analyses ordered by farmers cannot be considered as random data points. Most often the focus is on parcels with crop growth issues, and this leads to biased outcome of the following statistical analysis. Wouters *et al.* (2008a) likewise concluded (in Dutch): "*Het is verleidelijk om de gegevens uit afzonderlijke al dan niet gelijkaardige meetnetten in een projectcontext te bundelen, om hieruit informatie voor een hele populatie af te leiden. Hiervoor is er echter geen statistische basis, aangezien de individuele elementen geen aselecte steekproef vormen uit een vooraf omlijnde doelpopulatie.*".

The in 1.3.1 listed SOC monitoring initiatives for cropland and grassland are critically evaluated in Table 5. We conclude that firstly LUCAS and original Aardewerk sites seem to qualify for selection in the frame of a future C-MON grid. More specifically, Aardewerk measurement points selected and sampled by Meersmans *et al.* (2011) and Van Meirvenne *et al.* (1996) might be useful sites to be included in the C-MON grid. These and LUCAS will be further elaborated below in paragraph 1.3.3.

Table 5. Overview of prime past inventories of SOC stocks in agricultural land and evaluation if site selection was unbiased and the C-MON initiative could be (partially) aligned.

Soil Survey/monitoring initiative	**Selective localization of measuring points?**	**Should C-MON sampling locations (partially) overlap?**
SOC measurements collected by Bodemkundige Dienst van België vzw & studies in frame of CASTEC/METAGE	Not guaranteed as analyses are issued by private owners and farmers	Impossible as sampling locations are not known.
Van Meirvenne *et al.* (1996): Resampling of 939 profiles of the National soil survey in 1990, only croplands in West-Flanders	Might be selective towards older croplands because only locations which remained cropland since the national soil survey were included; study area limited to West-Flanders	Only if account is made for the bias in selection of 'permanent' croplands
Sleutel *et al.* (2007): resampling of 116 cropland fields in 2003 from Van Meirvenne et al. (1996)'s selection	Might be selective towards older croplands because only locations which remained cropland since the national soil survey were included; study area limited to West-Flanders	Only if account is made for the bias in selection of 'permanent' croplands
Meersmans *et al.* (2011): resampling top 30cm of 629 profiles of the National soil survey in 2006 (cropland and grassland)	Might be selective towards older croplands because only locations which remained cropland or grassland since the national soil survey were included; clear bias towards sand and silt textured soils	Maybe, but probable bias towards older croplands and grassland with sand or silt texture
Aardewerk database: soil profile SOC measurements dating back to the national soil survey (1947-1962)	No	Possibly
CARBIOSOL and (Goidts and van Wesemael, 2007) resampling soil profile from the national soil survey (1947-1962)	Probably not	Not possible, measurements situated in Wallonia
Mestdagh *et al.* (2009): SOC stocks (till 0.6m deep) in grassland plots in 2001-2004	Likely, because several fields were sampled per farm. So sampling sites are clustered together and furthermore not spread across Flanders	Impossible because the location is known for but a limited number of the sampled fields
LUCAS	Probably not	Possible, but there are only a very limited number of sites in Flanders

1.3.3 Compatibility of methodologies

Rawlins *et al.* (2017) asked themselves: "Are data collected to support farm management suitable for monitoring soil indicators at the national scale?" and concluded that in the UK at least measurements conducted by commercial labs were incompatible with the Countryside Survey (CS2007) en with the LUCAS (Land Use/Cover Area frame statistical Survey). This mainly due to deviating analytical determination of the OC concentration in collected soil samples.

Other elements could also hinder use of SOC stock data from past sampling campaigns. If so, there would be but limited added value when trying to integrate these former sampling sites into a new monitoring initiative:

- "parcel vs. point sampling", i.e. compatibility of the "support"
- Different sampling depth intervals
- Different pre-treatment of samples prior to C-analysis
- Absence of soil bulk density measurements

Table 6. Details on the methodology of selected past soil inventories in Flanders.

Soil Survey/monitoring initiative	Support	Depths	OC-analysis	Bulk density
Van Meirvenne *et al.* (1996)	6m diameter circle	Plough layer and subsoil	Wet oxidation	No
Meersmans *et al.* (2011) resampling top 30cm of 629 profiles of the National soil survey in 2006 (cropland and grassland)	6m diameter circle	0-30cm	Wet oxidation	no
Aardewerk database: soil profile SOC measurements dating back to the national soil survey (1947-1965)	6m diameter circle	Various horizons down to 1m	Wet oxidation	no
LUCAS	Plot	0-20cm	Elemental analysis	yes

Because of the general lack of soil bulk density measurements and adoption of outdated wet oxidation analytical methods SOC stock data from the above listed initiatives, except LUCAS, are most likely not comparable to future estimates from any new survey. Furthermore, the exact location of the coordinates of National Soil Survey soil profiles is perhaps insufficiently known to always ensure exact resampling. All of this constrains the usefulness of sub selecting C-MON measurement points from the locations visited in the frame of these initiatives. Finally, the intent of any future SOC surveying initiative is to monitor future changes in SOC stocks, not current and past. It seems unlikely that historical SOC stock data would aid in interpretation of any shifts in SOC stocks from 2021 onwards. Lastly, information is lacking to fully ensure if selection of points of the in

Table 6 presented SOC inventories was non-selective and so we conclude that only the LUCAS initiative may be relevant, but a main constraint is the limited depth of sampling.

1.3.4 Potential alternative value of former SOC inventory campaigns

In 1.4 estimates of the minimum detectable difference in SOC stock for candidate monitoring networks for monitoring of SOC stocks are presented. The methodology depends amongst others on reliable figures of the regional variation in current day SOC stocks. Soil monitoring networks described in 1.2 are used here below to predict this regional variation in SOC stocks and will be used to assess the temporal correlation between paired SOC stock measurements (see 1.4).

1.3.4.1 Grassland

Assessment of regional variation of changes in SOC stocks during the 1990ies

As detailed in the intermediate April 2018 report an analysis was made of variation in changes in grassland SOC Stocks according to soil texture/drainage combinations. Firstly we used the 'VITO Ruimtemodel Niveau 1' map to derive the area of permanent grassland situated on different soil texture/drainage combinations. To this end the digital soil map was firstly converted a 10x10m resolution raster and then an overlay operation with the 'VITO Ruimtemodel Niveau 1' assigned soil textural and drainage symbols to each 'permanent cultuurgrasland' grid cell. The resulting map was overlaid with a polygon map of average changes in topsoil (0-6 cm) OC% between 2000 and 1990 for grassland (dataset Bodemkundige Dienst van België vzw was used previously in the CASTEC study (BELSPO 2001-2005)) (Mestdagh *et al.*, 2009).

Three strata were used to explore the potential efficiency gain in detection of regional changes in grassland SOC by stratified sampling: (Texture A and Z – drainage class a, b, c, d, e, h; Texture S, P, L, E, U – drainage class a, b, c, d, e, h; All textures drainage class f + 'texture' V). This information was further used to derive required numbers of sampling points for detection of 4‰ yearly SOC stock (0-30cm) change for grassland with and without stratification (see April 2018 steering group report). But because SOC concentrations were lacking for deeper depths and the mismatch in aggregation level of SOC data and soil drainage information, the analysis was tentative and we will not further discuss calculations of required sampling pairs for detection of a given SOC stock change in grassland based on the above presented strata.

Assessment of variation in grassland SOC stocks caused by grassland age and management

In a second step, variation in Flemish grassland SOC stocks is once more calculated but now only using point measurements, based on two additional datasets provided by for this purpose. Plot-scale SOC stock measurements till a depth of 60cm, conducted in the frame of a PhD-research at ILVO & UGent (Mestdagh *et al.*, 2006). Next to SOC concentration of the 0-10, 10-30 and 30-60 cm layers for a total of 112 plots, corresponding bulk density measurements were available for 93 of these plots and soil texture was determined on all topsoil samples.

Mowed grassland had a significantly lower 0-30cm SOC stock (5.17 kg C m^{-2}) than grazed grassland (7.23 kg C m^{-2}), while no differences existed with Grazed+Mowed fields (6.10 kg C m^{-2}). Unfortunately, since no official record exists of mown or grazed land in Flanders, management could not function as base for stratification. At the same time, we in fact interpret the inferior stock in mowed plots as largely caused by their often younger age. Indeed, Mestdagh *et al.* (2006) found that temporary grassland had a significantly lower SOC stock than permanent grassland.

A logical next step would be to explore the usefulness of **grassland age** as potential base for stratification. In principle these ages could be estimated through analysis of ALV-landgebruikspercelen of locations. But retracing coordinates of Mestdagh *et al.* (2006)'s plots was unfortunately not possible because of imprecise knowledge on most sampling locations. Also tracing back grassland age would be anyhow confounded because soils were already sampled in 2003-2006 and ALV-landgebruikspercelen then only date back a couple of years.

A more reliable estimate of grassland age of fields to be sampled from presumably 2020 onwards is enabled by analysis of ALV-landgebruikspercelen maps dating back at least a decade. During phase II it needs to be ascertained that spread of sampling locations represents existing variation in grassland age.

Impact of soil texture and drainage on grassland SOC stocks

Sleutel *et al.* (2011) defined two strata for SOC monitoring of grassland: the Campines and the remainder of Flanders, based on an analysis of spatial spread of SOC at time of the National Soil Survey. In contrast to cropland management C-inputs are fairly homogeneous between permanent grassland in different parts of the landscape or within Flanders (permanent coverage with grass and mainly the same species mixtures are used *Lolium Perenne* as base). Grasslands also cover wetter parts of the landscape, conditions under which microbial mediated decomposition is frequently slowed throughout the year, leading to accumulation of SOC. So more than in croplands soil drainage and soil texture are likely significantly co-determinants of the resulting equilibrium SOC stock. This was indeed confirmed by Meersmans *et al.* (2011), who developed models to predict SOC stock in function of land-use, soil clay content, depth of the groundwater and manure inputs. Soil drainage and clay% jointly explained more variation in 1960 grassland SOC than all explored independents did for cropland.

During field campaigns in 2004–2008, Meersmans *et al.* (2011) resampled 136 National Soil Survey profiles under grassland. Texture and drainage class were derived from the National Soil Survey. Spread of sampled locations was not representative for Flanders with merely 13 profiles covering textural symbols S, L, E and U. Therefore statistics were calculated for three groups only, namely Sand – Z and Silt – A textured soils and soils with very poor drainage (drainage class f and g) irrespective of texture. Combining both Mestdagh *et al.* (2006) and Meersmans *et al.* (2011) datasets and using Mestdagh *et al.* (2006)'s bulk density data yielded a more robust ANOVA for 0-30cm SOC stocks in function of soil texture. These datasets were also complemented with 22 extra grasslands sampled in a study commissioned by De Vlaamse Waterweg NV. Soils were sampled in eight controlled flooding areas of tidal rivers (Schelde, Rupel, Dijle, Grote Nete, Kleine Nete) of the Sigmaplan (Verschelde *et al.*, 2013). Based on a first analysis of Mestdagh *et al.* (2006)'s and Meersmans *et al.* (2011) datasets it was apparent that a distinction between clay textured soils and other textures is relevant. Secondly, also soils with poor drainage (drainage classes f and g) displayed a significantly higher 0-30cm SOC stock. With the expanded data we tested also if other combinations of drainage classes would be helpful: 1° all textures a-d vs. e, f, g, i ; 2° all textures a-e vs. f, g, i; 3° textures Z-A a-d & h vs. or Z-A e, f, g, i & E,U,V ; 4° textures Z-A a-d & h vs. or Z-A e, f, g, i vs. E,U,V. ANOVA demonstrated that both options 1° and 3° yielded strata with differing mean SOC stock and variance, while use of three strata in case of option 4° were insufficiently dissimilar and a lesser distinction existed for option 2° strata. A large part of grassland is located in the 'Polders' area, for which a separate classification system was developed. So-called 'Unibodemtypes' have been matched with classes in this coastal classification system and so texture symbols can be assigned to mapping units in the 'Polders' and 'Dunes' areas. Since knowledge on soil drainage in these lands remains tentative, it would be safer and easier to proceed with a stratification in which E and U are grouped with drainage classes e, f, g, i. This will facilitate site selection in phase II. We therefore based further calculations of required sampling pairs for a given MDD on option 3 (Table 7) – see 1.4.

Table 7. SOC stock (kg C m^{-2}) for permanent grassland based on measured 0-30cm SOC concentrations provided by Meersmans et al. (2011) (bulk density estimated according to Meersmans et al. (2011)); SOC stock measurements by Mestdagh et al. (2006) for heavy textured soils and 22 SOC stock profiles measured in controlled flooding areas (Verschelde et al., 2013).

stratum	n	Mean	s	CV (-)
Z, S, P, L, A Drainage classes a-d, h	92	6.29b[a]	1.81	0.29
Z, S, P, L, A - Drainage classes e, f, g, i + E, U, V	103	9.03a	3.96	0.44
	195	*7.74*	*3.41*	*0.44*

[a] means followed by different lowercase letters are significantly different (P<0.01)

The spatial spread of both strata is illustrated in Figure 13, but still excluding grassland in coastal polders.

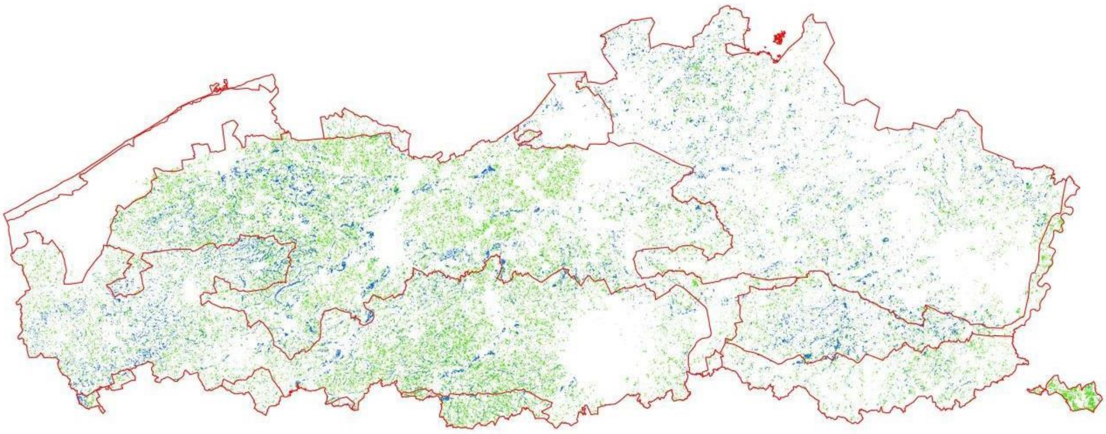


Figure 13. Spread of grassland over two identified strata Z, S, P, L, A Drainage classes a-d, h (green) and Z, S, P, L, A - Drainage classes e, f, g, i + E, U, V (blue) with grassland exclusive fields in coastal Polders & Dunes.

1.3.4.2 Cropland

Analysis of regional variation in Flemish cropland SOC stocks

The current project builds on BOD/STUD/2010/05 (Sleutel *et al.*, 2011) in which an analysis was made of regional variation in Flemish SOC stocks in cropland. In that study we used SOC data from the National soil survey to identify parts of Flanders with either relatively homogeneous spatial variation in SOC stock (down to 0-30 cm). Three areas were identified and based on topsoil SOC contents datasets for 1999, used amongst others within the CASTEC project (Sleutel *et al.*, 2003), means and standard deviations of SOC% were calculated. Using soil bulk density data proposed by Sleutel *et al.* (2003) regional scaled means and standard deviations were estimated, to be used for further calculations of required numbers of sampling pairs for detection of SOC stock changes in 1.4 (Table 8).

Table 8. Regional scaled variation in plough layer SOC% and SOC stocks (taken from Sleutel et al. (2011)) based on municipality-level aggregated SOC measurements conducted by the Bodemkundige Dienst van België vzw.

Region	**Variance in topsoil OC content**	**Mean SOC stock (0-30cm)**	**Standard deviation SOC stock (0-30cm)**
	($(\%OC)^2$)	**(kg OC m^{-2})**	**(kg OC m^{-2})**
Polders & North-western part Sandy Region	0.464	6.17	2.80
Eastern part Flemish Sandy region, Sandy Loam & Silt Region	0.269	4.94	2.23
Campines	0.426	7.59	2.72

An analysis of recent changes in input of effective organic carbon (OC_{eff})

Changes in SOC stocks are to a large extent driven by changes in the inputs of OC. It is then reasonable to assume that variation in current evolutions in input of OC would reflect expectable variation in future SOC stock changes. Put otherwise: a more spatially homogeneous evolution of SOC stocks would occur in parts of Flanders where at present homogeneous likewise shifts in inputs from manure and crop residues. Firstly we estimated mean inputs of effective organic carbon (OC_{eff}), i.e. the OC remaining in the soil after 1 year since field incorporation for each municipality (see Jun2018 steering group report). Only surfaces of most widespread crops were included (wheat, barley, grain maize, fodder maize, sugar beets, potato, temporary pasture, field grown-vegetables, and a category of 'other crops') and fixed assumptions were made with respect to OC_{eff} inputs, according to (Sleutel *et al.*, 2007). Based on corresponding crop acreages for 2006 and 2016 the difference in mean OC_{eff} input per ha yr^{-1} of cropland (including temporary pasture) between both years was calculated. We also calculated OC_{eff} inputs from animal manure for both years on the municipality level, using annual municipality-level animal manure P production/usage ratios (provided by VLM).

By summing changes in OC_{eff} inputs from crop residues and animal manure per municipality an integrated view emerges on spatial diversity of changes in annual OC inputs over the past decade (Figure 14).

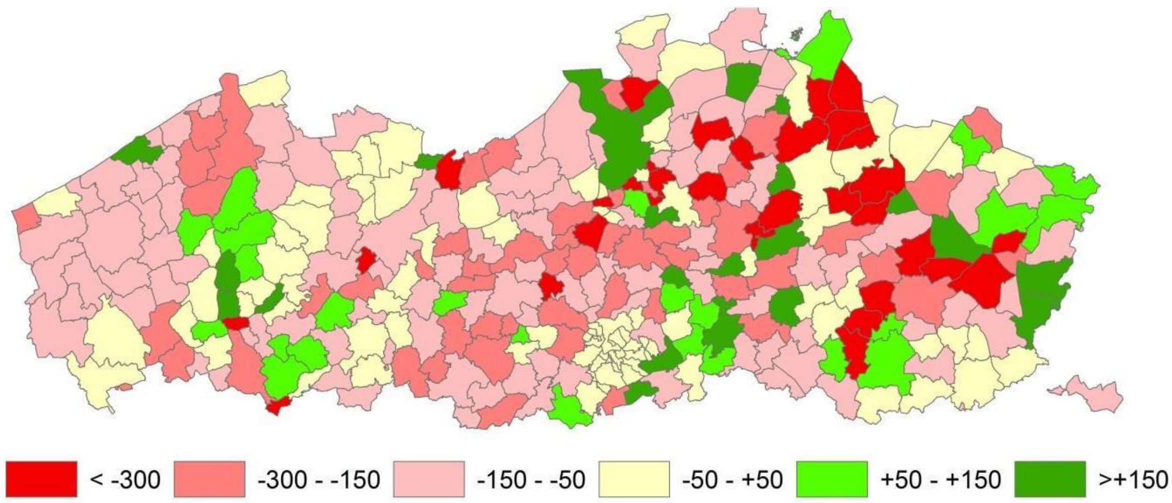


Figure 14. Estimated change in mean annual input of effective organic carbon (OC_{eff}) per ha from animal manure and crop residues between 2016 and 2006

Across Flanders **in more than half of all municipalities OC_{eff} inputs to cropland have declined**, out of which a substantial part with losses of at least **-150 kg OC_{eff} ha^{-1} yr^{-1}**. In about one fifth (Campines) on the opposite OC_{eff} inputs comparably increased. In a typical cropland plough layer SOC stocks are about 40 to 60 t OC ha^{-1} and a 4‰ relative change (160 – 240 kg OC ha^{-1} yr^{-1}) then compares to these on-going shifting OC inputs. This illustrates that the ambition to detect a 4‰ relative change in SOC stocks is probably highly pertinent, at least for cropland. But at the same time it becomes clear that no spatially homogenous monotonous shifts in cropland SOC stocks may be expected for Flanders. It is therefore not straightforward to identify regions to be considered as strata, except perhaps the observation that largest recent developments in OC_{eff} occurred in the central and Northern Campines area and to the east central sandy loam region. The in Table 7 proposed strata were further used in calculations in 1.4.

1.3.4.3 Forest

In contrast to intensively managed cropland we expect that mainly the physical drivers soil drainage and soil texture co-determine SOC stocks under forest, as could also be inferred from De Vos (2009)'s analysis of variation in Flemish forest SOC based on the HIBBOD+ database. However, that analysis was based on SOC figures dating back to the National Soil Inventory. An updated analysis of variance was presented in the Jun2018 steering group report based on more recent (1997-2002) SOC profile data (304 in total) contained in the ForSite database (De Vos, 2009). These data were based on SOC concentration and bulk density measurements per soil horizon.

Soil texture

In the Apr2018 steering group report then firstly SOC stocks in soil texture classes were compared (Figure 15). Sand (Z) and silt (A) textured soils appeared to contain less SOC and display a relatively small variation; S, P, L textured soils have intermediate SOC stock but were more variable (particularly L textured soils). Forest on heavy textured soil (E & U) contained high SOC stocks with intermediate (for E) or large (for U) variation. In practice, however, texture is not well known for a large share of forests on heavy textured soils because these are situated mostly in the Polders agro-peodlogical region, where a different soil classification system was applied. From a practical point of view E and U are then best combined.

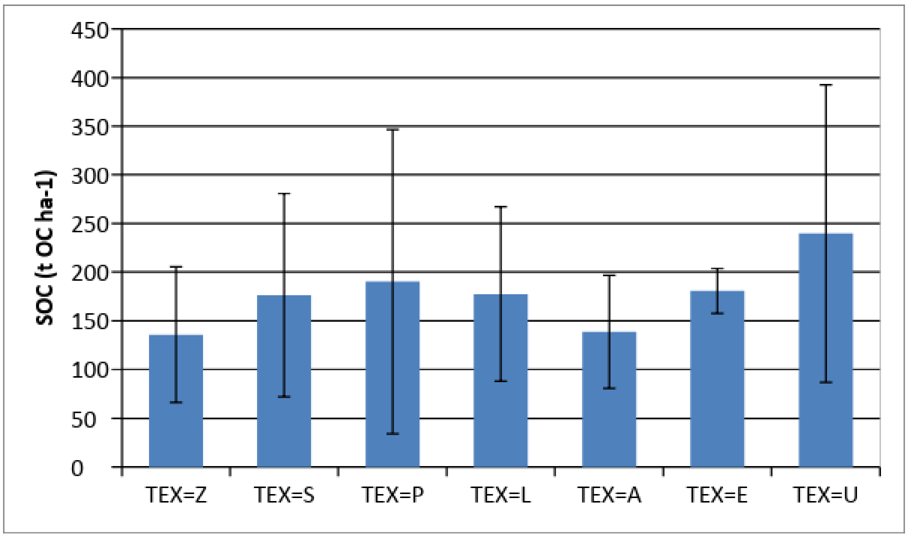


Figure 15. Mean SOC stocks (t OC ha^{-1}) below forest (0-100cm) in function of soil texture (ForSite Database). Error bars indicate the standard deviation around the means

For further MDD and required sampling pairs calculations, as elaborated in 1.4, three tentative strata were considered: 1° Z,A (0-1m SOC mean stocks$_r$: 137.1 ± 63.80 t OC ha^{-1}); 2° S,P,L (178.9 ± 117.8 t OC ha^{-1}); 3° E,U (187.9 ± 74.2 t OC ha^{-1}). These groupings more or less could be termed '1° low SOC stocks with low variance', '2° intermediately high and very variable SOC stocks' and '3° high SOC stocks with intermediate variance'.

Drainage

In the June2018 report based on the ForSite database also SOC stock variation among soil drainage classes was explored. Drainage symbols 'i' and 'g' were not included because too few observations were available. SOC stocks (0-1m) in the range 'a - very dry' to 'd - moderately wet' were relatively independent of drainage class and so was variation within these categories (on average 140 t OC ha^{-1}, n=217). SOC stocks in soils with imperfect drainage (symbols e and f) were more variable and 42% higher (on average 200 t OC ha^{-1}, n = 45). It then appeared pertinent to distinguish two strata, viz. forest with drainage symbol 'a-d' and 'e-f' and an analysis was made of efficiency gain when allocating sampling points based on this distinction (Table 9). Areas of forest soils with drainage 'i' or 'g' were also added to the 'e-f' stratum. SOC stock in case of drainage class 'h' was just 131 t OC ha^{-1}, comparable to e.g. 'b' (129 t OC ha^{-1}). In the interest of creating strata with minimal variation, the wet soils of 'h' and 'a-d' were combined in a single stratum.

Areas of forest located on specific drainage classes were derived by 'overlay' of the VITO2013Landgebruik grid onto the digital soil map, resulting in 10x10m forest grid cells with drainage symbol allocated. Since no drainage symbols were known for the coastal polders, these forests were not included in further calculations.

Table 9. Regional scaled variation 0-30cm SOC stock in Flemish forests (based on ForSite database) and surfaces (as derived from overlay of the digital Soil Map and the 2013 VITO Ruimtemodel).

Subarea	Surface according to 'VITO2013 Ruimtemodel'[a]	Mean SOC stock (0-30cm)	Standard deviation SOC stock (0-30cm)
	(ha)	(kg OC m^{-2})	(kg OC m^{-2})
a-d & h (well)drained forest	62444	8.71	3.75
e-f poorly drained forest	28299	12.04	7.41

[a]*Forest surfaces for Flanders, excluding the Polders and Dunes, and other soil drainage classes*

1.3.4.4 Nature

In contrast to agricultural land, SOC stocks under natural land-use have been poorly inventoried in Flanders. The extensive HINBOD database groups all profile data (Leroy *et al.*, 2002) of soils under nature land-use, dating back to the National Soil Survey and. This dataset was complemented with measurements conducted by INBO, mainly in heathland for the present analysis. Unfortunately, SOC concentration data was confounded to only 0-20 or 0-30cm depth and bulk density needed to be estimated. Land-use 'nature' covers a very wide range in terms of vegetation, management and physical environment.

With the limited data available, only a meaningful subdivision according to the most abundant types of vegetation: viz. habitat types '4xxx –Heide' (Heathland) (0-30cm), 'Ruigte' (0-20cm), '6xxx – Gras en Hooilanden ' (grassland) (0-20cm). For these three groups respectively 51, 66 and 79 measurements of topsoil SOC concentration were available. A pedo-transfer function was used to estimate bulk density (Table 10). No SOC data were available for less abundant types of nature, e.g. Swamp (moeras), dune (kustduin) and tidal flats (slik en schorre) and these were not considered in the present investigation of usefulness to stratify soils under nature land-use.

Total surfaces for land-uses forest, nature and residential use were derived from the VITO 2013 Ruimtemodel based on grid cells assigned to different distinguished land-uses.

Table 10. Regional scaled variation 0-20cm SOC stock in soils under 'nature' (based on ForSite database) and surfaces (as derived from the 2013 VITO Ruimtemodel).

Habitat type	**Surface according to 'VITO2013 Ruimtemodel'** (ha)	**Mean SOC stock (0-20cm) (0-30cm for heathland)** (kg OC m^{-2})	**Standard deviation SOC stock (0-20/30cm)** (kg OC m^{-2})
Heathland	10286	6.7	3.93
'Ruigte'	23278	18.12	6.72
Semi-Natural Grassland	28565	17.32	10.34

SOC stocks were much lower in soil under heathland, while comparable SOC stocks were found under 'ruigte' and semi-natural grassland. Because variation was clearly much larger under semi-natural grassland, all three strata were separately considered in further calculations of required numbers of sampling pairs to detect a given change in SOC stocks (1.4).

1.3.4.5 Residential Land use

To date no systematic inventory of SOC stocks within Flemish urban land has been published. This could be owed to lack of spatially resolved maps of non-sealed urban land as well as lack of soil analytical data. The VITO 2013 Ruimtemodel (Figure 16) only a distinguishes between 'overig laag groen' (low green) and 'overig hoog groen' (high green). Respective surfaces derived from the VITO 2013 Ruimtemodel were 132,721 ha and 70,293 ha.

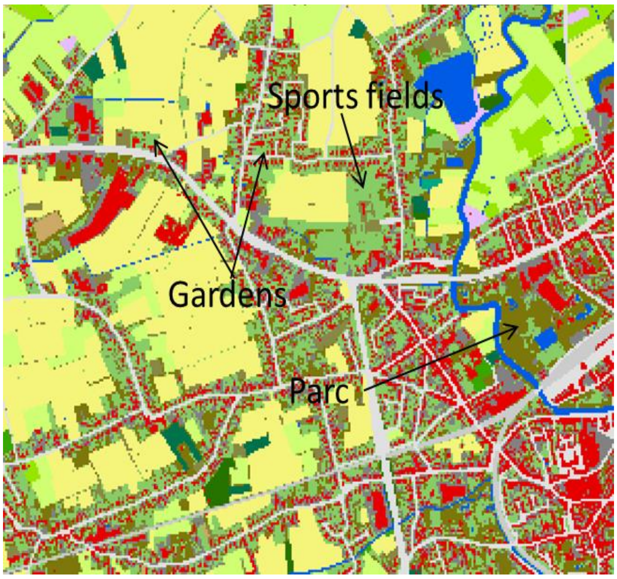


Figure 16. Location of 'overig laag groen' and 'overig hoog groen' in the landscape: the 'low green' is mainly reserved for lawn and shrubs in gardens as well as recreational fields (e.g. a soccer field), while 'high green' is individual smaller plots with trees (in gardens or parks or along roads)

Indeed no SOC statistics exist for either class. Over the various intermediate reports during completion of phase I, three approaches to nevertheless derive first estimates of variation in SOC stocks under residential land use:

1° We rather arbitrarily used statistics from other similar land-uses. SOC concentration and bulk density from Mestdagh *et al.* (2006) for mowed semi-natural grassland were used as proxy for 'low green', viz. a mean SOC stock 0-30cm of 14.40 ± 8.62 kg OC m^{-2}. For 'high green' we used the same HINBOD-data for 'Ruigte', viz. mean SOC stock 0-30cm of 18.12 ± 6.72 kg OC m^{-2}.

2° in a second step we used a limited dataset on SOC measurements made in the residential area of the city of Mechelen was made available by OVAM. By no means could these data be considered as representative for all Flemish residential land not only because of the limited spatial spread but also because sampling was tied to potential soil sanitation projects and therefore biased. However, at least these data allow some verification of our initial approach. Most of the OVAM measurements in residential land are unusable because: 1° situated under roads or built-up land (3/4th of all data), derived from soil depths > 1m. Consequently, out of all 5925 SOC measurements in the area of Mechelen only 646 points were usable. Following statistics were derived for 'Remaining High Green' and 'Remaining Low Green' and tentatively also 'Rough vegetation'. Assuming a bulk density of 1.4 g cm^{-3} SOC stocks in the 0-30cm layer would be 6.82 ± 5.43 kg C m^{-2} and 6.93 ± 6.63 kg C m^{-2}, much less than estimated for the first report (14.40 and 18.12 kg C m^{-2} (0-30cm)). These mean SOC contents are much closer between 'Remaining High Green' and 'Remaining Low Green' than anticipated in 1°.

3° The Bodemkundige Dienst van België vzw has completed 8414 samplings on lawns, ornamental gardens, greenhouses and vegetable gardens between 2009 and 2015 (Tits *et al.*, 2015). Samples were collected till a depth of 6cm for lawns and till 23cm elsewhere and a modified wet digestion method was used for C-concentration measurement. Since only a synthesis was presented in Tits *et al.* (2015) with histograms according to qualitative classes we are unable to calculate C% statistics for further use in MDD calculations. Only one country-wide SOC figure was presented in Tits *et al.* (2015): an average SOC content of 1.7 kg m^{-2} for the 0-6cm layer of lawns. If we assume a SOC depth profile similar to permanent pastures, this equates to about 5.5 kg C m^{-2} for the 0-30cm layer, comparable to data derived from the OVAM C-dataset.

In conclusion, available data sources for even drawing first estimates of SOC stocks under non-sealed residential land-use are inadequate. Dedicated surveys would be required to supply necessary statistics for most common forms of residential land-use: viz. different components of privately owned gardens, road side verges and alike, parks and other forms of public green, etc. For the present project, further optimization of sample number allocation over various land-uses was carried out devoid of residential land-use. Instead to the Residential land an arbitrary number of sampling locations will be allotted, as further explained in 1.4.

1.4 DESIGN OF INITIAL SURVEY AND MONITORING AND STATISTICAL BASE FOR REQUIRED NUMBER OF SAMPLES PER LAND-USE

During phase I, the first priority was to pass on an indicative total price for C monitoring in Flanders. Determining elements herein are the total number of measurement points and parameters to be analysed. However, the required number of measurement points for detection of a specific average SOC stock change is a function of its fundamental statistical design. Analogous to the core decisions drawn by Sleutel et al. (2011), we will a priori base this assignment on the following principles:

i. We opt for a network with **paired observations over time**, because of the superior statistical power compared to independent re-sampling.

ii. We choose to increase the efficiency of a monitoring network by identifying a **stratification** that leads to more geographically homogeneous units of SOC stock and expected changes in it.

iii. Within strata, sampling sites for the baseline measurement are **randomly selected** to ensure an undistorted sample (unbiased), thus maximizing the representativeness of the reality.

The start of these conditions then makes it possible to continue working with the methodology used in Sleutel et al. (2011) and to provide estimates of sampling point numbers. These three starting points are briefly explained below (i. under 1.4.1, ii. under 1.4.2 and iii. in 1.3 and WP2.1), with the formulation of further actions during Phase I.

Monitoring of SOC stock changes obviously occurs at a certain level of statistical significance. Equally important but often not considered is the power of a statistical test to detect such differences: 1- β. Herein β is the chance of making a type-II error: i.e. wrongly assuming that there was no difference in the average SOC stock between two samples. The power of a paired t-test is superior to a system with random re-sampling and can a priori be calculated in both cases. Especially with a higher temporal correlation, the advantage of a system with paired observations over random re-sampling becomes greater. The temporal correlation has yet to be estimated for different defined strata and for land-use forms not included in BOD/STUD/2010/05 and such an analysis is presented in 1.4.1.

1.4.1 Temporal autocorrelation estimated from past surveys on cropland and grassland

Sleutel *et al.* (2011) previously used plough-layer SOC concentration data from the Bodemkundige Dienst van België vzw, available on the municipality/agro-pedological region aggregation level for 1990 and 1999, to estimate the temporal autocorrelation. We calculated correlation between plough layer SOC stocks in West-Flemish cropland in 1990 and 1947-1960. These data were derived from a large-scale re-sampling of locations that were sampled for the National Soil Mapping survey (Van Meirvenne *et al.*, 1996). A subdivision is made per agro-pedological region (Table 11).

Table 11. Calculated temporal autocorrelation between topsoil OC% measured in West-Flemish cropland (plough layer) between 1947-1960 and 1990; and ratio of measured and predicted standard deviation of the change in SOC stock.

Zone	autocorrelation	number of pairs	$s_d / \sqrt{2} s_{survey}$
Sandy Region	0.71	207	0.28
Silt Region	0.61	14	0.33
Sandy Loam Region	0.34	403	0.57
Polders	0.33	315	0.69
weighted mean (number of points)	0.42		0.54

An average temporal autocorrelation of 0.42 was derived for croplands. For permanent grassland we estimated the temporal autocorrelation for repeated soil organic carbon measurements as follows: The correlation between the mean OC-content (0-6cm) measured in 1990 and 1999 was calculated based on a topsoil OC% monitoring datasets from the Bodemkundige Dienst van België vzw. Each data point is the mean OC% for on the municipality / agro-pedological region aggregation level. The correlation coefficient was based on a total of 300 municipality level / agro-pedological region pairs of the OC content measured at both surveys. This calculation was also conducted per agro-pedological region (Table 12). The estimated autocorrelation for Flanders (0.48) was close to the mean value for cropland (0.42).

Table 12. Calculated temporal autocorrelation between topsoil OC% measured in1999 and 1990 for Flanders and individual agro-pedological region.

Zone	autocorrelation	number of pairs
Flanders	**0.48**	**300**
Duinen	0.37	5
Kempen	0.59	49
Zandstreek	0.32	80
Leemstreek	0.39	27
Zandleemstreek	0.28	118
Polders	0.65	22

Consequences for estimates of s^2_d and required number of sampling pairs n

When auto-correlation exists the real value of s_d will be lower than as predicted from the variance of either one of the two paired SOC inventories. Saby *et al.* (2008) reported overestimations of s_d by 15%, 30% and more than 100% for cropland and grassland in England, respectively. The auto-correlations for cropland and grassland in Flanders (Table 11 and Table 12) suggest that by adopting Saby *et al.* (2008)'s method we likewise overestimate s_d and consequently the required number of sampling pairs to detect a given change in SOC. For example the mean topsoil SOC stock for West-Flemish Sandy region rose between the National Soil Inventory (1947-1962) and 1990 by 10.098 ± 16.878 kg OC ha^{-1} on average. So s_d was directly derived from 207 pairs of SOC inventory at both sampling times and equal to 16.878 kg OC ha^{-1}. When predicted based on $s^2_{i1947\text{-}1962}$ and s^2_{i1990} , s_d was predicted to be 31.278 kg OC ha^{-1}, i.e. an overestimation by a factor 1.85 (and even a factor 3.5 s_d^2). The temporal autocorrelation, 0.71, was however very high for points in the West-Flemish Sandy Region, indicating that the cause for SOC storage was also relatively homogeneous within that stratum. In the 1960-1990 period there was a widespread expansion of livestock numbers and inputs of OC from animal manure in the entire West-Flemish Sandy region – and this drove SOC storage in the majority (149 out of 207) of the sampled locations (Van Meirvenne *et al.*, 1996). A similar large-scaled overall change in the SOC balance seems less likely for the foreseeable future and so the overestimation of MDD introduced by adopting Saby *et al.* (2008)'s approach would be smaller. We calculated ratios of the measured and predicted s^2_d. An average overestimation of 1.84 compared to the one predicted from the SOC inventories, then also makes that the required number of samples *n* to detect a given MDD will be a factor 1.84 lower:

$$n = \frac{2s_d^2 z_\alpha^2}{MDD^2} \quad (1)$$

In addition, **also the relation between achieved statistical power and required sample size depends on the temporal autocorrelation**. This was illustrated in the Apr2018 report for the case of West-Flemish cropland. This was illustrated again for the detection of SOC accumulation between 1947-1960 and 1990 in cropland in the West-Flemish Sandy Region as studied before by Van Meirvenne et al. (1996). We found that out of the 207 sampling pairs that were available for the West-Flemish Sandy Region in Van Meirvenne *et al.* (1996)'s study, in fact only 46 and 29 samples were required considering autocorrelation of 0.5 and 0.7 to detect the widespread large accumulation of SOC with (1-β) = 0.85. It is then very clear that the impact of temporal autocorrelation on efforts for monitoring future changes in SOC stocks is thus large, but obviously it is impossible to beforehand reliably predict future temporal autocorrelation. As explained above it seems less likely that large-scale driving forces resulting in relatively homogenous changes in SOC like further intensification of agriculture and widespread expansion of livestock after WWII and imposing of nutrient legislation from 1990ies onwards (and substantial conversion of permanent grassland into cropland) will manifest in future as well. A more conservative estimate for temporal autocorrelation is then preferable. In the Sandy-loam area of West-Flanders for instance agriculture is relatively more diverse with arable, field vegetables and livestock production: and as expected temporal autocorrelation 0.33 was lower than in other agro-pedological regions in Flanders.

Assuming a future temporal autocorrelation of 0.3, then approximately s^2_d and required sampling locations *n* are overestimated by ± a factor 1.4. For other land-use forms large scale resampling campaigns in Flanders are missing. Saby *et al.* (2008) reported overestimations of s_d by more than 100% for forest in England. We can then only conclude that for non-agricultural land-use there is no sound basis at present to assume a certain expected degree of autocorrelation. Again a **conservative** stance is then in order: **e.g. temporal autocorrelation = 0.2**.

1.4.2 Stratification within land-use categories

In essence, the intended monitoring network aims at investigating changes in SOC stocks, assuming a statistical significance level α. By subdividing the area to be sampled via so-called **stratification** it is possible to:

i) Limit the regional component of the variation s^2_r in the OC content (e.g. permanent meadows with limited drainage compared to arable fields with forage crops or coniferous forests on sandy soils, etc.), leading to a direct reduction of the minimum detectable difference, at least within the relevant stratum. In the following example we illustrate how much efficiency gain might be expected from such stratified sampling. For example one may want to predict the required number of measurements to detect a C-storage of 4 t OC ha^{-1} at α=0.05 and power=0.90. Suppose that the average SOC stock at time 1 is 50000±10000 kg OC ha^{-1} and at time 2: 54000±15000 kg OC ha^{-1}). Then as explained in Sleutel et al. (2011) and in 1.4.2.1 we predict that 96 locations are required to detect this 4 t OC ha^{-1} change. Suppose we reach a 25% smaller standard deviation in a more homogeneous stratum, then the required number of samples lowers to only 54.

ii) Increase the temporal correlation between both sampling times. This is because within relatively uniform combinations of management, the same driving factors for SOC stock change are likely to occur and therefore a more systematic change may be expected. Illustrative herein is e.g. Sleutel et al (2007), who found a smaller spread on 2003-1990 SOC changes for textures S, P, L and A compared to Z and U on the one hand and on average under all textures together on the other.

The second aspect ii) has already been looked at in 1.4.1, but not for individual strata. With too limited information available a further refining of this à priori unknown temporal correlation was not attempted here. With respect to i), limiting the variation of measured SOC stocks in strata within specific land-uses can obviously only be done based on existing available SOC stock data. In the following subsections (1.4.2.1 till 1.4.2.6) variation in SOC stocks is explored for cropland, grassland, forests, nature and residential land-use.

1.4.2.1 Calculation method for the minimum detectable difference in SOC stock

Sleutel *et al.* (2011) provided first estimates for the minimum detectable difference (MDD) in Flemish cropland and grassland based on a methodology according to Saby *et al.* (2008). This method is described in Sleutel *et al.* (2011) but shortly explained here again. Assuming a normal distribution for the mean change in SOC concentration (invoking the Central Limit Theorem), estimates of a 100(1-α)% confidence interval for this mean change *D* can be written (Barnett, 2002):

$$\bar{d} - z_{\alpha} s\sqrt{2/n} < \bar{D} < \bar{d} + z_{\alpha} s\sqrt{2/n} \quad (2)$$

where z_{α} is the value of the standardized normal distribution at probability *a* and s^2 the variance on measured SOC concentrations (or stocks) at one of both sampling times. the minimum detectable difference (MDD) is:

$$MDD = z_{\alpha} s\sqrt{\frac{2}{n}} \quad (3)$$

The variance s^2 is the natural heterogeneity of SOC concentration across the landscape, as well as the variation due to the measurement of SOC concentration. It has been found that the best estimate of s^2 is a combination of the estimate of the regional variation from previous studies $s^2_{regional}$ and the expected measurement errors (Ramsey, 1998). All these sources of error can be assumed to be independent so that

$$s^2 = s_a^2 + s_s^2 + s_r^2 \quad (4)$$

where
s^2: total variance on SOC-concentration (or stock)
s^2_a : analytical variance
s^2_s : variance from the sampling of the soil in the field

s^2_r : variance on SOC on the regional scale

This prediction bears on several assumptions:

1° Since the standard deviation of a future SOC stock change s_d is not known, it is estimated from the variances of the two SOC inventories (s^2_{i1} and s^2_{i2}):

$$s_d = \sqrt{s_{i1}^2 + s_{i2}^2} \tag{5}$$

2° Assuming that the variance on SOC inventories within strata does not change over time s^2_{i1} is then equal to s^2_{i1} , yielding $s_d = s_{i1}\sqrt{2}$.

3° Correlation between SOC inventories at two sampling times is small.

For each stratum s^2_r was estimated based on best available SOC stock data for Flanders. We considered the 0-30cm layer only due to lacking data for subsoil SOC stocks in most considered potential strata. The MDD was then calculated as an area weighted average for all considered strata within a particular land-use. Next to this default scenario in which the number of sampling pairs per stratum were proportional to its area, we also optimized the distribution of number of pairs across strata to yield a lowest possible area weighted MDD for the concerned land-use. Such optimization was achieved by Excel's Solver function, with the goal to minimize the total number of sampling pairs for a given MDD by adjusting the distribution across strata.

1.4.2.2 Cropland – stratification according to regional differences in spatial variation of SOC

We estimated the required minimum number of sampling pairs and their optimal distribution across three strata defined by Sleutel *et al.* (2011). The estimates presented now use a within-plot CV on SOC concentration of 4.55% (we used the average CV for 1-400m² and 400m² to 1ha classes presented by Saby *et al.* (2008)). s^2 was then predicted from s^2_a, s^2_p and s^2_r. Two scenarios were considered: i) a sampling scheme to obtain a MDD equal to detection of a consistent 4‰ yearly change in SOC over a 20-year period (0.428 kg OC m^{-2} on average for the whole of Flanders); and ii) a scheme for the same change over a 10-year period (0.214 kg OC m^{-2}) (Table 13). As explained in 1.4.2.1 also an Optimization scenario was calculated to see if the stratification would yield lower the total required number of sampling pairs for the same MDD.

Table 13. Required number of samples (per survey) to detect a MDD in 0-30cm SOC for Flemish cropland.

Stratum	s²	Optimal spread (0-30cm)			
		4‰ 20yr		4‰ 10yr	
	((%OC)²)	n	MDD (kg OC m^{-2})	n	MDD (kg OC m^{-2})
Polders & North-western part Sandy Region	0.464	155	0.623	620	0.311
Eastern part Flemish Sandy region, Sandy Loam & Silt Region	0.269	332	0.339	1327	0.169
Campines	0.426	78	0.856	311	0.428
Flanders (total number & MDD)		**565**	**0.428**	**2258**	**0.214**

A large number of sampling sites (2258) would be needed to detect a mean 4‰ change in SOC within 10 years. In case of a 20-year monitoring period, the number of required sites drops to 565.

Statistical power

The analysis presented in Table 13 is pessimistic because the s^2_d is predicted assuming virtually no temporal autocorrelation (set at 0.01). In the 10-year 4‰ scenario assuming a more realistic temporal autocorrelation of 0.5 the statistical power rises from 0.50 to 0.82, 0.78 and 0.79. In other words, the chance to mistakenly conclude that no change in SOC ≥ 0.214 kg OC m^{-2} occurred in Flanders drops then to about 20%.

Efficiency of Stratification

In a scenario of no stratification or, in other words when sampling locations are distributed randomly across the cropland area of Flanders we can again calculate the achieved statistical power and achieved overall MDD. In this case up to 780 (instead of 565) and 3119 (instead of 2258) sampling locations are required to achieve an overall MDD of 0.428 and 0.214 kg OC m^{-2}, respectively.

In conclusion: it appears that some efficiency gain in SOC monitoring could result from stratified sampling according to the above discussed three regions with differing spatial variation in topsoil SOC concentration.

1.4.2.3 Grassland – stratification according to drainage and soil texture

Minimum detectable difference and required sampling pairs for detection

As explained in 1.3, based on currently available SOC statistics for grassland it is most meaningful to explore the added value of stratified sampling along strata that differ in either soil texture, drainage or both. We again used equation 2 to calculate the required number of sampling pairs to detect a monotonous change in SOC at a relative rate of 4‰ over a 20-year period for the two strata defined in 1.3.4.1 (Table 14).

Table 14. Estimated required number of sampling pairs to detect a grassland SOC stock change (0-30cm) equivalent to a 20-year monotonous annual 4‰ relative change in SOC. Numbers without and with optimization of allocation over both strata are compared.

Strata	s^2	Surface	Spread proportional to surface		Optimal spread	
	((kg OC m^{-2})²)	(ha)	n	MDD (kg OC m^{-2})	n	MDD (kg OC m^{-2})
Z, S, P, L, A Drainage classes a-d, h	3.28	92573	235	0.33	159	0.35
Z, S, P, L, A Drainage classes e,f,g,i + E, U, V, X	15.68	34444	87	1.18	99	1.24
Flanders (total number sampling pairs & MDD)			**301**	**0.563**	**296**	**0.563**

Remarks:

- From Table 14 it emerges that an 7.9% efficiency gain was obtained by stratification along soil textural groups.
- The datasets used are not representative for textures S, P and L
- Bulk density had to be predicted for over half of the data

- Especially the regional variance of SOC stock in the first stratum appears unusually low
-

The above elements render the presented estimates of required sampling pairs again tentative. It would be safer to e.g. consider that variance on SOC stock within the first stratum (Z-A a-d,h) would rather be closer to estimates made in the Jun2018 report (viz. 5-8 (kg OC m^{-2})^2). This would inflate the total number of **required sampling pairs for grassland** to 434 (no optimization) or **370** (with optimization). It again appears that stratification would serve in reducing the required number of sampling locations to monitor future SOC stock changes in Flemish grassland.

1.4.2.4 Forest – Analysis of variation in SOC stock for soil texture classes and implications for monitoring

In the April2018 report calculations were presented of required sample pairs to detect a 4‰ monotonous change in forest SOC stocks over 20-years. Some limited efficiency gain (150 less pairs) resulted from optimized distribution of sampling pairs over **soil textural strata**. In the Jun2018 report we expanded the analysis of the ForSite database (De Vos *et al.*, 2015), by looking into SOC stock variation among soil drainage classes, as estimated during the national soil inventory (1.3.4.3). Drainage symbols i and g were not included because too little observations were available. In Table 15 we present MDD calculations again for non-stratified and optimized allocation of samples across two strata representing forest with different drainage.

Table 15. Estimated required number of sampling pairs to detect a forest SOC stock change equivalent to a 20-year monotonous annual 4‰ relative change in SOC. Numbers without and with optimization of allocation over different strata according to soil drainage are compared.

Strata	s^2	Surface	Spread proportional to surface		Optimal spread	
	((kg OC m^{-2})^2)	(ha)	n	MDD (kg OC m^{-2})	n	MDD (kg OC m^{-2})
a-d & h (well)drained forest	29.76	62444	426	0.73	405	0.75
e-f & g poorly drained forest	152.58	28299	193	2.46	200	2.42
Flanders (total number sampling pairs & MDD)			**619**	**1.272**	**605**	**1.272**

All in all but a very limited efficiency gain was achieved by optimized allocation of measurements, namely a reduction by 14 points from 619 to 605. Soil drainage did not appear a useful basis for forest stratification.

1.4.2.5 Nature – Analysis of variation in SOC stock for different habitat types

Analogous to 1.4.2.3-1.4.2.4 we used the in 1.3.4.4 proposed strata along different habitat types to calculate the required number of samples to detect a continuous mean yearly 4‰ change in SOC stock over 10 or 20 years (Table 16). Total surfaces for habitat types use were derived from the “VITO2013 Ruimtemodel” based on grid cells assigned to different distinguished land-uses.

Table 16. Estimated required number of sampling pairs to detect a MDD in SOC for Soils under Nature land-use in Flanders.

Strata	s^2	Surface	Spread proportional to surface		Optimal spread	
	((kg OC m^{-2})^2)	(ha)	n	MDD (kg OC m^{-2})	n	MDD (kg OC m^{-2})
Heathland	15.5	10286	128	0.96	106	1.06
'Ruigte'	45.1	23278	289	1.09	260	1.16
Semi-Natural Grassland	106.9	28565	354	1.52	397	1.44
Flanders (total number sampling pairs & MDD)			**772**	**1.269**	**763**	**1.269**

The number of sampling pairs required to detect a MDD corresponding to 4‰ rise in SOC over 20 years was much larger than in e.g. cultivated grassland, in spite of a smaller area of soils under nature. In case of random spread of sampling pairs across heathland, 'ruigte' and semi-natural grassland 772 sampling pairs are required: clearly the considered stratification was ineffective and it is justified to randomly spread sampling locations within this land-use category. In doing so, it would then be best to also include here non-considered habitat types. The above presented calculations again are confounded by the availability of just topsoil SOC data and lack of soil bulk density measurements.

1.4.2.6 Residential Land-use – Analysis of variation in SOC stocks for 'low' and 'high' green

In the White Paper Policy Plan on Spatial Planning, 'Ruimtebeslag' (**Land take**) is defined as 'the space occupied by our settlements, i.e. by housing, industrial and commercial purposes, transport infrastructure, recreational purposes, greenhouses, etc.'. Parks and gardens, ecoducts and some verge strips and embankments along (road) infrastructures are also part of land take (Flemish Spatial Planning Department, 2017, p. 183). Land take thus bundles a myriad of land coverages, which are probably predominantly characterized by that they cannot be readily categorized as neither agricultural land, forest nor nature. However, in practice the contrast between certain forms of land-take and these other land-uses is small (e.g. an extensively managed verge vs. natural grassland; a park vs. managed secondary forest). Definition of residential areas is obviously based on the administrative designation of the land (e.g. private owned gardens vs. public areas). With respect to detecting SOC stocks and changes therein in residential land, a grouping of measuring points by vegetation type instead of by administrative status may prove more meaningful. After all, the vegetation determines the SOC supply and also regulates the microclimate in the soil, and consequently the SOC balance. It seems plausible, for example, that SOC stocks under lawns, grass in roadside verges, grass in parks, and sports fields are more similar than with SOC stocks under shrubs and trees in gardens and other parts of the land use such as parks. In the 2016 VITO Spatial Model, the level 1 categories 'Other Low Green' and 'Other High Green' provide a relevant basis for such a further overarching breakdown of land take by vegetation.

At onset of the C-MON project no SOC statistics existed for either class. In order to nevertheless explore the meaningfulness of defining strata we arbitrarily used statistics from other similar land-uses, as presented in the April2018 report. We tentatively estimated that 582 sampling locations would be needed to detect 4‰ annual changes in residential SOC stocks over a 20-year period. In the

June2018 report we alternatively used SOC data derived from OVAM dataset for the city of Mechelen and reached a very different conclusion, viz. 1737 locations were needed to detect a corresponding MDD of 0.549 kg OC m^{-2}. We concluded that SOC data quality was too low to derive reliable estimates of required number of sampling pairs to detect SOC stock changes in residential land. In following attempts to optimally reallocate sampling points over land-uses we therefore excluded residential land-use. Instead a fixed number of sampling points, based on a first "best" estimate was set, enabling detection of 4‰ relative changes over a much less stringent 40-year period. This target corresponds to an MDD of 1.10 kg OC m^{-2}, requiring 441 samples spread out randomly across residential land.

We concluded that updated estimates of variation in residential SOC stocks, would be needed to analyse if C-MON monitoring plots could be distributed across strata within land take and across land-uses. In 2019 a new study was issued by the Flemish government to deliver this information, "MONITORING VAN HET ORGANISCHE KOOLSTOFGEHALTE IN VLAAMSE BODEMS IN OPENBAAR DOMEIN EN PARTICULIERE TUINEN (assignment VPO-OMG_VPO_2018_15-F02)", acronym '**C-Gar'**. Here below we summarize main conclusions from the C-Gar final report (Sleutel et al., 2020). In unbiased estimate was made of the 0-1m SOC stock in 137 plots distributed across gardens, roadside verges and 'ruigtes' and parks and recreational areas:

1° VITO Space model level 1 qualifiers 'Overig Hoog Groen' vs. 'Overig Laag Groen'

The average OC stock did not differ for any depth interval between classes "Other High Green" and "Other Low Green". Nor was there a difference in the variance between the two groups (Table 17). Sleutel et al. (2020) thus concluded that it makes little sense to use the qualifiers 'Other High Green' and 'Other Low Green' as a basis for a stratified sampling within land take. Moreover, these VITO Spatial Model level 1 categories are unknown for Verges, which would have further complicated using them to define land take strata.

Table 17. OC stocks per VITO Spatial model class 1 'Other High Green' and 'Other Low Green' across all Spatial subcategories and result of an independent t-test (from Sleutel et al. (2020))

VITO-Ruimtemodel	**OC stock (t OC ha^{-1})**		
Niveau 1 klasse	**0-30cm**	**0-60cm**	**0-100cm**
Overig Hoog Groen	81.4±32.7	136.2±51.4	196.2±94.2
Overig Laag Groen	81.0±26.3	136.4±50.1	178.0 ±76.8
Independent samples t-test p-value	0.944	0.985	0.301

2° Land take subcategories

Multiple comparison of means showed that vegetable gardens up to 60cm have a significantly higher OC stock than 'Parks and verges' and 'Lawns and ornamental gardens' (Table 18). Up to 100cm deep this difference was also almost significant (P=0.077). With a somewhat larger number of measurements it would probably have been possible to demonstrate a higher OC stock in vegetable gardens. Sleutel et al. (2020) thus ought it appropriate to further investigate vegetable gardens as a useful separate stratum. Strikingly enough, the average OC stocks of 'Lawns & Ornamental Gardens' and 'Parks & Roadsides' do not differ significantly. The variances do not differ either. It thus did not appear useful to consider 'Lawns', 'Ornamental Gardens', 'Parks, Recreational Areas and Sports Fields', and 'Verges and 'Ruigten'' as separate strata for monitoring OC stocks in Flemish land take.

Table 18. Comparison of the mean stock of organic carbon for different forms of land take in Flanders. (from Sleutel et al. (2020))

		OC stock (t OC ha^{-1})		
	N	0-30cm	0-60cm	0-100cm
Parks + Verges	48	82.4±31.2ab	131.1±57.7b	174.6±78.9a
Lawns + Ornamental gardens	55	71.9±19.1b	125.1±42.0b	176.9±73.8a
Vegetable gardens	20	98.4±31.8a	163.5±46.0a	220.4±94.5a
Global average	123	80.2±27.9	134.0±50.9	183.4±80.5
ANOVA-F-value		6.23**[a,b]	5.90**[b]	2.61[c]

[a] ***: p<0.001; **:p<0.01; *:p<0.05

[b] result F-test on log-transformed data & Tukey's post-hoc test

[c] result F-test with Welch correction on untransformed data & Games-Howell post-hoc test

3° Soil texture

There appeared to be no significant difference between the OC stocks of different texture classes (Belgian soil classification system) (Sleutel el al., 2020). Especially for the 0-30cm layer, the p-value of the Welch test was high, indicating that not texture, but other factors determine the OC stocks. Strikingly the p-value decreased strongly with depth and so the influence of texture on OC stocks does seems to increase for subsoil (Table 19). The 0-100cm OC stock of classes L and A taken together (150.2±62.1 t OC ha^{-1}) was on average significantly lower (p=0.012, one-way ANOVA) than the average of all other textural classes together (193.8±80.5 t OC ha^{-1}). The variances of both groups (L+A) and (Z+S+P+E+U) did not differ statistically (Levene's test p = 0.075). Also, the average 0-100cm OC stock of the grouped Z+L+A textures (159.7±63.0 t OC ha^{-1}) was significantly (p=0.003) lower than the group S+P+E+U (201.5±87.7 t OC ha^{-1}). However, there was a difference in their variances (Levene's test p=0.035). It seems appropriate to further investigate the usefulness of the following strata L+A with respect to Z+S+P+E+U and L+A+Z with respect to S+P+E+U.

Table 19. Comparison of the mean organic carbon stock for different soil texture classes (from Sleutel et al. (2020)).

		OC stock (t OC ha^{-1})		
	N	0-30cm	0-60cm	0-100cm
Z- sand	24	78.6±25.2	129.7±42.6	171.2±63.7
S- loamy sand	36	78.8±20.3	139.9±40.4	200.5±76.8
P – light sandy loam	16	76.9±33.2	145.3±57.2	207±104.8
L – sandy loam	24	78.5±27.8	118.6±63.7	150.7±69.0
A – silt	7	74.9±14.8	114.3±20.9	148.6±38.5
E+U – clay	16	94.5±42.4	147.6±61.8	198.2±98.8
Total	123	80.3±28.0	134±50.9	183.4±80.5
p-value Welch-test		0.769	0.146	0.064

Solver calculations (see 1.4.3) show that optimized allocation of the pairs of points over these two strata yielded but a limited advantage compared to random distribution. An analogous result was obtained for groups L+A and Z+S+P+E+U. It therefore does not appear to make sense to define land take strata on the basis of soil texture for monitoring OC stock changes. Finally, it can also be noted that point allocation on the basis of texture class strata is made more difficult in practice because often only soil series OB or OT were assigned in the digital soil map.

Conclusion

We conclude that by means of an optimized allocation of 558 test areas over the strata 'Parks and roadside verges', 'Ornamental Gardens and Lawns' and 'Kitchen Gardens' an average relative 0-100cm soil carbon stock change of 4‰ per year can be observed after 20 years. The most variable subcategory within land take turned out to be 'vegetable gardens'. Monitoring OC stock changes in vegetable gardens is therefore rather inefficient. Moreover surfaces of vegetable gardens vs. lawns and ornamental garden not well known. For the above calculations an estimate of the share of vegetable gardens within gardens was based on figures reported in a survey by VLACO. The Departement Economie, Wetenschap en Innovatie van de Vlaamse overheid citizen science project 'MijnTuinlab' also estimated the surface share of vegetable garden to but 5.3% of unsealed garden surface. Resulting estimated surfaces of lawns, ornamental gardens and vegetable gardens were then 66156 ha, 69947ha and 7582 ha, respectively. In that case only 515 sampling points would suffice to reach the 4‰ mean SOC stock change detection over 20 years for land take as a whole.

1.4.3 Optimized allocation of sampling points over land-use categories

Original estimates reported during C-MON Phase-I

In 1.4.2 the required number of sampling pairs to detect a certain MDD were calculated isolated per land-use form. Further optimization is likely possible by re-distributing number of points among land-uses. Over the April 2018, June2018 and September2018 reports several optimizations of sampling point allocations over the five considered land-use categories have been presented. Consecutively these attempts were updated with improved estimates of required SOC data. It was assumed that the requirement of a monitoring network capable of detecting a MDD equal to a 4‰ monotonous change in SOC stocks over 20-years would be met when averaged across all land-uses. This has the advantage that in total less sampling locations are required for the whole of Flanders. But, on the downside: within individual land-use categories this will no longer be the case. Two scenarios were considered:

1° No optimization of required number of sampling points: i.e. an equal spread according to area

2° Optimized allocation of sampling pairs across land-uses and strata therein with a stringent 20-year 4‰ MDD-target for cropland, grassland, forest and nature only

All SOC stocks were re-calculated to a 0-30 cm basis (only for forest statistics were available from the ForSite dataset, for grassland and cropland 0-6 cm and 0-23cm SOC concentrations from the 1990ies were depth-extrapolated as detailed in 1.3. For natural land-use SOC stocks were calculated from the HINBOD database, respectively. Only scenario 2 is presented here, the other scenarios was discussed in the Phase I final report. The required number of sampling pairs to detect this MDD were again calculated now with optimized allocation of points among land-uses (Table 1) and setting the target for residential land to detection over only 40 years.

Table 1. Number of required sampling pairs to detect a MDD in Flanders corresponding to 4‰ yearly change in SOC over 20 years (0-30cm) within different land-use classes with optimized distribution over land-uses and strata, excluding residential land-use – without use of updated data from the C-Gar study.

Land-use	Surface (from VITO model) (ha)	Optimized spread over land use classes & strata	MDD (kg OC m^{-2})	ratio MDD relative to 4‰MDD scenario with no optimization
Cropland	540,214	816	0.356	0.83
Permanent Grassland	149,859	373	0.586	1.04
Forest	133,595	490	0.871	1.12
Nature	68,801	472	1.614	1.28
Land Take (40yr ‰)	203,014	441	1.097	2.00
Total (Cropland, Grassland, Forest, Nature)		**2151**	**0.568**	
Total Flanders incl Land take		**2592**	**0.666**	

From the C-Gar study also SOC stock estimates till 1m depth in residential land had become available after closure of phase I. The original C-Mon Phase I data were supplemented with updated figures for Land take subcategories Parks & verges, Lawns & Ornamental Gardens and Vegetable Gardens from Table 18 and the here below presented calculations are thus an update over the C-Mon phase I report. C-Gar revealed that SOC stocks under Land take were larger, but at the same time less variable than originally assumed during phase I of the C-Mon study.

The 20-year 4‰ MDD for the whole of Flanders is equal to 0.569 kg OC m^{-2} (0-30 cm). The required number of sampling pairs to detect this MDD were again calculated now with optimized allocation of points among land-uses (Table 21).

Table 21. Required number of measurement sites to detect an average OC stock change of 4‰ over 20 years spread over all Flemish soils (0-30cm).

Land Use	Surface (from the VITO Spatial Model) (ha)	Number of sampling sites	MDD (kg OC m^{-2})	ratio MDD relative to 4‰MDD scenario with no optimization
Cropland	540,214	794	0.361	0.84
Permanent Grassland	149,859	363	0.594	1.05
Forest	133,595	477	0.882	1.13
Nature	68,801	459	1.636	1.29
Residential	203,014	442	0.534	0.87
Total Flanders		**2535**	**0.568**	

The scenario calculation taking into account the updated C-Gar figures for 'Land take' states that with 2535 measurements the objective of detecting an average OC stock change of 4‰ per year over 20 years is achieved. The optimisation exercise assumes a preferential allocation of measurements to 'Cropland'. For that land use, a better MDD is achieved than strictly necessary to achieve its 20 yr-4‰ standard. On the other hand, disproportionately fewer points were allocated to 'Nature' and 'Forest' at the expense of their MDD. But per unit area **Cost calculations performed during Phase I 1.6 assumed the sampling site estimates presented in Table 20 and will be further on used in phase II.** So in reality the achieved MDD will be a bit more optimistic than here presented in Table 22. The implications for the MDD reached per land use compared to the estimate without accounting for the updated C-Gar data (Table 20) were small for all land-uses, except for Residential land use for which a total of 442 measurements are reserved. With this number, the proposed 20-yr 4‰ MDD target up to 1m deep was not entirely achieved, which in fact would have required 556 measurement points. However, this outcome is still by far more optimistic than previously estimated by the C-MON study, where we only assumed detection of such an MDD over a period of 40 years (see phase I end report please). The global optimisation exercise across all land uses predicted that 159, 215 and 68 points would best be allocated to Parcs+Verges, Lawns+Ornamental gardens and Vegetable Gardens, respectively. The MDDs are then 1.74, 1.41 and 3.20 kg OC m^{-2}. It can be concluded that the C-Mon monitoring network will then actually enable us to detect plausible OC stock changes within Land take over a period of about 20 years, except in vegetable gardens.

1.4.4 Balancing ensure adequate statistical power for detection of 4‰ yearly loss of SOC stock?

Next to targets with respect to MDD, policy makers are also interested in having sufficient certainty that SOC stocks to be able to test that SOC stocks have not declined more than a set out target. Choice of such a target is rather arbitrary. For the present monitoring grid we might again account for a loss no larger than 8% over 20years (or 4‰ per year, i.e. the MDD). The statistical power can then be calculated on a **one-sided** pairwise t-test with H_1: $SOC_{t1} - SOC_{t2} > MDD$. The **power** of this one-sided test is superior (**0.70**) to that of the two-sided test (0.50), referred to in all preceding calculations.

The in 1.4.3 presented scenarios with optimized allocation across strata and land-uses result in most efficient monitoring of SOC stock changes. However, for some strata the number of samples becomes rather low and this consequently restricts the associated statistical power, should the aim have been to maintain at least a 20-year 4‰ target for each stratum individually. Following one-sided powers are achieved for scenario 6 if we adhere to a 20-year 4‰ target:

- Cropland: Central sandy to silt region: 0.92; Campines: 0.54; NW-Flemish Sandy region and Polders: 0.62
- Grassland: Z-A a-d,h: 0.70 and for Z-A e,f,g,i & E,U,V: 0.51
- Forest: a-e: 0.69 and e,f: 0.30
- Nature (scenario 6): heathland: 0.15; Rough vegetation: 0.253; semi-natural grasslands: 0.505

An additional criterion for point allocation could have been to at least have a one-sided pairwise t-test power of 0.50 for a 4‰ yearly loss of SOC <u>within each stratum</u>. This criterion was always met for grassland and cropland. This was not the case for forests on drainage classes e and f. Lifting the power to 0.50 would require 451 sampling sites on such poorly drained forest sites, more than doubling the currently allocated 210 under scenario 5 (Figure 17).

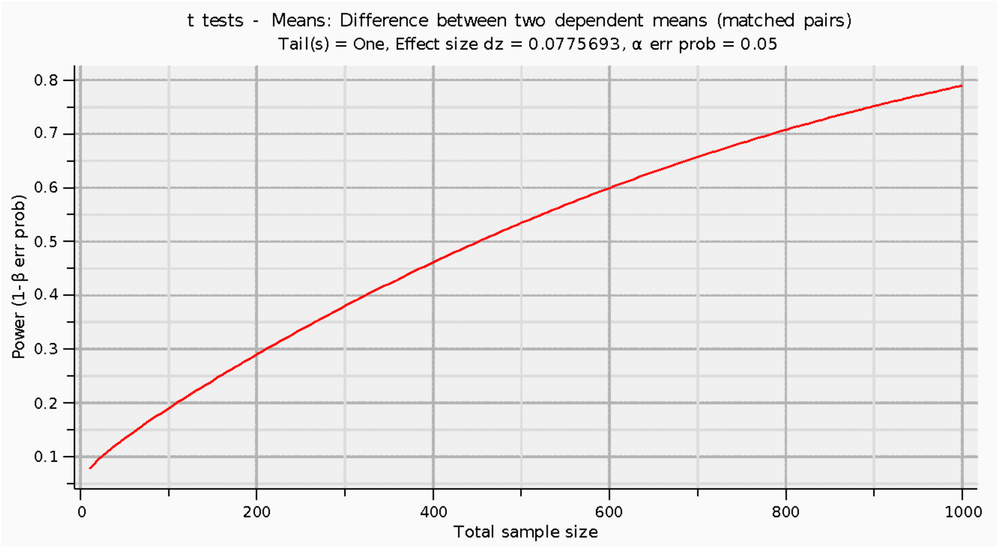


Figure 17. Obtained statistical power in function of number of sampling pairs for detection of an 8% (=20 years x 4‰) loss of SOC stocks from poorly drained forest in Flanders (drainage class f-g).

A similar situation exists for heathland and 'roughness - Ruigte' under the scenario presented in . It is clear that an unrealistically large number of samples is needed to more or less guarantee that SOC stocks losses of 8% did not occur. We therefore refrained from adding an additional corresponding criterion to the optimization of point allocation across land-uses and strata.

1.4.5 Conclusion

Past SOC stock inventories were used to gain insight in the magnitude of **temporal auto-correlation** between paired resampling to detect changes in SOC stocks. This is important because the variation on a future change in SOC stocks cannot be known in advance. A method was used to calculate required number of sampling pairs to detect a specific minimum difference in SOC stock (MDD) under the assumption that no correlation exists in pairwise SOC stock measurements.

The statistical power to detect such a SOC stock change is at least 0.5, averaged across cropland, grassland, forest and nature land-uses. This is likely a pessimistic estimate, because under the assumption of no temporal autocorrelation. In practice we expect rather a power of 0.6-0.8. Based on an analysis of past studies at least we could estimate the extent by which this assumption leads to overestimation of required sampling pairs, possibly by a factor 1.4. Given the degree of uncertainty associated with used best-available data and several assumptions were made, we nevertheless advocate a more conservative stance and continue with calculated (possibly overestimated) required numbers of sampling pairs.

MDD and sampling location numbers were run for 0-30cm SOC stocks because of lack of depth-differentiated data. At this stage it is very difficult to predict how accounting for detection of SOC stock changes at 30-100cm bears consequences for the sampling design. On the one hand, we expect a much lesser variation in SOC at deeper depth and then a less intensive sampling will be required to detect a given MDD; but on the other hand changes in time are likely disproportionally slower than in topsoil and then on the contrary more points are required. This effect will be different for individual land-use classes. Presented estimates rely on assumptions and imperfect (limited / outdated) SOC datasets. A more accurate evaluation of usefulness of stratified sampling within each land-use category could be based on 1m SOC stock measurements obtained from initial years of sampling. It would be a sound strategy to then also study variation in SOC stocks in function of depth and re-assess the necessity to resample all locations till 1m deep. This conclusion is essentially a re-iteration of Wouters *et al.* (2008a)'s plea: *"Tijdens de opstartfase van het meetnet gaat de meetnetontwerper uit van enkele veronderstellingen die noodzakelijk zijn om bijvoorbeeld de vereiste steekproefgrootte te berekenen. Deze veronderstellingen zullen niet altijd voldoende overeenstemmen met de uiteindelijke metingen. Met als gevolg dat de oorspronkelijke berekeningen van de steekproefgrootte mogelijk niet meer volledig van toepassing zijn (overschatting of onderschatting). Dat heeft uiteraard consequenties voor de resultaten van het meetnet. Het is de taak van de meetnetbeheerder om op vooraf vastgelegde evaluatiemomenten na te gaan of een bijsturing van het meetnet noodzakelijk is."*

In the present study **the choice was made to work with a relative target MDD**, depending on SOC stock present: i.e. a 4‰ yearly change in SOC sums up to more OC for a forest than for a cropland. The consequence is that MDDs for land-uses with generally larger SOC concentrations were also much higher than in cropland. If we would want to detect SOC stock changes corresponding to a yearly 4‰ yearly change in SOC stocks over shorter periods, e.g. within 10-years, thousands of sampling locations would be required, a probably unrealistic goal. Lowering the ambition to detection over a 20-year period reduces required sampling pair numbers to 620, 433, 670, 775 and 441 for cropland, grassland, forest, nature, and residential land-use, respectively. These numbers do assume that within each land-use category or stratum the 20-year 4‰ MDD is met; although this is not needed to reach the 20-yr 4‰ goal for Flanders as a whole.

Stratification has often been forwarded as a means to more efficiently sample SOC stock and changes therein. Several approaches to stratify were looked into. Essentially, many other combinations are possible as well, provided that datasets are available. For cropland, grassland and forest we focused on soil texture and soil drainage as factors to define strata. Efficiency gain was about 30% for cropland, but much smaller for the other land-uses. Other potential strata were tested as well: for example based on recent changes in the OC-inputs for cropland or a distinction between older and newer grassland. But because of a lack of geo-referenced up-to-date SOC data, these extra analyses remained only indicative and inadequate to robustly propose alternative strata. **Introducing stratification within land-use categories appeared to yield a modest gain in efficiency (2344 locations required instead of 2498 with no strata).** <u>Please note that these calculations date back to the initial phase I C-MON report in which ambitions to detect SOC stock changes were set lower for Residential Land and for Nature.</u>

Optimizing the spread of sampling pairs between land-uses led to a further gain in efficiency achieve a 20-year 4‰ MDD for cropland, grassland, forest and nature in Flanders (2151 locations, again witj lowered ambitions for Nature and Residential Land – phase I report), but allowing deviations from achieved and targeted MDD within individual land-use categories. With then also the ambition to detect mean 4‰ annual changes in SOC over a 40-year period only for Residential land (update based on C-Gar vs. phase I), **a total number of sampling locations of about 2600 would suffice to monitor SOC stock changes in Flanders. This number is further used in cost estimates in 1.6.** This scenario favours detection of SOC stock changes within cropland, at the expense of SOC stock changes in the other land-uses. The MDD of cropland then becomes 3.56 t OC ha^{-1}, equivalent to mean change of 180 kg OC ha^{-1} year^{-1} (in fact to a 3.3‰ target). Such MDDs indeed would allow to detect realistically expectable changes in cropland SOC stocks (as discussed in 1.3.4.2), whether by intentional management or region-wide policy or by other unknown factors.

The achieved statistical power to detect **losses of SOC** varies strongly per strata, spanning from 0.9 in most croplands and only 0.15 for heathland. These estimates are probably pessimistic, and might be larger (if we for instance assume 0.5 temporal autocorrelation): in other words, when a SOC stock change at least as large as the MDD occurs, there is a 50% chance that we instead falsely conclude that no significant change (at 5% significance level) occurred. Such accompanying power analyses will aid in lifting public-wide trust in the carbon monitoring network's robustness, and safeguard users to draw poorly supported conclusions.

1.5 POTENTIAL ALIGNING WITH EXISTING ENVIRONMENTAL MONITORING NETWORKS (EMNS)

1.5.1 Introduction

Several monitoring networks exist in Flanders that monitor environmental variables that could be relevant for the interpretation of SOC stocks. The land use type, the measured variables, the frequency and the level of detail of the measurements determine who is responsible for the implementation and management of these networks. Proper alignment of the C-MON network with the existing Flemish monitoring networks could improve the interpretation of the new SOC measurements. However, it is not a good idea to simply adopt the design of the existing monitoring networks for the C-MON network, since the purpose, scale and objectives may be different. For instance, results from a network that was designed to take policy decisions at the local level, are not useful for the regional level, since they do not adequately represent this broader level.

In 1.5 we present an overview of existing or future monitoring networks that are possibly of interest to incorporate (partly) in our C-MON network. The presented networks vary from networks with a high number of locations that are extensively measured to networks with a low number of intensively monitored sites.

1.5.2 Risk to induce biasedness by coupling to existing EMNs

Onkelinx *et al.* (2008): "*Niet de uitkomsten van het meetnet op zich interesseren ons, maar wel de veralgemening ervan naar een welomschreven doelpopulatie. De steekproefpunten van het meetnet moeten een onbevooroordeelde selectie zijn uit alle mogelijk indenkbare elementen van de doelpopulatie en elk element van de doelpopulatie moet een gekende selectiekans groter dan nul hebben. Indien aan deze voorwaarden niet voldaan is, hebben we geen basis om de resultaten te veralgemenen naar de doelpopulatie.*"

It is most crucial to unbiasedly select of the target population within each stratum, e.g. all sandy croplands, or e.g. any broadleaved forests. Especially land-use changes merit extra attention: an unbiased selection within strata will ensure that the occurrence of land-use or management change on the selected locations of the zero-survey is proportional to overall evolutions. Only in doing so, could the monitoring network's representativeness of reality be ensured.

Coupling of the SOC monitoring network to existing EMNs then might endanger achievement of this condition, depending on the original design of the EMN. For instance, Rawlins *et al.* (2017) and Arrouays *et al.* (2012) warn that soil surveys conducted on command of farmers are never random nor unbiased. Of the in the Sep2018 steering report listed EMNs, particularly the WATINA (WATer In NAtuur), the VMM phreatic net 8, the phosphate saturation degree mapping grid and the Flemish Forest inventory are of interest and will be discussed in more detail, compared to other initiatives.

1.5.3 Hydrological monitoring networks

1.5.3.1 Phreatic net 8

The Flanders Environment Agency (VMM) manages the primary and phreatic groundwater network ('primair en freatisch grondwatermeetnet'). The former consist of ca. 435 measuring locations where water height is measured monthly and the chemical composition of the deeper water layers is analysed yearly. The main goal is to determine the regional groundwater reserves and to evaluate the trends of water quantity during the year. The phreatic groundwater network is a collection of 2100 piezometers where water height and chemical composition of the first aquifer is measured every six months (Eppinger and Thomas, 2007).

The vulnerability of aquifers for excess nitrate depends strongly on subsurface properties, such as hydraulic permeability and reduction capacity. In order to better assess the risks, the density of measuring locations is higher in vulnerable areas than in less vulnerable areas. Therefore, the location of the piezometers is not random. Since this network has been installed in order to monitor and evaluate the effects of the Flemish action programs (Manure action plan - MAP), the locations were chosen to represent agricultural catchment areas.

A coupling of SOC monitoring to wells from the phreatic net 8 would be highly relevant to better assess the degree to which soil drainage status co-controls SOC stocks and changes therein. Mainly so because current estimates of soil drainage are outdated and also subject to the Belgian Soil Map's uncertainty (associated with not accounting for variation within mapping units as well as the methodology used, viz. groundwater levels were indirectly inferred from oxido-reduction features in subsoil). From the multi-year monitoring of groundwater levels, phreatic filters yield a much more actual and reliable indication of drainage status). Any future changes in hydrology (global change) may affect groundwater levels. In finely textured soils, where a vadose zone is fed by not too deep groundwater due to capillarity, changes in groundwater dynamics will influence the hydrological regime of the topsoil. This could then indirectly echo into altered soil processes including crop growth and microbial mediated decomposition of organic matter. One of the crucial questions for future land use/land management is what impact climate change may have on groundwater height and soil moisture availability. Linking SOC to groundwater height of piezometers nearby will provide valuable information of the impact of decreasing or increasing water tables on SOC. Including sites were groundwater height measurements occur in the C-MON network is an interesting option.

It should be considered though that placement of phreatic grid 8's 2100 wells was not entirely random: localization depended on several factors: 1° First of all, on the regional scale stratification occurred along so-termed HHZs (hydrogeological homogeneous zones: i.e. areas in which processes involved in diffuse transport of NO3- are considered relatively equal). More wells were allocated to HHZs more prone to NO3- leaching and transport to surface water. 2° Secondly, more wells are concentrated in areas with a predominant agricultural land-use. 3° Thirdly, to ensure accessibility wells were mostly located right next to roads, never for example within an agricultural field.

- A bias introduced by aspect 1° could be circumvented by selecting points proportional to the HHZs' areas, not to their well numbers.
- A bias introduced by aspect 2° cannot be solved, but should not really form a problem if only an linking with sampling plots for cropland and grassland is aimed at.
- A bias introduced by 3° is avoidable: Coupling of monitoring plots (10x10m² or 20x20m²) would only be meaningful if these are sufficiently near to the filter (e.g. within a 30m range), and so also relatively close to the border of parcels aside roads. Such selection may not introduce any significant bias at all, but at present this cannot be assessed. But any bias for the entire population could be avoided by ensuring that plots not aside groundwater wells are disproportionately further away from roads and field borders to compensate.

We propose to preferentially position 15% of all grassland (56) and cropland monitoring plots (122) in close vicinity of phreatic grid 8 wells. As a final safeguard: A post-hoc ANOVA on SOC stocks will reveal if systematic differences exist with otherwise completely random selected plots. In the unlikely event that such a bias exists, the consequences for the representativeness will be relatively constrained: In the worst-case scenario that 15% of locations are excluded entirely, the MDD (0.409 kg OC m^{-2}) is still below the cropland 20-year 4‰ target. With temporal autocorrelation = 0.2 the statistical power for maintaining at least the 20-year 4‰ target in each stratum then drops from 0.58 to 0.52 for cropland in the Polders, from 0.88 to 0.84 for cropland central Flanders and from 0.64 to 0.57 for cropland the Campines. These could still be deemed acceptable. Once more, the actual power guaranteed for the MDDs set out in scenario 6 (Table 20) are better. Likewise drops in power of about 0.06 seem occur in grassland as well when 15% of points are omitted and then the power still suffices per individual stratum (for grassland Z-A e,f,g,I & E,U: from 0.55 to 0.50).

These alternative scenarios with a preferential positioning of 15% of the sampling sites near phreatic groundwater monitoring wells are presented in 2.1.2.2 and 2.1.3.3.

1.5.3.2 WATINA

WATINA stands for “WATer In NAtuur” and is an online database for hydrological monitoring in around 250 groundwater dependent nature areas. The database is managed by the Research Institute for Nature and Forest. The network, which was initiated around 1989, consists of piezometer tubes and gauges in almost exclusively wet soils and for the most part in the upper aquifer (tubes extend maximum 3m below the surface). Although WATINA contains measurements of groundwater height of more than 3000 piezometer tubes and gauges, recent measurements are available for only ca. 1350 locations. The main land cover is forest, with a smaller number of locations on semi-natural grassland, heathland and bogs. In the piezometers, the water height is measured every two weeks on average by local site managers (ANB, Natuurpunt, municipalities,..) or by INBO. For part of the WATINA sites, vegetation studies, groundwater analyses and soil data were collected by INBO (Callebaut *et al.*, 2007).

One of the crucial questions for future land use/land management is what impact climate change may have on groundwater height and soil moisture availability. In finely textured soils, where relatively shallow groundwater may become available due to capillarity, changes in groundwater dynamics will influence the hydrological regime of the unsaturated zone. Linking SOC to groundwater height of piezometers nearby will provide valuable information of the impact of decreasing or increasing water tables on SOC. Therefore, including sites were groundwater height measurements occur in the C-MON netwerk is an interesting option.

With respect to a coupling of the C-MON network to the WATINA network, benefits for interpretation of future SOC stock changes will be equally large as in the case of the phreatic well net. The selection of the measurement locations was however not random, but ad hoc. Depending on projects studying certain sites, models, etc, new piezometers were installed. Also, prior to the official recognition of nature areas as nature reserve, terrain managers were asked to install piezometers for hydrological monitoring. The result is that, even if this is not exclusively the case, still most of the measurement locations are not privately owned, but are situated on public property. In addition it is obvious that WATINA sites are mostly situated on wetter parts of the landscape, and mainly in forest. Consequently, WATINA locations do not represent the entire forest and nature area in Flanders. As such a coupling with C-MON could in the first place be made with the stratum forest with drainage class e-f. Any added value for interpretation will then also be confounded to that part of the entire ‘forests’ population. Again, if 15% of the current 236 forest sites with drainage e-f (35) are coupled to WATINA, and very pessimistically all of these would be omitted from the sample, then this would lower the power of a one-sided pairwise t-test to detect a 8%loss to 0.29 in case of scenario 6. However, with all 236 plots the power was already low (0.32) and so we must accept less stringent ambitions in terms of ability to detect SOC stock losses for poorly drained forest. In fact, a higher % could then be considered just a s well: e.g. 25% or 58 locations.

To a lesser extent also coupling with strata in the land-use 'Nature' seems possible as well, but then it should be considered that with the current strata (Heathland, semi-natural grassland, 'roughness) this may introduce a bias, because drier vegetation types would be underrepresented. To implement a coupling then also drainage class of the current nature areas needs to be considered when allocating the remaining 85% of sites, so that a disproportional part thereof is allocated to less wetter parts. Because of uncertainty about representativeness of the WATINA grid, perhaps the more conservative stance, namely to allocate just 15% of all nature plots is appropriate.

We propose to preferentially position 25% of all poorly drained forest (59) and 15% of nature plots (51) next to WATINA wells.

1.5.4 Monitoring networks in agricultural land

1.5.4.1 Good practice guidelines soil protection

Since the reform of the Common Agricultural Policy of EU, the direct payments to farmers are linked to compliance by farmers (cross-compliance). This means that basic standards have to be met regarding soil erosion, soil organic matter content and soil structure as well as the requirement of maintaining land in good agricultural and environmental condition. These basic standards were established by decree by the Flemish government (Ministerieel Besluit van de Vlaamse Regering van 24 oktober 2014 betreffende de specifieke regels voor vergroening).

For C-MON, especially the standards regarding soil erosion and soil organic matter are relevant. When farmers can prove that the C content in a soil sample is at least 1.7% and the pH is in the optimal zone, the erosion risk class of the parcel may be lowered. The farmer is responsible for optimizing soil fertility and soil structure. For each farm, the pH and C content of a subset of parcels with annual crops had to be determined by an accredited lab. Again, Rawlins *et al.* (2017) warned that field selection by farmers cannot be considered random. In addition, these data are strongly aggregated (the parcel location is not recorded) and the location is not randomly chosen. **We judge that these data have limited use for designing the C-MON network and a coupling of sampling locations to fields previously sampled is not in order.**

1.5.4.2 Flemish Land Agency Land development projects

During land development projects ('landinrichtingsprojecten') or reparceling operations of the Flemish Land Agency (VLM), the Belgian soil map is updated based on profile descriptions. In some cases, especially during nature development, abiotic monitoring is carried out of the sites before and up to several years after development of the site. This monitoring takes place in plots of 2 x 2 m2 of 3 x 3 m2 and involves among others C measurement (% carbon) (Carole Ampe, VLM, pers. mededeling, oktober 2017). However, abiotic monitoring of land development projects is currently becoming more rare. **Due to the limited number of locations, the scarcity of OC measurements and the absence of historical measurements, the C-MON network will not take into account the Land development locations.**

1.5.4.3 Derogation network

The derogation monitoring network closely follows 160 farms during three years (2016-2018). At each farm, three parcels are monitored. Half of the farms are derogation farms and the other half are non-derogation farms. They are further classified by crop (maize, grass or grass-clover) and soil type (sand or sand-loam). The crop management is further documented by a questionnaire for the farmer and farm visits. Soils are sampled and nitrate residue is measured among others in spring and autumn. Subsamples are collected within the whole parcel and the investigated parcel may change over time (e.g. if the current crop changes to a non-derogation crop). There are no C measurements available. Though soil nutrient management holds relevance for SOC dynamics, the metrics obtained from the derogation network will be outdated quickly. Also it is unlikely that included farms were chosen randomly and therefore inclusion of plots from this network probably results in a biased sampling of land-use categories cropland and grassland. **Due to the lack of OC measurement and the different plot size, and risk to introduce a bias in the sampling design, the derogation network is not further considered as relevant for the C-MON network.**

1.5.4.4 Phosphate saturated areas in Flanders

In order to map the areas in Flanders where soils are saturated with phosphate ('Fosfaatverzadigde gebieden'), 3644 point locations were sampled and analysed in 1997 (De Smet *et al.*, 1997), following a regular grid. In 2007 708 additional were carried out in order to refine the map (Van Meirvenne *et al.*, 2008). The survey was non-recurrent en limited to sandy to sandy loam textured agricultural soils. Moreover, C was not measured on the soil samples, and neither was bulk density determined. Part of the soil samples of the 0-30, 30-60 and 60-90cm layers were however archived at the Ghent University.

A partial resampling of sites visited for the phosphate saturation degree mapping in Flanders could be of interest for two reasons. First of all this would enable to re-assess soil orthophosphate profiles till 90cm depth for 'agricultural land', i.e. cropland and permanent grassland. Secondly, OC analysis of the archived locations (all three depth layers) and selective resampling would then enable a pairwise-comparison to assess SOC stocks changes since 1994-1997. Both opportunities are, however, only ancillary to the target set out for the current soil monitoring network. Knowledge on changes in PSD or past SOC stock evolutions will not necessarily forward interpretation of observed SOC stock changes from 2020 onwards. Mabilde *et al.* (2017) used correlation analysis and structural equation modeling (SEM) to assess driving factors for groundwater orthophosphate concentrations in Flanders. Also the factor, topsoil OC% was integrated in the SEM, but no link could be found with groundwater P levels or soil PSD levels. The soil poorly crystalline Fe and Al content, by standard measured during PSD-assessment has often been demonstrated to be a relevant predictor of SOC concentrations (e.g. recently by Van De Vreken *et al.* (2016) for a set of cropland topsoils). But if needed the archived samples could always be analysed afterwards for their poorly crystalline Fe and Al levels. Lastly, the number of potential locations to be resampled would always remain limited compared to the many more point observations made for the original PSD sampling. Hence any comparison of either PSD or SOC vs. 1994-1997 levels would just be indicative.

At the same time again preferential allocation of measurements bears the risk to introduce a bias in the sampling. While the grid followed for PSD-mapping ensures unbiased sampling, in practice on the smaller scale deviations were introduced by the soil surveyors. 'Point locations' were most often again near the sides of parcels facing roads. As explained in 1.5.2.1 this could be compensated for by when choosing samples that are not linked to former PSD-mapping point observations.

Another point of attention is the field sampling methodology:

- + The PSD mapping depth increments could well be matched with depths foreseen in the new sampling protocol,
- - bulk density was not measured.
- - There would be a mismatch in dimensions of the foreseen 20x20m plots (a final decision follows in Phase II) and the approximately 6m radius circle sampled for PSD mapping.
- - The most important restriction though will come from imprecise knowledge on sampling locations; No GPS was used and locations were just indicated on paper field maps. In analogy: Although (Goidts *et al.*, 2009) resampled within a radius of 11 m of the original site of the Belgian National Soil Survey (1947–1974), the source of error related to imprecise resampling of each location was quite large (i.e., relative RMSE ranging between 12% and 31%) due to large variability in SOC concentration, bulk density, stone content and sampling depth at very fine spatial scales (i.e., variability within the same field) (Arrouays *et al.*, 2012).

Considering the above analysis we propose not to couple the C-MON network to the PSD-survey grid.

1.5.5 Monitoring networks in Forest and Nature

1.5.5.1 Flemish Forest Inventory (FFI)

The Flemish Forest Inventory uses a 1 x 0.5 km² grid. During the first regional inventory (1997-1999), 3281 sites were visited and measured by the Agency for nature and forests of the Flemish Government (ANB). Measured or observed variables quantified, among others, wood volume, tree and vegetation diversity, forest management, tree health and presence of dead wood (Wouters *et al.*, 2008b). For a subset of 138 VBI plots, soils samples were analysed. In 2009, the ANB started a second campaign, in which they visited 10% of the locations each year. Currently, around 80% of the plots have been re-visited.

Based on the data that are measured in the FFI, biomass organic carbon stocks can be computed. Linking these results to soil organic carbon stocks would be very interesting to compute and model total C stocks. Since sampling is unbiased since it follows a regular grid, and the actual selection of sampling plots happened according to statistically sound guidelines (Wouters *et al.*, 2008b). The sampling plot consists of four concentric circles with diameters ranging from 4.5 to 36m. In the smallest circle the diameter and height of all trees are measured, while only the larger trees are measured in the second and third circle. The largest circle is used to determine characteristics such as forest management type and stand type. Vegetation is studied in a 16 x 16m² plot.

We propose to preferentially position 10% of all forest plots in close vicinity of the FFI plots. Selection of these plots should be independent of ownership (private or public).

1.5.5.2 LTER sites

LTER-Belgium stands for the "Long-Term Ecosystem Research Network in Belgium". LTER-Belgium is a network of sites engaged in long-term, site-based ecological and socio-ecological research (Cools *et al.*, 2016). The network consists of 33 sites (16 in Flanders) where regular monitoring and research of broad spectrum of environmental variables at a local level (LTER Sites) and of environmental as well as socio-ecological variables at a sub-regional level (LTSER platforms) is carried out. The network aims to support national and international cooperation and exchange of data. A complete description of all sites can be found on the LTER-Belgium website (www.lter-belgium.be). In Flanders 8 sites are situated in forest, including the 5 ICP Forests Level II plots that are described below. The other sites have natural vegetations ranging from heathland, to dunes, alluvial areas and one site in a park, namely the Plantentuin Meise. **At the sites that are not part of the ICP Forest network, emphasis is on monitoring of vegetation and management, and less on abiotic conditions. Those sites appear less relevant for the C-MON network.**

1.5.5.3 International Level I, Level II and Level III forest plots of the UN/ECE ICP Forests monitoring network

During the European BioSoil+ survey, soil carbon stocks were computed in 10 Level I sites in Flanders. These sites are part of a European-wide 16x16 km2 systematic grid for the selections of sites in forests. Based on these results and the result of 5000 other European forested plots, the European SOC stock has been estimated (De Vos *et al.*, 2015). Flemish SOC stocks can now be compared to these European benchmark values.

More intensive monitoring of forest ecosystems is carried out since 1991 in five ICP Level II plots in Wijnendale, Ravels, Gontrode, Hoeilaart and Brasschaat. C in soils is measured every 10 years and has been measured three times since 1991 and since 2002 DOC in wet deposition and soil solution is measured every two weeks (Verstraeten *et al.*, 2014).

The Integrated Carbon Observation System Research Infrastructure (ICOS RI) (Level III) is part of the European research infrastructure (ESFRI) network and counts three terrestrial sites in Flanders: Brasschaat (Scots pine), Lochristi (short rotation coppice of poplar and willow) and Maasmechelen (dry heathland). Fluxes of CO2, CH4, H2O and heat are continuously measured at these sites, together with other ecosystem variables in order to quantify the exchange of energy and greenhouse gases between ecosystem and atmosphere. INBO and the University of Antwerp work closely together at the site of Brasschaat. There are currently no ICOS sites on agricultural land in Flanders, unlike Wallonia, where cropland is intensively monitored every 4 years in Lonzée.

Since long time series of data on soil and biomass carbon are available for the Level I, II and III plots, integration with the C-MON network should be considered.

1.5.5.4 Meetnetten natuurlijk milieu

Currently, there exists no systematic monitoring of the natural environment of the Natura 2000 habitats in Flanders. The Research Institute for Nature and Forest is currently designing such a monitoring network, with separate networks for the compartments groundwater, surface water, air and soil. These were named the 'Meetnetten Natuurlijk Milieu' (MNM) (Vanderhaeghe *et al.*, 2017). This network will determine the status and trends of specific environmental variables in order to better understand the main threats for certain habitat(sub)types. Environmental information is necessary to support planning, justification, evaluation and adjustment of nature policy in Flanders. It is important to determine why the conservation status of Natura 2000 habitat types is unfavourable and/or insufficiently improving (if that is the case). Currently, the exploratory study needed to further clarify the research questions and the involved policy relations has been completed (Vanderhaeghe *et al.*, 2017). In the next phase, the individual networks will be developed, the first two being groundwater and surface water.

Although this study may provide valuable information on procedures of monitoring network design, the actual selection of monitoring sites will not start before 2019 (for groundwater and surface water).

Therefore, the usefulness for C-MON is limited. The results of the C-MON network will be of value for the MNM in soils, by delivering information on variability.

1.5.6 Mapping land-use and land-use changes

1.5.6.1 GARMON project

The approved federal BELSPO project (CONTRACT NR SR/00/363) with the acronym 'GARMON': The Garden Monitor – mapping and characterizing gardens using remote sensing, was set up by Information Flanders Agency (AIV) of the Department Environment (LNE) and the KULeuven. This project is financed within the framework of the Belgian Science Policy Office's (BELSPO) research program for earth observation 'STEREO III'. The project runs from December 2017 until the beginning of 2020.

The project aims to explore image processing techniques to extract spatially explicit information on the location and area of gardens in Flanders. Based on remote sensing data (both airborne and satellite-based), the different garden cover components (e.g. trees, grass, low green, sealed surface and water) will be mapped, characterized and monitored. The project proposal mentions that currently, reliable and integrated baseline data and databases concerning gardens are non-existent in Flanders, mainly due to the difficult accessibility that hampers data collection. The goals of the project mention explicitly that "The collected garden data will allow the calculation and optimization of regulating, maintenance and cultural ecosystem services of garden vegetation (like carbon sequestration, cooling effect, air quality, water regulation, habitat provisioning, recreation). This data would support: policy preparation, policy execution and policy evaluation".

Clearly, the GARMON project and the C-MON project need to join forces. The results of the GARMON project will be ready after the implementation of the C-MON project, **but early results may be useful when selecting the measurement locations. Moreover, we can deliver the necessary ground truth data for calibration and validation of models that predict SOC stocks.**

1.5.6.2 Land use, land use change and forestry inventory by Bauwens et al. (2010)

In 2010, Bauwens *et al.* (2010) of the Université de Liège, carried out an inventory of land use in Belgium in 1990 and 2008. They used a regular grid of 2 x 2 km^2 (6799 locations in Flanders) and determined for every grid node the land use according to six land use classes based on thematic maps and photo-interpretation of topographical maps and orthophotos. The grid they used was identical to that of the Flemish Forest Inventory. The total area of each land use class was derived from the number of points falling within the land use class and a matrix containing the area of land use change between 1990 and 2008 was derived. This matrix has been updated in 2012 and 2015 and is currently being updated for 2019. It is currently used by the Flanders Environment Agency (VMM) for reporting to the EU and to the UN (under the commitments of the UNFCCC and the Kyoto Protocol).

The Bauwens land use monitoring network is a useful tool for international C reporting. **The known land use history may also be of value for the C-MON network.** When designing the C-MON network, special attention will be given to locations were recent land use changes have taken place, as here the changes in soil carbon are especially relevant. The Bauwens network may be useful for the selection of these points.

1.6 TOTAL COST ASSESSMENT OF THE T0 INITIAL SOC SURVEY

1.6.1 General approach

The total cost for the setup and full execution of the SOC T_0 survey across Flanders is based on the sum of three sets of plots for each land-use type (Table 22):

1. the number of random sampling locations (Level I plots) required to detect a MDD corresponding to a 4‰ yearly change in SOC over 20 years (Scenario Table 20);
2. a selection of plots with documented land-use-change in either direction (e.g. forest ⇔nature, cropland ⇔permanent grassland) needed to ensure a balanced dataset for LULUCF reporting needs;
3. a selection of plots for quality assurance and quality control (QAQC), inter-calibration of teams and labs, repeatability assessment, and quality checks by independent parties and authorities.

Table 22. Total number of plots by Land use class for execution of the T_0 SOC stock survey.

Land use	Number of regular	LULUCF plots	QAQC	Total plots
Cropland	816	20	41	877
Permanent Grassland	373	20	19	412
Forest	490	20	25	535
Nature	472	20	24	516
Residential	441	20	22	483
Total plots	**2592**	**100**	**130**	**2822**

The LI plots are selected using the Generalized Random Tessellation Stratified sampling (GRTS) approach (Onkelinx, 2017), providing a spatially balanced set of Level I plot locations for each landuse class across Flanders. In addition to this LI set, 20 plots are added to each landuse class (5 extra plots for LU change in one direction towards the 4 other landuse classes) to ensure a balanced statistical design to compute SOC stock changes for all potential landuse changes. The QAQC plot set, is a 5% subset of the total LI plots per landuse class, and used for independent resampling and re-analysis for quality assessment. Hence, the costs for these extra sets should be accounted for in this chapter. The total number of plots for the T_0 survey is 2822 plots.

For the total cost estimations we assumed a basic survey strategy in which all sampling plots are surveyed once over a period of 10 years, assessing 10% of the plots each year (i.e. planning, sampling, laboratory analysis. data processing and reporting within each year). Preliminary cost estimations for a T_0 survey period of 5 years were advised against by the project's steering committee and are not elaborated anymore in this chapter. At this point we did not estimate costs for the monitoring phase (i.e. a second assessment of the Level I plots to allow paired sampling). If the same plot sampling scheme is applied the costs for monitoring are equivalent to those of the T_0 survey, but most likely we will simplify the plot sampling scheme (less sample depths, less analytical parameters, …) so that the monitoring costs will be reduced substantially.

During two Steering Committee meetings preliminary cost calculations were presented in various scenarios for (i) the regional sampling scheme, (2) the plot sampling scheme and (3) the soil analytical parameter set.

During the last Steering Committee (on 2/10/18) it was decided to do the final cost estimation for (1) selected scenario N°6 of the regional sampling scheme as mentioned higher, (2) one (preferred) selected variant of the plot sampling scheme and (3) one selected set of soil analytical parameters. Details of the chosen variants for (2) and (3) are shortly provided below, but will be further elaborated in Phase II of this project (WP 2.3. Protocols). Since these chosen options determine significantly the total cost, we are forced to take these into account already in this phase of the project.

The first 'survey' year the costs include the buying of new equipment (vehicles, mechanical and manual sampling devices, recipients, etc.) for the survey teams which is depreciated over a period of 10 years. To feed the cost estimations, we collected actual "Belgian" prices (including VAT).

The field sampling costs are based on effective cost accounting by INBO (for soil surveys) and ANB (Forest Inventory already ongoing for 15 yrs). The laboratory costs are averages of 5 relevant laboratories (BDB, EUROFINS, PC Groententeelt, ILVO and INBO). The overall cost for the T_0 survey is the sum of all 10 sampling years.

1.6.2 Cost information

Following state-of-the-art cost information was collected:

- **Personnel costs** for coordination, administration, field work, data elaboration and reporting
- **Equipment costs:** all equipment needed to conduct the **field** survey, excluding laboratory equipment (depreciated over a 10 yr period)
- **Operational costs:** consumables, fuel, maintenance and repair of **field** vehicles and equipment
- **Analytical costs for laboratory work**: lab prices for each analysis encompass all costs (lab staff, chemicals, use of analysers, … (so full analytical cost per sample)
- **Costs for quality assurance and quality control:** 5% of samples are resampled both in the field as in the lab (excluding internal standards and control checks normally included in standard lab practice)
- **Costs for archiving all soil samples**

For the cost assessment over 10 years we assume prices to increase with 3% per year which is realistic (Comm. EVINBO administration). In the total estimated cost we do not take into account extra overhead costs, because all costs for performing the survey are already included.

1.6.2.1 Personnel costs

For conducting the T_0 survey a full time (FTU) survey network coordinator is required, doing all planning, administrative and technical coordination, coaching, data evaluations, quality assurance and control, reporting and communication. We selected a senior bio-engineer profile or equivalent, with 12 years of experience.

Because considerable administration work needs to be conducted (e.g. finding out field owners based on 'kadaster' information, asking permissions for sampling, paperwork for equipment purchase, stock assessment, etc.) a half time administrative assistant is essential (B level).

Table 23. Annual personnel costs for coordination and field work to conduct the T0 SOC survey, daily costs with and without (w/o) overhead are listed.

PERSONNEL	DAILY COST

COORDINATION	Level	Sen	FTU	ANNUAL COST	w/o OH		with OH	
NETWORK coordinator	A166	12y	1	**€ 77239**	€	430.0	€	570.9
Administration assistant	B111	3y	0.5	**€ 23712**	€	263.5	€	332.4
A-TEAM								
Field technician	B	12y	1	**€ 52112**	€	289.5	€	362.2
Field technician	C	12y	1	**€ 46394**	€	257.7	€	327.4
B-TEAM								
Field technician	B	12y	1	**€ 52112**	€	289.5	€	362.2
Field technician	C	12y	1	**€ 46394**	€	257.7	€	327.4
TOTAL COST PER YEAR				**€ 297963**				

Abbreviations: Sen: Seniority (Dutch: Anciënniteit), FTU: Full time unit (Dutch: VTE), OH: Overhead

Field technicians are best grouped by two in a team, a level B profile who has more responsibility over a level C. We selected an A-team that may be specialized in sampling arable land and grassland soils with adequate mechanical devices and a B-team for soils of forests, nature reserves, parks, etc. with specific expertise and equipment. Hence, field technicians should have a certain level of experience, and therefore a seniority of 12 years to start with is considered in the calculation.

Lab technicians are not included in Table 23 because their costs are fully accounted for in the analytical costs.

Average total annual cost of a coordinator, administration assistant and two field crews equals **294412 euro** (Table 23). Daily costs for senior field technicians are on average 275 euro (without overhead as applied in this cost estimation). Costs with ~20% overhead (OH) include daily allowances, use of vehicles, devices, training, computers, etc. provided by an institute (as INBO, ILVO) or company. Daily costs reported by private labs for soil sampling is between 265 and 363 euro (VAT included), equivalent with the daily costs including overhead as listed in Table 20.

Effective number of project working days per year is set at 180. The remaining days within a FTU are required for meetings, training, disabilities and recovery from health problems, etc.

1.6.2.2 Equipment costs

Based on information from ILVO and INBO total equipment costs for 2 teams for a period of 10 years is estimated at **121153 euro** (Table 23).

This includes an A-Team heavily equipped with 4x4 pickup jeep with trailer (2.6 ton) to transport a mini tractor or gator, a hydraulic corer system, a GPS rover for field positioning, a laser rangefinder for fast positioning of sampling locations and a complete set of augers and gouges for manual soil sampling (Figure 18). The same all-terrain vehicle and manual sampling devices are foreseen for the B-team which does not need the mechanical devices in non-agricultural plots.

Table 24. Initial costs for basic survey equipment for field work.

	EQUIPMENT	COST, VAT incl.
A-TEAM		
	Jeep + remorque + gator	€ 54288
	Hydraulic corer system	€ 13189
	GPS rover + laser rangefinder	€ 6500
	Augers and gouges (complete set)	€ 3828
	100 Kopecky steel rings	€ 1886
		€ 79691
B-TEAM		
	Jeep (4x4 pickup for all augers and gouges)	€ 29248
	GPS rover + laser rangefinder	€ 6500
	Augers and gouges (complete set)	€ 3828
	100 Kopecky steel rings	€ 1886
		€ 41462
	EQUIPMENT COSTS	**€ 121153**

Figure 18. Examples of surveying equipment (from left to the right: Pick-up 4x4, Gator with hydraulic corer system, Manual augers and gouges).

1.6.2.3 Costs for consumables, fuel, maintenance and repair

Equipment needs fuel, maintenance and sometimes (external) repair, which should be accounted for in the cost assessment. Based on our experience we estimated the prices in Table 25. Fuel consumption is based on average number of travelled distance for field work and transporting the samples to the laboratory. Machine maintenance includes vehicles and mechanical sampling devices. GPS rover hardware and software updates are included as well as external repair of augers and core samplers.

With respect to administration, costs for 'kadaster' information and correspondence with field owners is included.

Table 25. Annual costs for consumables, maintenance and repair.

Cost item	
Administration (Kadaster, printing, licencing, software)	**€ 2000**
Consumables (recipients, liners, …)	**€ 3000**
Fuel, vehicle and machine maintenance	**€ 8000**
Other maintenance & repair (sampling tools, GPS, laserfinders)	**€ 5000**
TOTAL	**€ 18000**

1.6.2.4 Analytical costs for laboratory work

Analytical costs depend on number of samples, type and group of analyzed soil variables and type of instrument used. Recent instruments like CN total analysers can determine C and N concentration in the same run, while separate instruments were used in the past. However, inorganic carbon (TIC) requires an extra run.

On 21/06/18 three options for analytical sets were presented to the steering committee, ranging from the most essential set for carbon stock calculation (carbon concentration and bulk density) to an extended set with explanatory soil variables like pH, N and particle size analysis (texture).

During the last committee (02/10/18), it was advised to add Vis-NIR spectroscopy for topsoil samples as well, in order to get spectral fingerprints for OC calibration to be used in future remote and proximal sensing surveys.

Finally, the steering group decided to select following variables:

Table 3. Analytical costs for the selected set of variables.

Variable	Standard	Specification	Average cost per sample (euro)*	Analytical cost range (euro)*
Sample pretreatment	ISO 11464	(cooling), drying, crushing	12.8	6.0-25.0
Soil bulk density	ISO 11272:2017	Kopecky ring	14.5	8.4-25.0
Total C and N analysis	ISO 10694 and ISO 13878	Separately or using a C:N analyser	34.1	22.0-56.3
pH-$CaCl_2$ or pH-KCl	ISO 10390	potential pH	13.0	8.5-17.6
Total Inorganic Carbon (TIC, Carbonates)	ISO 10694	Only when pH_{CaCl2} > 6.5	17.3	12.0-28.7
Vis-NIR spectroscopy	-	See Stevens *et al.* (2013)	7.0	5.0-9.0
Soil texture	ISO 11277	Here sieving/pipette (lower cost with laser diffraction ~15 euro)	41.7	25-50

(*) personnel costs lab technicians included (**) costs based on information provided by 5 labs: BDB, EUROFINS, PC groententeelt, ILVO and INBO

The average analytical cost for this complete set is **140 euro** per sample. Assuming only 20% of the samples need TIC analysis (conditional on pH) the average cost is reduced to **127 euro.**

When instead of standard pipette method laser diffraction is used for texture analysis the cost is further reduced to **93 euro per sample**. Determination of Vis-NIR spectra for topsoil samples only, increases the cost to **100 euro per sample**.

For the total analytical cost calculation, costs are determined per type of sample (Table 26) and multiplied by the annual number of samples to be analysed each year.

Table 47. Analytical costs for different types of samples.

Type of sample	Variables	Cost /sample
Organic layer (in forest soils only)	TOC, TN, dry mass	€ 46.9
Mineral soil disturbed, 0-10 cm	TOC, (TIC), TN, LD-Texture, pH and Vis-NIR	€ 85.4
Mineral soil disturbed, > 10 cm	TOC, (TIC), TN, LD-Texture, pH	€ 78.4
Mineral soil undisturbed	Bulk density	€ 14.5

It should be noted that there is a draw-back in using the cheaper laser diffraction method for particle size analysis. Laser diffraction provides the optical particle diameter of soil particles and is not easily related to particle sizes determined with standard pipette method (Stokes diameter) and sieving methods. Comparison with the Belgian textural classes is not straightforward.

On the other hand, LD particle size distributions are highly reproducible and offer the full textural fingerprint from 0.04 µm to 2 mm enabling various discrete texture class ranges to be applied.

1.6.2.5 Costs for sample archiving

Since soil samples hold information for a very long time, storage in a soil archive is essential for reanalysis (quality control), calibration and validation of innovative methods and instruments and potential for analysis of extra soil variables (aggregate fractions, black carbon, labile pools, …).

The costs for storage in an existing soil archive is provided in Table 27. Archive installation costs nor rent for storage rooms is included here, because this may be quite different depending on the host (governmental/private institute) of the archive.

Table 58. Analytical costs for different types of samples.

Type of costs	Description	Cost /sample
Recipients	PE with lid & cover	€ 0.60
Printer + stickerlabels	Barcode printer	€ 0.15
Labour (Technician C level)	Physical archiving (80 samples/day)	€ 3.70
Database registration	Data entry (500 samples/day)	€ 0.70
Archiving cost per sample		**€ 5.15**

Archiving maximum 5 disturbed composited samples per plot for the complete T_0 survey (2822 plots) equals 14110 samples which will cost **72 667 euro** or **7267 euro** per year in a 10 year scenario.

1.6.3 Plot sampling schemes

1.6.3.1 Sampling plot

Based on discussion of the 3 plot sampling schemes suggested earlier, one specific design was suggested to the steering committee of 02/10/2018 and adopted. This design will be further described under **WP 2.3 Protocols** during Phase II of this project, but we need it here for more precise cost estimation.

We now suggest that the sampling plot fits in a land-use specific homogeneous **10 x 10 m plot which equals one pixel** of the VITO landuse raster. This 10 x 10 m sampling plot is subdivided in **one-hundred 1 x 1 m cells** which are potential sampling locations.

Based on variogram modeling of real-life datasets the number of samples is determined based on the variance within a 14 m lag distance (the maximum lag within a 10 x 10 m plot) and according to a specified precision (e.g. SD is 10% of the mean stock, or CV=10%) that we wish to attain for composited soil samples.

The number of sampling locations is determined for two depth ranges: **0-30 cm (topsoil)** and **30-100 cm (subsoil)**. The required number (e.g. 16 subsamples for 0-30 cm) of sampling locations is allocated within the sampling plot using the same GRTS algorithm as applied for the plot selection over Flanders region. Hence, the sampling locations are evenly distributed over the plot area (spatially balanced design). If some sample locations drop out (due to 'hard' obstacles for sampling) extra sample locations can be easily selected.

Less samples will be needed for the subsoil (for the same precision) and these form a subset of the topsoil locations.

The sample locations for each plot are fixed. When the plot is revisited after 10 years another set of locations within the plot will be selected to avoid disturbance. Each sampling location will be easily and swiftly determined in the field using pre-calculated polar coordinates (distance, angle) from one corner of the plot using a laser-rangefinder or total station.

For the cost calculation it is only important to know that we need one pooled undisturbed and one pooled disturbed sample for each depth interval.

1.6.3.2 Depth intervals

The Steering Committee adopted the proposal that sampling will be done according to minimum 4 specific fixed depth intervals (Figure 19):

- Organic layer/Forest floor (LFH) if present
- 0-10 cm
- 10-30 cm
- 30-60 cm
- 60-100 cm

Field soil sampling to detect the changes of organic carbon stock in mineral soil

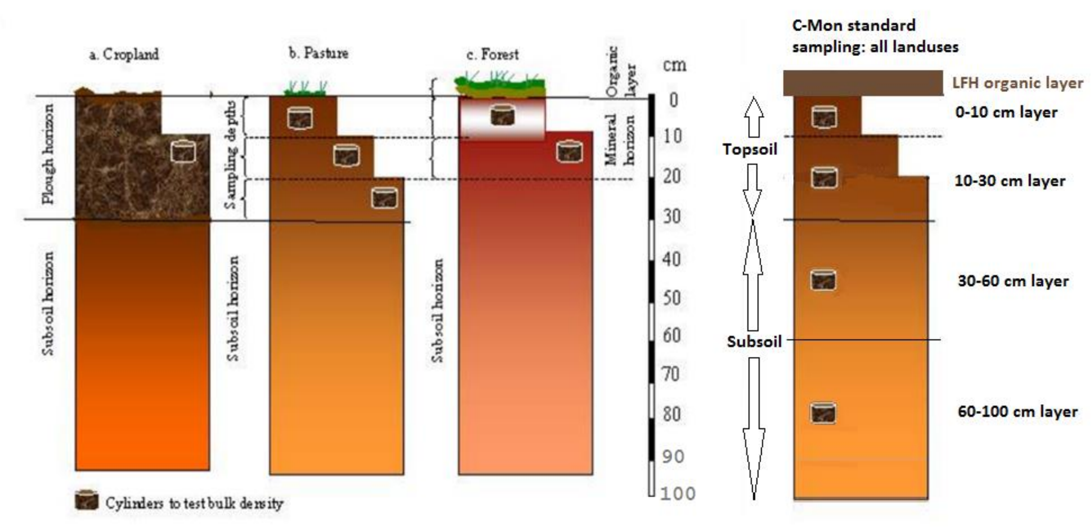


Figure 19. Selected standard sampling depths for the C-Mon survey. Adapted from Stolvoboy et al. (2007). Carbon Sink Enhancement in Soils of Europe: Data, Modeling, Verification

The topsoil includes 0-10 and 10-30 cm layer, while the subsoil the fixed depths 30-60 and 60-100 cm. For each depth interval the subsamples are pooled. The disturbed samples are taken over the whole length of the depth interval while the undisturbed sample (for bulk density) is taken in the middle of the depth interval.

This results in 4 composited disturbed samples (5 if organic layer is present) and 4 undisturbed samples per plot. Total sampling duration is estimated at 3 h with a 2 technician crew allowing 2 plots per day.

1.6.4 Annual cost assessment

1.6.4.1 Annual analytical costs

Combining the information of the selected regional sampling scheme, the selected plot sampling scheme (pooled samples and depth intervals), and the selected analytical set, the annual analytical costs for sampling 10% of all level I plots is given in Table 28.

Table 6. Analytical costs for different types of samples per sampling year.

N° of samples for analysis per year	
Composited organic samples (forest only)	53
Undisturbed comp. mineral samples	1129
Disturbed composite samples	1129
Disturbed topsoil samples for Vis-NIR spectra	282
Samples for archiving	1182
Analytical costs (€) standard set per year	
Analysis of organic samples	€ 2507
Analysis of mineral samples	€ 90460

Analysis of undisturbed samples	€ 16365
	€ 109332
Analytical cost (€) per plot	**€ *387***

The pure analytical costs amount to **109332 euro** each year, which equals an average cost of **387 euro per plot**. For storage of the samples 7267 euro is required.

1.6.4.2 Annual estimation for technical working days

Each year theoretically 283 plots need to be sampled with an average of 2 plots a day. However, even with a perfect planning and preparation, some plots will inevitably drop-out because they cannot be reached (e.g. fenced, no admittance, bad field conditions (flooded, disturbed, just manured) or (temporary) unsuitable for sampling (e.g. harvest or exploitation at the time of sampling). Some of these plots may be resampled later (revisited) while others need to be replaced according to strict guidelines. We estimate the number of replaced and revisited plots at 10% of the total. So, technicians need to visit 283+28=311 plots each year which means 156 field days (Table 30). For each day of fieldwork with effective sampling technicians need half a day preparatory work (organising and checking materials and equipment, planning routes, preparing forms, etc) and half a day processing work after the actual field work (cleaning augers and recipients, recharging devices, storage and processing (e.g. crushing, root and coarse fragments extraction) of samples, organizing forms, unload data from devices, etc). Hence, 142 extra days are required for the teams consisting of 2 persons each.

Experience of soil surveying learns that two persons are a minimum for carrying all devices and samples and that three persons in a team may be beneficial if a lot of site and soil (profile) description needs to be done. This is not the case here. However, the coordinator can join the 2P-teams occasionally for quality control and method validation.

Table 7. Estimate of field work days and technicians.

TECHNICAL WORK	Unit	Amount
Plots per year	Number of plots	283
Replacement of drop-out plots and revisits (10%)	Number of plots	28
Capacity	Plots/day/team	2
Preparatory work	Days	71
Field sampling work	Days	156
Processing work	Days	71
No of technician days required	Days	596
Technicians per year (180 project days)	Number of technicians	3.31
2P-Team per year required	Number of teams	1.66

In total 596 man-days of technicians are required which means about **3.5 technicians a year, or 1.75 2P teams per year**. Hence, the total cost for field work estimated at 197012 euro per year (Table 20) is multiplied by a factor 0.87 (=3.5/4) and equals **171400 euro.**

1.6.4.3 Cost summary for year 1

A summary of all costs for the first year is given in Table 31, amounting to 528103 euro. From this total, half (51%) are personnel costs, about a quarter equipment costs and another quarter operational costs (field sampling, lab analysis and archiving). The second year the annual cost drops to 406950 euro because no equipment costs are needed, but since costs raise with 3%, the costs for the second year are 417999 euro (Table 30).

Table 8. Estimated costs for the first year of T_0 survey.

YEAR 1	Cost	
Personnel costs		
Coordination, Adm. & Reporting	€ 100951	19%
Fieldwork 2P teams	€ 171400	32%
Equipment costs	€ 121153	23%
Analytical costs standard set	€ 109332	21%
Consumables, fuel, maintenance	€ 18000	3%
Archiving of soil samples	€ 7267	1%
SUM	**€ 528103**	**100%**

1.6.5 Total cost T0 measurement over 10 years

When combining all cost information, the total cost for the complete T_0 survey is computed (Table 31), amounting to 4.79 mio euro. From year 2 onwards, between 420000 and 531000 euro is needed for the T_0 sampling.

Table 31. Costs for T_0 survey.

Year	T_0 in 10 year
1	€ 528103
2	€ 419159
3	€ 431733
4	€ 444685
5	€ 458026
6	€ 471767
7	€ 485920
8	€ 500497
9	€ 515512
10	€ 530977
TOTAL T_0	**€ 4 786 379**

The order of magnitude of these costs may already be used for political and administrative reconnaissance when planning a future SOC stock survey in Flanders.

Ideally, the total budget should be granted to an executing body having enough capacity for field surveillance and laboratory analysis to perform this surveying task **during the whole 10 years period and beyond (monitoring phase)**. Periodical change of survey teams or laboratories will inevitably introduce methodological changes and increased bias in sampling and analysis, even when protocols are clearly described.

To ensure continuation, stability and adequate execution of this long term soil survey we suggest therefore that Flemish governmental agencies and/or research institutes perform this task, maximally building on available analytical capacity, field experience and existing governmental database infrastructures and facilities (like soil archives).

In case different bodies are involved in the future execution of the T_0 survey, responsibilities for the survey may be split along three conventional landuse groupings per sector:

- Agricultural plots (cropland and grassland)
- Forest and Nature
- Residential areas (public and private parks and gardens)

A rough estimate of budget split based on the average total cost of 1696 euro per plot and the number of plots listed in **Error! Reference source not found.**, is given in Table 9.

Table 9. Total budget (euro) required for T_0 sampling, analysis and reporting according to three sectors.

Land use group	**Total plots**	**Budget for 10 yr T_0 survey**
Agriculture Cropland & Grassland	1289	€ 2 186 274
Forest & Nature	1051	€ 1 782 602
Residential	483	€ 819 217

2 PHASE II OPERATIONALIZATION BASELINE MEASUREMENT

2.1 FIXING C-MON SAMPLING LOCATIONS

2.1.1 Introduction

2.1.1.1 Stratified sampling & GRTS

As explained in 1.4 the choice was made to pre-allocate the in 1.4.4 overall specified number of sampling locations within delineated strata: i.e. stratified sampling. For cropland, grassland and forest we focused on soil texture and soil drainage as factors to define strata. For residential areas there was a differentiation based on 'Ruimtebeslag'-subcategory ('Land take'). The positioning of the sampling locations within such strata is based upon:

- the geo-data of the perimeters of the strata within each land use
- the number of measurement points as statistically determined in WP 1.4.3 for the different strata within each land use

Based on these inputs, the R-package **GRTS**, which stands for **Generalized Random Tessellation Stratified sampling** (Onkelinx, 2017, Stevens et al., 1999, Theobald et al., 2007) will provide a spatial allocation of samples for measuring points within each stratum.

The GRTS approach is a statistical approach that generates a spatially balanced random survey design for natural resource applications. The Biometrics and Quality Assurance team at INBO uses this technique for all Natura 2000 monitoring networks, both for habitat characterization (vegetation sampling and abiotic sampling of water and soil) and for sampling of (red list) species (from insects over amphibians to mammals) for which 6-yearly reporting to Europe is required. This technique is robust and tested in practice. In practice, GRTS has shown to maintain a better spatial balance than simple random sampling and of course the sampling is random and representative for the specific strata.

We used GRTS to allocate sampling locations for :

i) the state monitoring (the so-called zero measurement). In this way, for each stratum within each land use, a number of measurement points will be spatially allocated so that an average SOC stock with associated uncertainty can be determined for each stratum.

ii) and in part for the monitoring of SOC changes due to land-use changes as well. In theory a fully randomized site selection is needed to have a balanced set of observations for each form of land-use change (e.g. cropland to pasture and vice versa, cropland to forest (deforestation) or vice versa (e.g. conversion of forest back to cropland, etc.) so that reliable figures can be provided for LULUCF reporting and other C-budgets and/or models. But in practice, as will be detailed in 2.3.1 fully random selection of sites would not allow to find suitable sites to track SOC stock changes for less frequent land-use changes. An alternative methodology is presented in 2.3.

2.1.1.2 Locations and timing for resampling

Because we want to base the monitoring on **paired measurements** (cf. WP 1.4), the measurement points spatially defined by GRTS for the baseline measurement will also serve as measurement points for repeated future SOC surveys with a strong increase in reliability of SOC changes after one measurement cycle. Some further clarification:

We design a SOC monitoring network for a minimum period of 20 years with a measurement cycle of 10 years. Each year, 10% of the total required plots per stratum are effectively sampled. After year 1 an average SOC stock can be determined for each stratum, but the uncertainty on this average will be quite large. After year 2, a new average is estimated and the uncertainty on this average will decrease and this will continue until year 10. Moreover, by random sampling for each stratum, a trend in SOC change can be determined which gets stronger every year in statistical strength. Only after year 11 will the measurement points be 'paired' and the reliability of the SOC changes will strongly increase. After 20 years, the monitoring network is at full power and further measurements (both averages per stratum and trends in SOC changes) will become more and more statistically secure.

This means that, especially on the basis of sliding averages, we can report SOC stocks and their changes over time periodically (e.g. every 3 to 5 years) to regional, national and international bodies.

GRTS also allows us to deal with the measurement point allocation in a flexible way. In practice, planned measuring points are sometimes not accessible for sampling (e.g. refusal of owner to his/her plot, recent land use change, etc.). For this purpose, an excess of sampling points is determined as a safety margin that can then serve as an alternative for the inaccessible locations, without affecting the balanced sampling. It is possible to use additional spatial or temporal criteria for the replacement points.

Certainly if the monitoring runs over many years, in a strongly changing landscape like Flanders, the originally determined measurement points can change stratum/land use, but the GRTS system will adapt proportionally to the changes and maintain the pairedness of the measurement points as much as possible over time.

A random selection of 10.000 GRTS points (based on the 10mx10m grid used by VITO) was produced. For nature and residential land this selection did not suffice and extra GRTS points were added (from another draw of 10.000 locations).

2.1.1.3 Update of sample allocation calculations

As detailed in Table 20 a total of 816 sampling sites were foreseen for SOC monitoring in cropland. Based on the optimization calculations presented in 1.4.2.2 and 1.4.3 a stratification of cropland based on regions differing in spatial variation in topsoil SOC stock was foreseen to yield an efficiency gain of about 38% (i.e. for detection of the 20-yr 4‰ within cropland only, just 556 sites would in fact be needed instead of 778 without stratification). These strata were taken from the earlier study by Sleutel et al. (2011) and by means of overlay of the .shp layer and the cropland GRTS-set we obtained locations of the all cropland GRTS-points for each one of these three strata.

For phase II these initial estimates of the variation on SOC stocks s_r were updated for the three foreseen strata. For these refinement we also adopted cropland acreages from the VITO2016 Space model, which were not available during initial phase I calculations. Overall, with these new estimates variation seems to be smaller in the Polders & North-Western sandy region (s_r = 2.1 kg OC m^{-2}) while a larger variation than initially predicted is now used for the combined Eastern Sandy, Sandy-loam and Silt regions.

According to resulting updated solver-optimization calculations with these figures only 2428 locations would then be required to reach the 20yr 4‰ target for Flanders as a whole. However, this target would not be met for grassland, forest and nature. Also, the number of sites for cropland would become in fact disproportionally small to the large surface of this land-use. In consensus with the steering group the total cost calculation and total number of sites was set to 2594. We therefore allocated the spare locations (not strictly needed to reach the overall 20yr 4‰ target for Flanders as a whole, viz. 2594 - 2428 = 166) across cropland, grassland and forest. Nature was not considered to take up spare locations because of i) the already large sampling density when compared to other land uses & ii) the substantial uncertainty on SOC stock data used to predict variation in SOC stocks. This updated final distribution of sampling locations across strata is presented in Table 34.

Table 34. Final number of required sampling pairs to detect a MDD in Flanders corresponding to 4‰ yearly change in SOC over 20 years (0-30cm) within different land-use classes (recalculations vs. 1.4.3 based on updated SOC data and surfaces of strata for cropland)

Land-use	Surface (from VITO model) (ha)	Optimized spread over land use classes & strata	MDD (kg OC m^{-2})
Cropland	540,214	794	0.336
Permanent Grassland	149,859	406	0.562
Forest	133,595	490	0.912
Nature	68,801	446	1.670
Residential Land use	203,014	458	0.519
Total Flanders		**2594**	**0.555**

2.1.2 Cropland

2.1.2.1 Spread of sampling sites across cropland strata

A total of 794 locations was foreseen for cropland. With optimized allocation of sampling sites the Polders & North-Western sandy region, the combined Eastern Sandy, Sandy-loam and Silt regions, and the Campines were granted 201, 384 and 209 locations, respectively. The first GRTS-ranked sites per stratum were taken as the final selection (Figure 20). The spread of the sampling sites largely followed density of cropland acreage across Flanders.

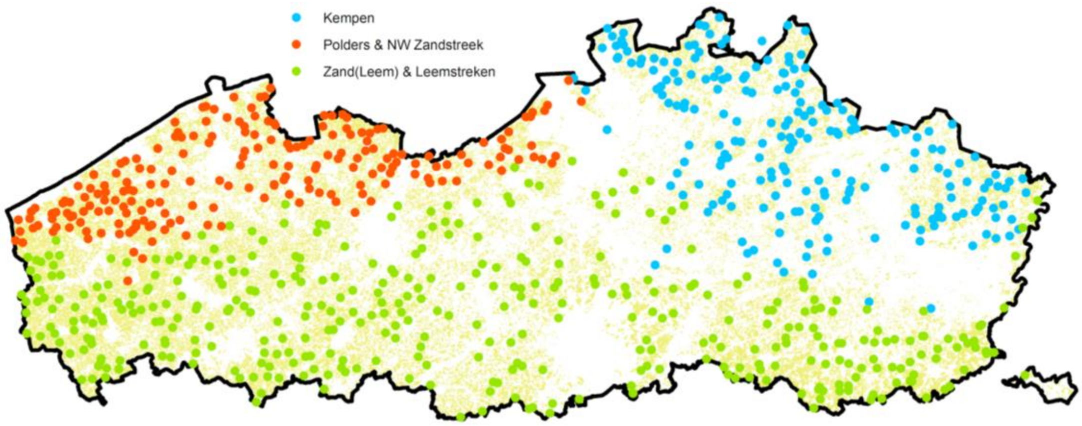


Figure 20 Location of the 794 selected monitoring sites for the baseline measurement in cropland (shown in yellow). The spread across the three discerned strata for cropland are presented.

2.1.2.2 Alternative scenario with preferential positioning near groundwater monitoring wells

In 1.5 the recommendation was made to allocate preferentially position 15% of all cropland monitoring plots (117) in close vicinity of phreatic grid 8 groundwater monitoring wells. The current GRTS-draw of 3019 cropland plots included 133 cells at a distance of <200m to the groundwater monitoring wells. Out of these only 32 were in fact already included in the 794 cropland selection, and so we would still need to preferentially re-allocate 85 sites. This was done in an unbiased way by selecting the lowest GRTS-ranked cell <200m close to a groundwater monitoring well and alongside discarding the largest GRTS ranked cell from the 794 selection (Figure 21).

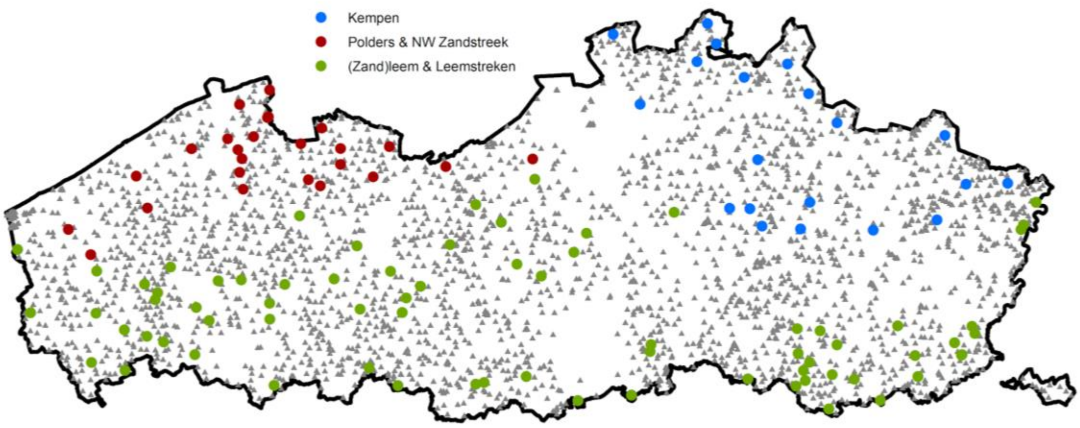


Figure 21 Location of 117 selected monitoring sites (out of a total of 794) with distance <200m from groundwater monitoring wells (shown in grey) for the baseline measurement in cropland.

2.1.3 Grassland

2.1.3.1 Spread of sampling site allocation across strata

For permanent grassland initially 373 sites were foreseen (Table 20), with a small (7%) efficiency gain based on stratification. As explained in 2.1.1.3, recalculations of s_r for cropland let to re-assignment of

54 extra sampling points for grassland monitoring. So a total of **406 sampling locations were available for monitoring of grassland SOC stocks** (Table 34).

Within all of Flemish permanent grassland two strata were defined for SOC stock surveying, see 1.4.2.3, viz.:

- Sand to silt textured soils with drainage classes a till d and h
- Clay textured soils (and peat soils) and soils with poor drainage (drainage classes e, f, g, i)

By joining drainage and textural symbols from the digital soil map to the grassland GRTS-set we assigned any potential locations for grassland sampling sites to these two strata. The first ranked points per stratum were withheld until the required numbers were obtained: 246 for 'a-d,h non E&U' and 160 for 'e,f,g,i & E,U,V' (Figure 23).

2.1.3.2 Account for grassland age & spread of sampling sites across grassland strata

Random stratified sampling of current day grassland sites would result in a share of sites that had annual crops grown over the past years: i.e. temporary grassland. To retain only 'permanent grasslands' plots with grassland age of <6years were filtered out. For this, firstly the 'Landbouwgebruikspercelen' maps for the period 2007-2017 were used to produce a grassland age map. These 10 individual polygon maps were combined to yield a raster map with grid cell values representing the years of continuous grassland cultivation anterior to 2017.

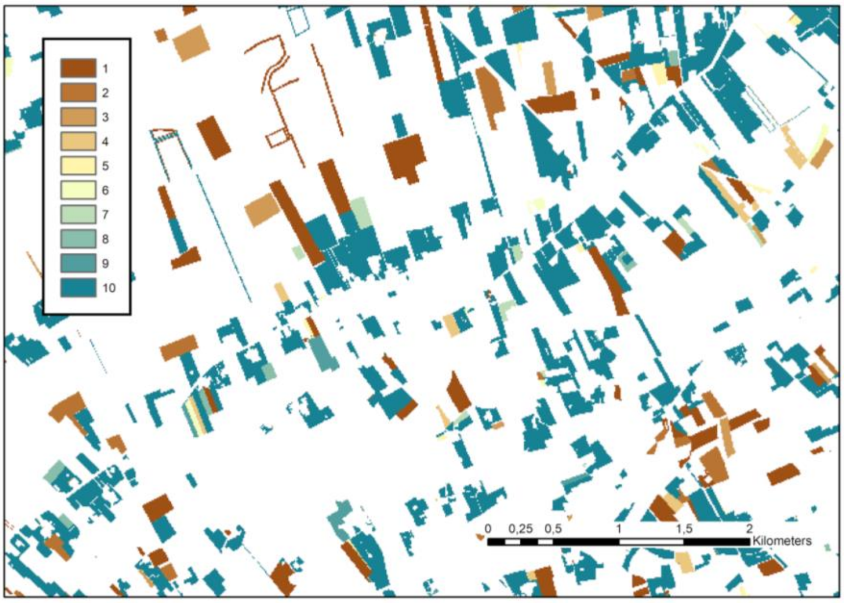


Figure 22 Grassland age raster map derived from overlay of 2007-2017 'Landbouwgebruikspercelen' polygon maps. The value indicates the number of years grass continuously grown prior to 2017.

The grassland GRTS-selection was overlain to this map and only points coinciding with grassland ages of >6years were kept. Similar to the spread of grasslands in Flanders, more sampling locations were positioned in the West (Figure 23).

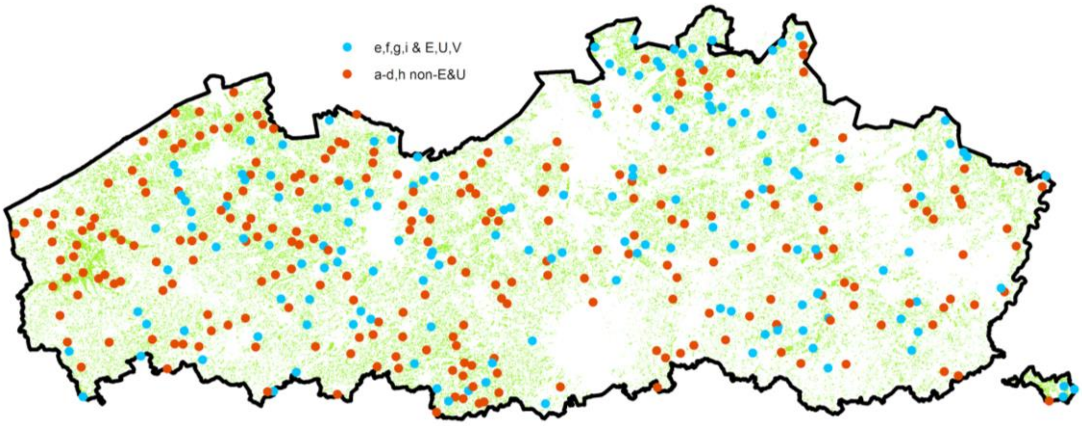


Figure 23 Location of the 406 selected monitoring sites for the baseline measurement in grassland (both permanent as well as temporary shown in light green). The spread across the two discerned strata for grassland are presented.

2.1.3.3 Alternative scenario with preferential positioning near groundwater monitoring wells

Again we explored the alternative scenario in which 15% of all sites (15% of 406 = 61) would be set close to phreatic grid 8 groundwater wells. No more than 32 permanent grassland locations were available with a distance <200m to a groundwater well and so a full preferential re-allocation of this number of sites was impossible (Figure 24). Expansion of the selection till 61 would require an extra GRTS-draw.

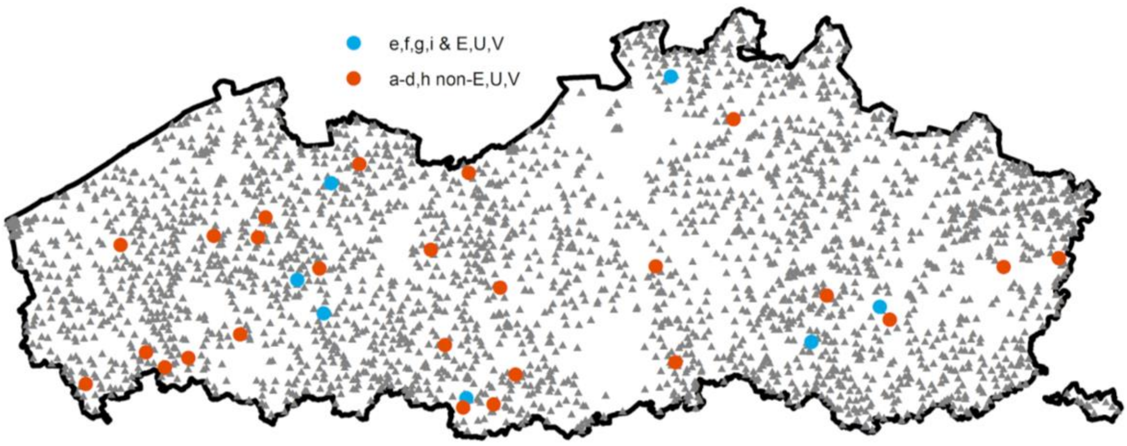


Figure 24 Location of 32 selected sampling sites with distance <200m from groundwater monitoring wells (shown in grey) for the baseline measurement in permanent cultivated grassland.

2.1.4 Forest

For Forest initially 486 sites were foreseen after recalculations based on updated s_r for cropland. As explained in 2.1.2 (Figure 25). With virtually no efficiency gain based on stratification (1.4.2.4), the allocation of the sampling sites was only based on the GRTS-ranking.

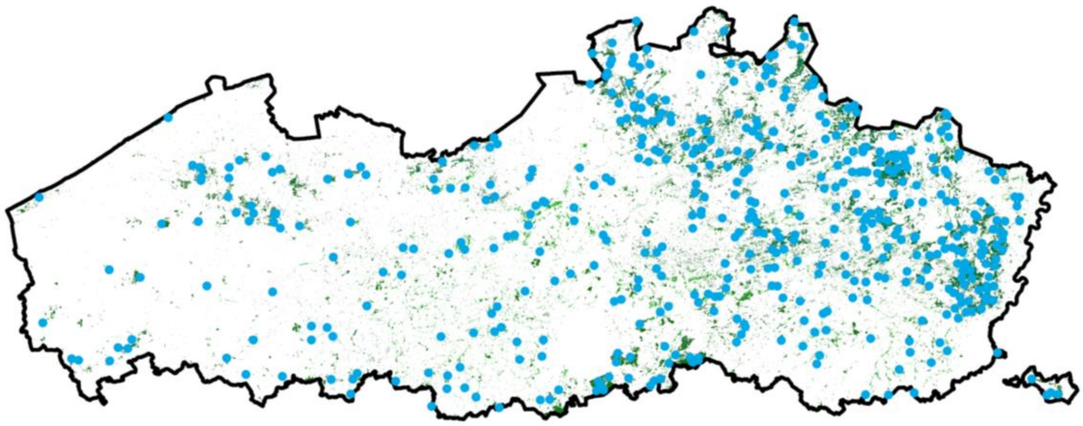


Figure 25 Location of the 486 selected monitoring sites for the baseline measurement in forest (shown in green).

With most forest area concentrated in the East, so was the spread of forest monitoring sites as well skewed.

2.1.5 Nature

As per the updated optimization calculations a total of 446 was allocated to land-use 'Nature'. In the VITO space model level 1 various habitat types are distinguished: 'halfnatuurlijk grassland' (half natural grassland), 'heide' (heathland), 'duinen' (dunes), 'slikken en schorren', 'moeras' (marshes). Only very few SOC stock data were available for Nature land-use and only some basic statistics (means and standard deviations) were known for three of these habitat types. This factor was explored as grounds for stratification but only accounting for Heathland, 'Ruigte' and Semi-Natural grassland. Optimized allocation of points over these strata yielded but a negligible advantage over random spread of sampling sites within the land-use type 'Nature'. The in 1.4.2.5 presented calculations were moreover strongly confounded by the availability of just topsoil SOC data and lack of soil bulk density measurements for these and other habitat types. Other factors like texture or drainage class could not be explored as potential base for stratification due to lack of available data. Analogous to forest the allocation of the 'Nature' sampling sites was thus solely based on the GRTS-ranking (Figure 26).

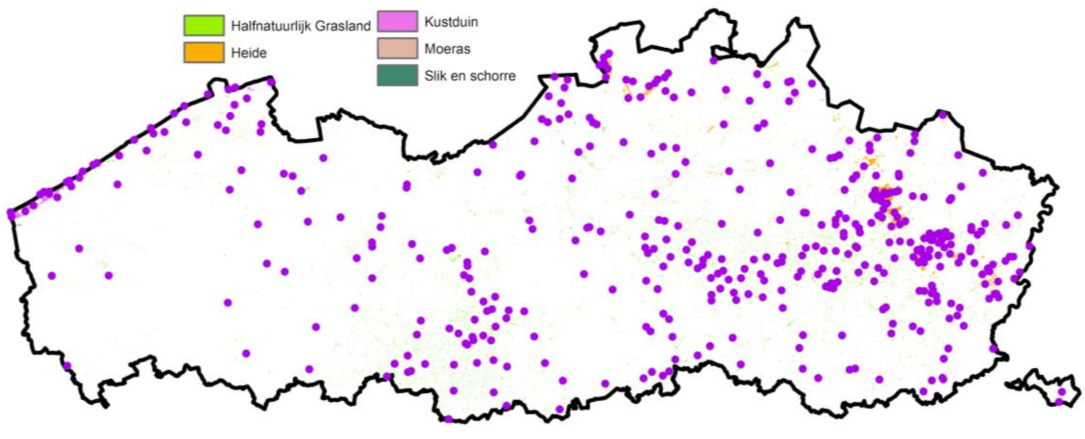


Figure 26 Location of the 446 selected monitoring sites for the baseline measurement in Nature.

2.1.6 Residential Land use

2.1.6.1 Definition of strata

In the C-GAR study it was found that stratification based on the strata 'Vegetable gardens' vs. 'Parcs+Verges' (incl. 'Ruigte' (roughness)) and 'Lawns+Ornamental Gardens' would yield a 7% advantage over random allocation of all sampling locations. Mainly, the contrast between SOC stocks of vegetable gardens and all other subcategories of 'Land Take' proved significant. However, neither the VITO Space model, nor other geodatasets distinguish between private owned gardens and vegetable gardens therein. It is then not possible to a priory select vegetable gardens. **Given the difficulty to map these strata and given the just small gain in SOC inventory efficiency over a randomized survey, the stratified sampling of Residential land use was not considered further.**

The VITO Space model level 1 value, however, does not directly lend itself as base for a random selection of sampling locations. With a large share of this land-use category sealed it is necessary to firstly filter out potential unsealed sampling locations. But in doing so, many roadside verges and smaller gardens would be omitted as well. Viz. from the C-Gar study, it was clear that roadside verges are most often misclassified in the VITO Space model as being either sealed (Space model level 1 value 22, 23) but more often into other land-uses like cropland or grassland. The second point makes that any roads outside built-up areas (e.g. motorways) are excluded. Lastly, the C-GAR steering group decided to omit 'Cycling and walking routes' and 'Earth roads', as these mostly have no managed roadside.

In consideration of the above it is clear that a tailor-made procedure is needed to ensure representative selection of subcategories of 'Residential Land use'. For this it will be necessary to in advance subdivide the total number 'Residential Land-use' sampling points across various subcategories 'Verges & Ruigte, 'Gardens' and 'Parcs & Recreational areas', proportional to their surfaces in Flanders. These surfaces are not precisely known. According to Ruimterapport Vlaanderen, the total area of gardens is 143686ha. According to https://www.vlaanderen.be/beheer-van-de-wegbermen-in-vlaanderen the area of verges is about 22500ha. The area of 'Parcs & Recreational areas' was derived in the C-GAR study by querying the VITO-Space Model and found to be 28372 ha. The global optimisation exercise across all land uses allocated 458 sampling sites to 'Residential Land Use'. **Using these surfaces, 306 points would be allocated to 'Gardens' (of which, 32 points to Vegetable gardens). The other 120 points would need to be spread out across Verges (53) and 'Parcs & Recreational areas' (67).**

2.1.6.2 Assigning sampling points

A practical way would be to first assign a qualifier 'Parcs and Recreational areas' to the Residential Land Use GRTS selection. From this selection the first 67 cells with lowest GRTS-ranking are selected as sampling locations for 'Parcs and Recreational areas' (Figure 27). Then, occurrence of points inside privately owned lands is used to label GRTS points as potential sampling sites for 'Gardens' (incl. grounds from enterprises). This is achieved by keeping all points with a known 'Kadastraal nummer' (land registry number) by a join operation with the GRB-Adp datalayer. This selection of 'Garden' sampling sites will need to be further refined during actual execution of the zero survey.

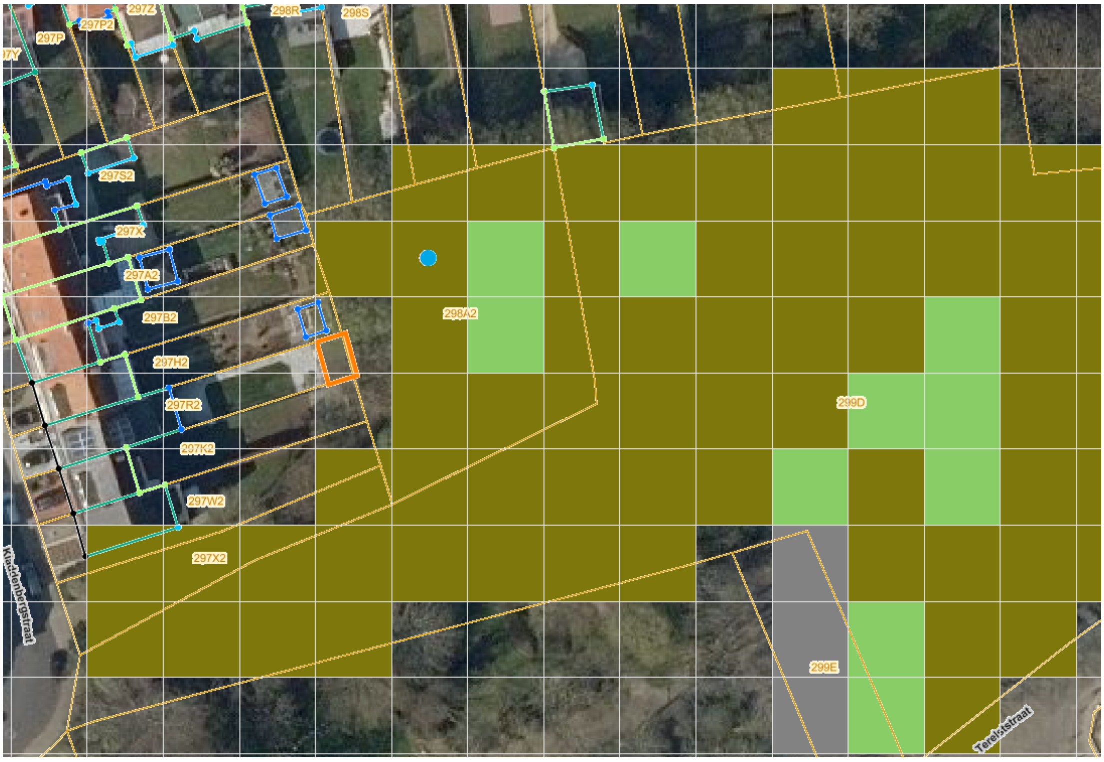


Figure 27 Overlay of a derived raster map of 'Parcs & Recreational areas' (green, brownish-green and grey coloured cells) on top of the GRB (yellow lines & text). The light grey grid subdivides the whole of Flanders into 10x10m cells. The blue dot indicates for example GRTS-cell 163, with GRTS.Residential rank 4. This point is labelled as potential sampling location for 'Parcs & Recreational areas'. The point is furthermore assigned a Kadastraal nummer (land registry number) but is nevertheless excluded as sampling location for 'Gardens' since it was already taken up in the 'Parcs & Recreational areas' pre-selection.

Any still remaining Residential Land Use GRTS points are lastly considered as potential sampling sites for 'Verges' according to their GRTS ranking. The ground cover map (bodembedekkingskaart) could be used as a concluding step to facilitate their eventual selection or rejection: i.e. by in addition excluding locations with a certain cut-off sealed %.

Based on these rules following spreading of sampling locations across the residential land-use category was obtained.

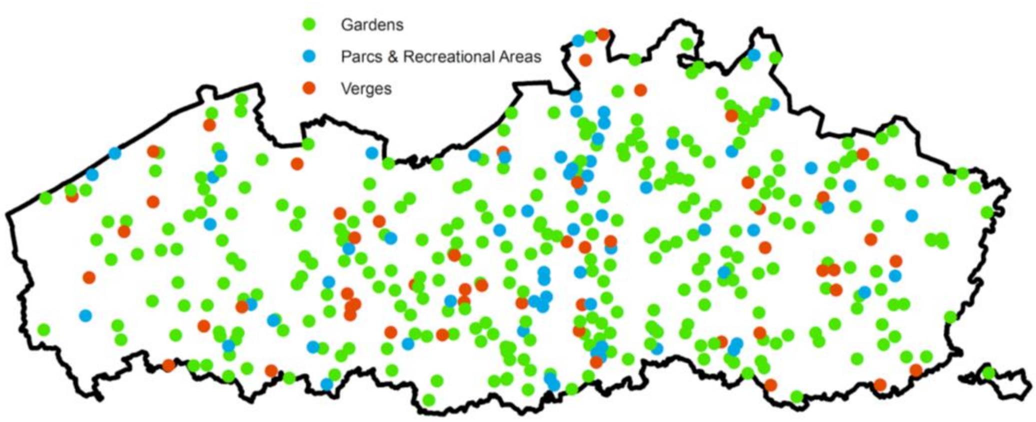


Figure 28 Location of the 458 selected monitoring sites for the baseline measurement in Residential Land Use.

2.2 CHARACTERIZATION OF ZERO-SURVEY SAMPLING SITES

2.2.1 General characterization

Here below all fields listed in the shapefiles containing the GRTS-selections for the separate land-uses are presented. Attribute Field names are indicated in **bold**.

All measuring points have been characterised in terms of:

Selection for the zero-survey

- **sel** = letter code indicating selection for the zero-survey. Rows with no value indicated represent spare sampling locations.
    - Cropland: Ck, Cz or Cp – selected, with subdivision to stratum Ck – Campines; Cz - Combined Eastern Sandy, Sandy-loam and Silt regions; Cp - Polders & North-Western Sandy Region).
    - Grassland: Gz, Ge – selected, with subdivision to stratum Gz - Sand to Silt textured soils with drainage classes a till d and h; Ge- Clay textured soils (and peat soils) and Soils with poor drainage (drainage classes e, f, g, i)
    - Forest: F – selected , no further stratification
    - Nature: N – selected, no further stratification
    - Residential: Rp, Rg, Rv – selected, with subdivision to stratum Rp – Parcs & Recreational Areas; Rg – Gardens (private owned and enterprises); Rv – Verges (& 'Ruigte').

Soil type: based on the 'Digital vectorial dataset of the analogue soil map of Belgium for the territory of Flanders' version 20141212. Only 'bodemtype', 'bodemserie', 'textuursymbool', 'drainage symbool' en 'profielontwikkelingsymbool' have been added:

- **Bodemtype** = The code for the soil map units according to the Belgian soil classification system. This is the code that appears on the analogue Belgian soil map. For the sea polders, a letter has been added at the front, indicating the region.
- **Bodemser_c** = The Belgian soil map (with the exception of the sea polders) is coloured according to the soil series. The soil series is the core part of the soil type and consists of three letters referring to the three main characteristics of the soil profile: the texture class, the drainage class and the profile development group. Information about substrates, phases and/or variants is not part of the soil series, but is part of the soil type.
- **Textuu_c** =Code for the texture class. This class indicates the granulometric composition of the soil.
- **Drainage_c** = Code for the drainage class. During soil mapping, the drainage class was determined by the depth and intensity of oxido-redutive phenomena and/or the depth of a reduction horizon. These are historical observations and the current drainage class may differ from the historical one due to, among other things, drainage or embankment.
- **Profontw_c** = Code for the profile development group, which represents the nature and sequence of the horizons and is determined by observation of the colour, structure and grain size composition of the various horizons.

Land use: VITO Space models levels 1, 2, 3 and 4 codes:

- **Niveau1_vl** = ground cover (22 classes)
- **Niveau2_vl** = (urbanised) land use (38 classes)
- **Niveau3_vl** = multifunctional land use categories (6 classes)
- **Niveau4_vl** = legal delimitation (2 classes: port and military areas)

Elevation:

- **DHMVIIDTMRAS25m** = Elevation in m extracted from the DHM -Vlaanderen, raster, 25m geoTIFF 6.0 (.tif) file

Soil coverage:

- **BBKVl1** = Code according to the 'Bodembedekkingskaart Vlaanderen 2015 - 5m'

Administratief perceel from the GRB layer - Adp - 'administratief perceel' in GRBgis ver. 5.1.0.

- **CAPAKEY** = Key 'kadastraal perceel' (land registry parcel)
- **OPPERVL** = Surface of the 'kadastraal perceel' as registered in GRB – Adp (in m²)

2.2.2 Cropland

Extra attributes for cropland

An alternative selection of cropland sampling locations was defined to reach a 15% allocation of sites to GRTS-cells within a <200m distance of groundwater wells of the Phreatic monitoring grid level 8. This alternative selection for croplands is defined by a letter code in a separate field.

Vicinity Phreatic grid 8 groundwater wells:

- **Selfrea** = letter code indicating selection for the zero-survey with 15% of sites selected close to groundwater wells. Ck1, Cp1, Cz1, Ck2, Cp2, Cz2 – selected locations near groundwater wells; Ck, Cp, Cz – selected locations away from groundwater wells. No values – not selected for the zero survey. (qualifiers 1 & 2 denote if sites were already included in the initial GRTS-selection – 1; or where reallocated – 2 at the expense of other points away from groundwater monitoring wells)

Crop rotation:

To characterize the rotation of the cropland sampling locations 10 extra fields with the main crop grown in the years 2010-2019 were added. This information was derived from the 'ALV-Landbouwgebruikspercelen LV' maps for 2010-2019 via consecutive joins based on location of the GRTS-cells and the polygon maps.

Following fields were thus included:

- **HFDTLT 10, HFDTLT 11, HFDTLT 12, HFDTLT 13, HFDTLT 14, HFDTLT 15, HFDTLT 16, HFDTLT 17, HFDTLT 18, HFDTLT19** = Code main crop of the parcel. By definition, this is the crop on the parcel on 21 April of the relevant year. Values of the attribute HFDTLT from the Agricultural Crop Code Table (LbgebrpercLktHfdtlt).

- **OPPLandbouw19** = total surface of the parcel as registered in the ALV-Landbouwgebruikspercelen LV shapefile for 2019 (in m²) calculated from the polygon dimensions

DHMVIIDTMRAS25m	BBKVI1	CAPAKEY	OPPERVL	HFDTLT10	HFDTLT11	HFDTLT12	HFDTLT 13	HFDTLT14	HFDTLT15	HFDTLT16	HFDTLT17	HFDTLT18	HFDTLT19	OPPERVL19
109,61	10	71026C0754/00A000	5453,6	9712	9712	9725	9725	9725	9725	9725	9725	9725	202	10859,8
69,17	7	72022A1010/00A000	8217,27	201	201	201	201	201	201	201	201	201	201	24673,12
15,36129	1	11053C0251/00A002	44627,16	9552	62	62	62	62	60	60	60	60	60	7952,53
18,39	7	13019B0044/00_000	6945,46	201	201	201	201	201	201	201	201	201	201	6226,66
19,96	7	11026C0717/00E000	32881,24	201	201	201	201	201	201	201	201	201	201	21522,31
18,74	7	11053D0242/00A000	94656,86	201	71	201	901	201	201	201	71	901	60	28755,13
119,19	7	71040C0466/00A000	11101,67	901	311	91	311	311	311	901	311	91	311	29056,01
74,43	7	72022C1566/00K006	6090,81	201	331	62	201	201	201	201	201	201	201	6197,52
14,47	10	13019F0308/00A000	8217,91	201	702	702	702	702	700	201	201	201	700	59138,53
70,64	7	72036B0003/00G000	10200,33	201	201	201	201	201	201	201	201	201	201	22166,13
74,83	7	72022C1566/00Z009	6269,05	201	201	321	201	201	71	202	71	201	71	11855,06
15,75	10	13047D0203/00C000	20415,01	201	201	702	702	702	721	201	201	201	201	58574,13
0,16	7	38007A0418/00_000	22660,82	91	311	201	201	311	91	201	311	901	311	52014,02
106,09	7	71017B0415/00B000	8448,13	311	91	9535	9711	9711	9711	9711	9711	9711	9711	12843,49
17,03	10	11682G0106/00A000	9906,13	62	62	62	62	62	60	700	700	700	700	37019,86
74,07	7	72011C0145/00E000	10881,29	202	202	201	201	201	201	201	201	201	201	54234,87
18,5	10	13009A0192/00G000	16698,16	62	62	62	201	62	60	700	700	700	700	81943,07
17,71	7	11053E0198/00A000	20642,57	201	201	201	201	201	901	201	201	901	201	20788,04
63,47	7	72011B0352/00A000	17325,42	201	201	201	201	201	201	201	201	201	201	32008,91
15,48	7	11026E0335/00C000	32273,06	62	62	62	201	201	201	71	201	201	700	32244,8
17,73	7	11026B0163/00B000	15901,45	201	201	201	201	201	201	201	201	700	700	15620,14
14,63	10	13019D0644/00_000	18833,06	62	62	201	201	201	60	60	60	201	60	35269,96
73,38	7	72036B0003/00W006	8009,9	201	201	201	201	201		201	201	201	201	16286,28
62,11	7	72008A0324/00G000	15542,68	35	701	201	35	62	60	201	201	35	60	10057,17

Main crops grown in 2019 on the cropland selection were 201 – 'Silomaïs' (silage maize) (224 plots), 311 – 'Wintertarwe' (winter wheat) (122 plots), 901 – 'Aardappelen' (potato) (79 plots), 202 - 'Korrelmaïs' (cereal maize) (79 plots).

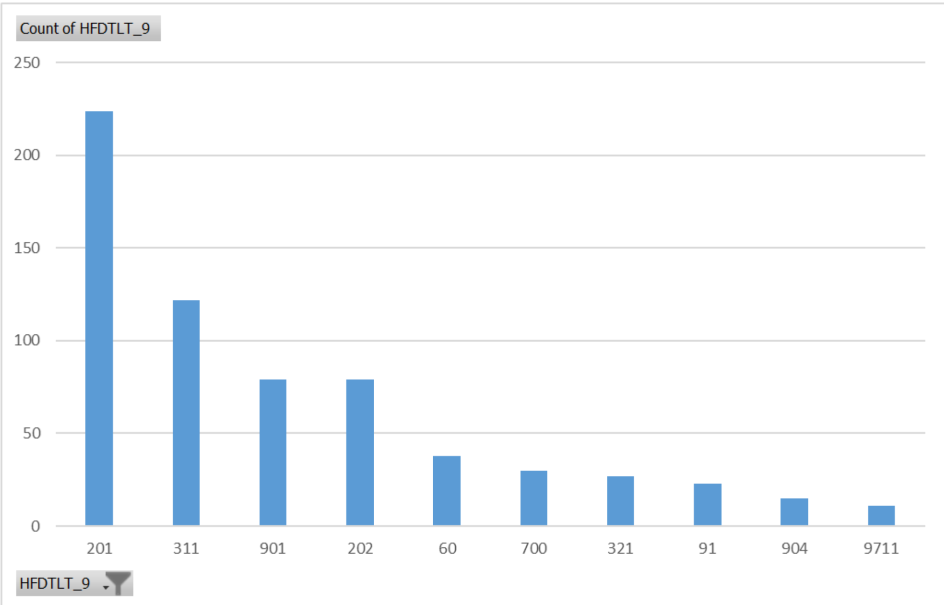


Figure 29 Occurrence of crop codes of the main crop grown on in 2019 on the cropland sampling locations (derived from the 2019 'Landbouwgebruikspercelen' map)

Texture and drainage

The cropland plot selection is more or less uniformly distributed across sand to silt textures. Only few sites were assigned to clay textured croplands (U and E totalling to just 17 sites). However, in the group of 83 sites with no textural symbol most of sites are situated in the Polders area. An important share of these soils has a clay texture: as for instance indicated by: oA5 (Oudlandpolders - 'kreekruggronden, zware klei tot klei, tussen 60 en 100 cm diepte overgaand tot lichter materiaal'), mE1 soils ('middelland dekkleigronden - zware klei tot klei, meer dan 100 cm') or mD5 soils ('Middellandpolders - zware klei tot klei, tussen 60 en 100 cm diepte overgaand tot lichter materiaal').

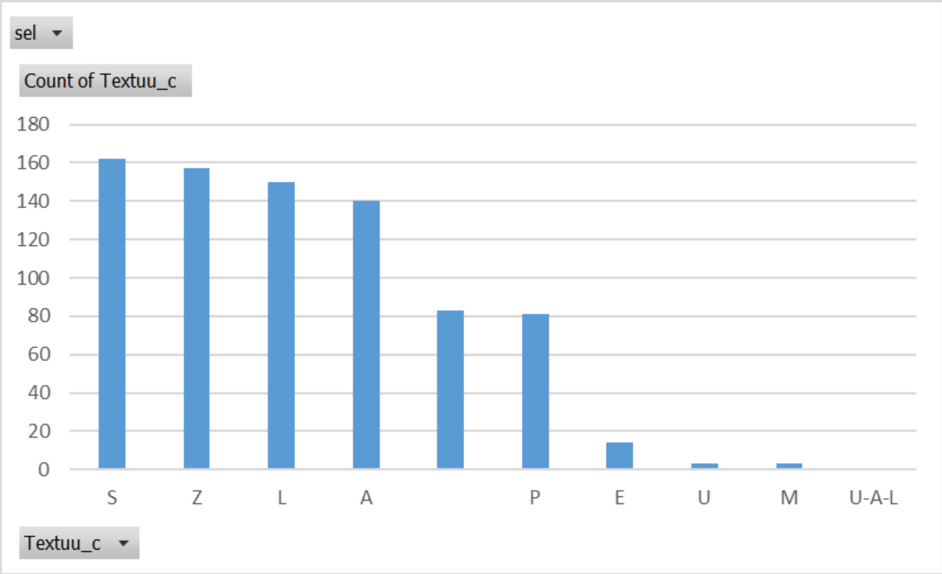


Figure 30 Occurrence of textural classes across the cropland sampling locations selection

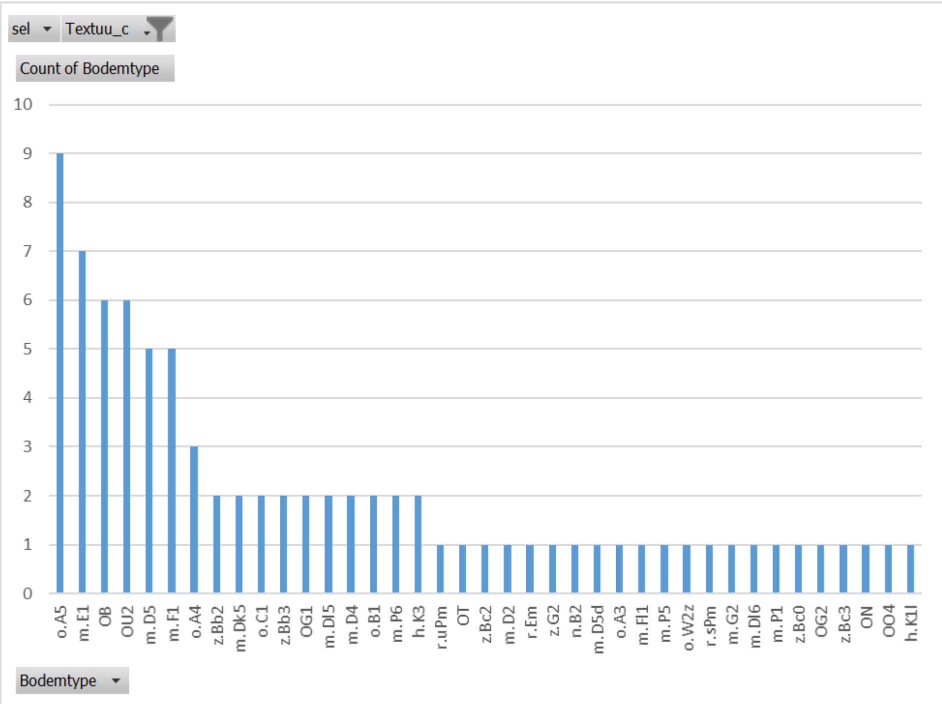


Figure 31 Occurrence of ‘Bodemtype’ across the cropland sampling locations selection with no textural symbol defined

Most sampling locations are positioned at fields with insufficient (d) to favourable (b) drainage according to the Belgian Soil map. Only a remarkable small number of locations (3) is located at croplands with drainage symbol a (too strongly drained). No drainage symbol was defined for 87 sampling locations – again with the majority being positioned in the Polders area.

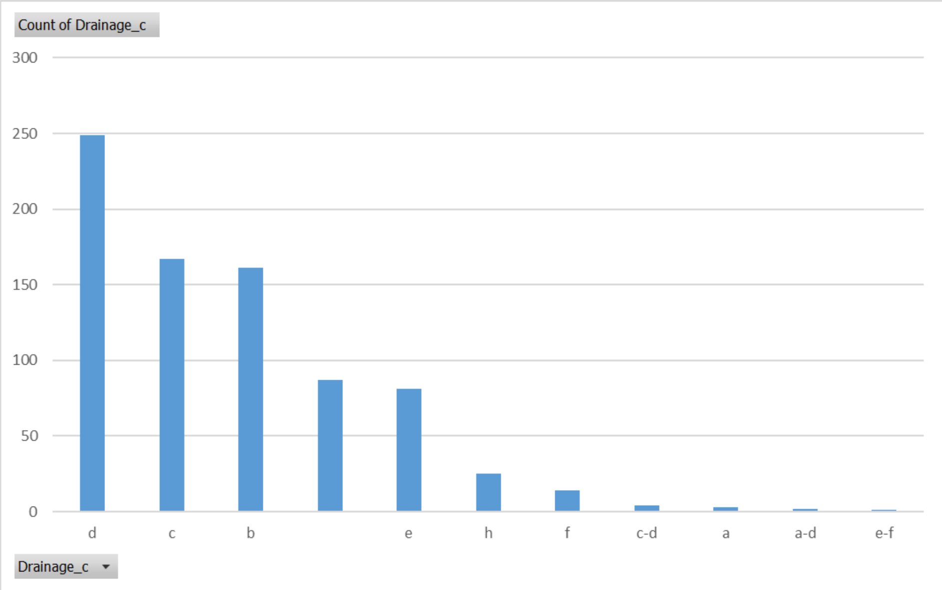


Figure 32 Occurrence of drainage classes across the cropland sampling locations selection

2.2.3 Grassland

Extra attributes for grassland

Vicinity phreatic grid 8 groundwater wells:

Analogous to cropland, an alternative selection of grassland sampling locations was defined with 15% allocation of sites to GRTS-cells within a <200m distance of groundwater wells of the phreatic monitoring grid level 8. This alternative selection for grasslands is defined by a letter code in a separate field.

- **Selfrea** = letter code indicating selection for the zero-survey with 15% of sites positioned close to groundwater wells. Gz1, Ge1, Gz2, Ge2 – selected locations near groundwater wells; Gz, Ge – selected locations away from groundwater wells. No value – not selected for the zero survey. (qualifiers 1 & 2 denote if sites were already included in the initial GRTS-selection – 1; or where reallocated – 2 at the expense of other points away from groundwater monitoring wells)

Grassland age:

As explained in 2.1.3.2 a raster file Graslandkaart2007-2017_1.tif was produced with a 10mx10m resolution from the ALV-Landbouwgebruikspercelen LV maps. The value of this raster was extracted for each point in the grassland GRTS-selection and inserted in a new field:

- **Graslandleeftijd 2007-2017** = integer defining the grassland age in 2017. The maximum value is 10, indicating that the age of the permanent grassland was at least 10 years in 2017.

Texture and Drainage

Half of the sampling locations are positioned at fields with insufficient (d) to moderately poor (e) drainage favourable (b) drainage according to the Belgian Soil map. Nearly no sites were located at grasslands with drainage symbol a (too strongly drained). No drainage symbol was defined for 55 sampling locations – again with the majority being positioned in the Polders area.

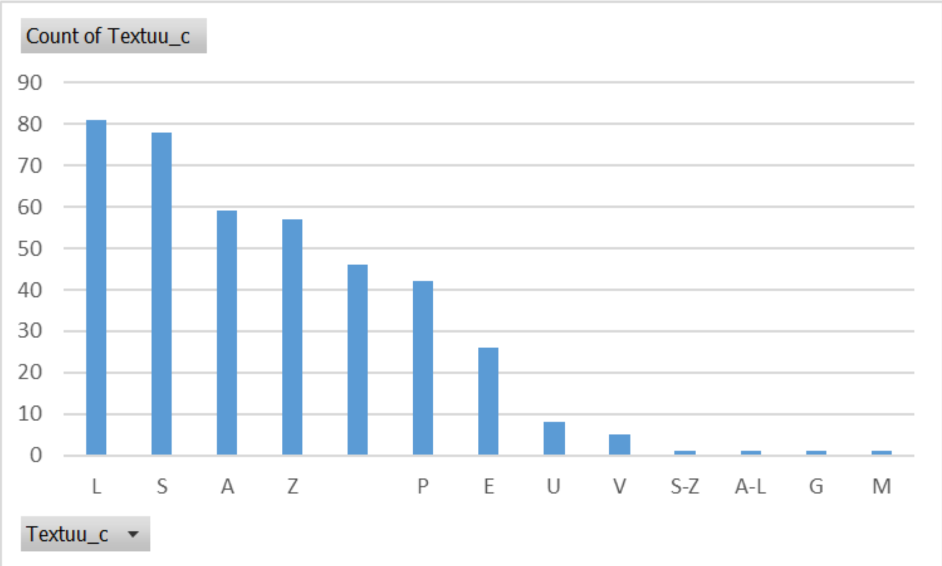


Figure 33 Occurrence of textural classes across the grassland sampling locations selection

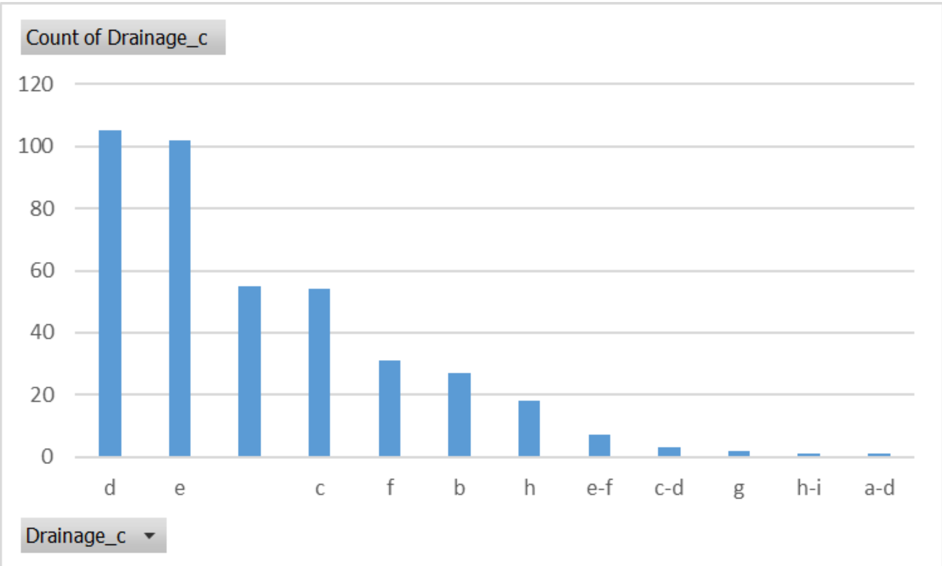


Figure 34 Occurrence of drainage classes across the grassland sampling locations selection

2.2.4 Forest

Extra attributes for forest

For the forest GRTS-selection the 'Bosleeftijd, Opname 1771-2001' map was spatially joined and the following field was included:

- **BLKCODE** = Unique code fort he 'bosleeftijdsklasse'. 1: Bos ontstaan vóór 1775, 2: Bos ontstaan tussen 1775 en 1850, 3: Bos ontstaan tussen 1850 en +/- 1930, 4: Bos ontstaan na +/- 1930.

About 4 out of ten of the plots were situated in forest no older than 1930, most others date back till the 1850 till 1930 period.

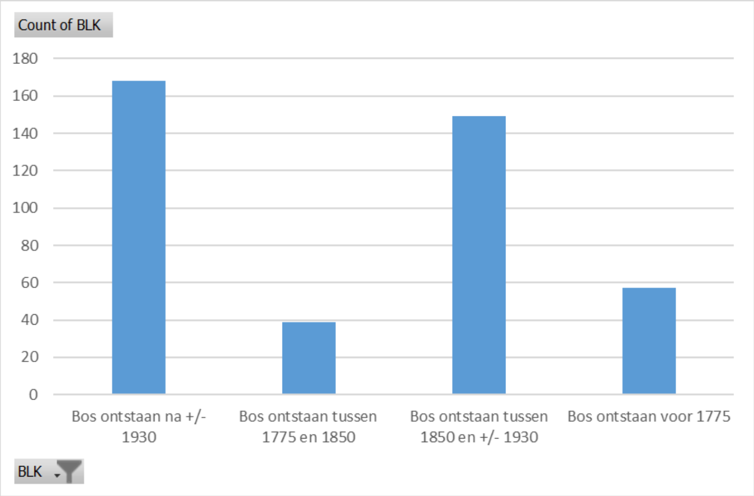


Figure 35 Occurrence of forest ages within the forest sampling locations selection (derived from the 'Bosleeftijd, Opname 1771-2001' map)

In addition the 'Biologische Waarderingskaart' Natura 2000 habitat types were linked to the GRTS-Nature selection (see 2.2.5).

Out of a total of 486 plots 225 were situated at sites judged as biologically valuable 'w' ('waardevol'); 90 as 'wz' ('complex van biologisch waardevolle en zeer waardevolle elementen') and 157 as 'z' ('biologisch zeer waardevol').

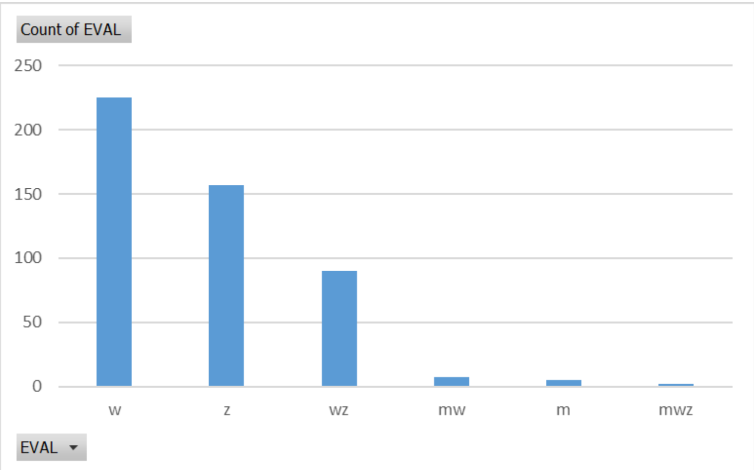


Figure 36 Occurrence of 'biologische waardering' classes within the forest sampling locations selection (derived from the 'Biologische Waarderingskaart')

The most prevalent (>30 cases) mapping units (karteringseenheden) were: ppmb ('Naaldhoutbestand van grove dennen met ondergroei van struiken en jonge bomen'), n ('Loofhoutaanplant exclusief populier'), ppms ('Naaldhoutbestand van grove dennen met ondergroei van bramen, varens, blauwe bosbes, brem, struikheide of jonge struiken') and qs ('zuur eikenbos').

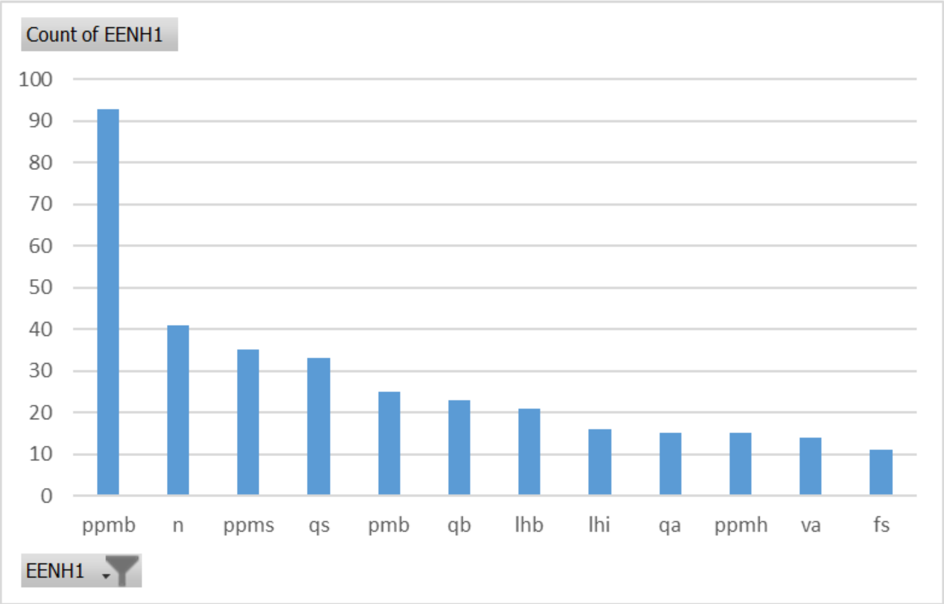


Figure 37 Occurrence of most prevalent 'karteringseenheden' within the forest sampling locations selection (derived from the 'Biologische Waarderingskaart')

Texture and drainage

Most plots are situated on sandy soils (Z: 179 & S: 76).

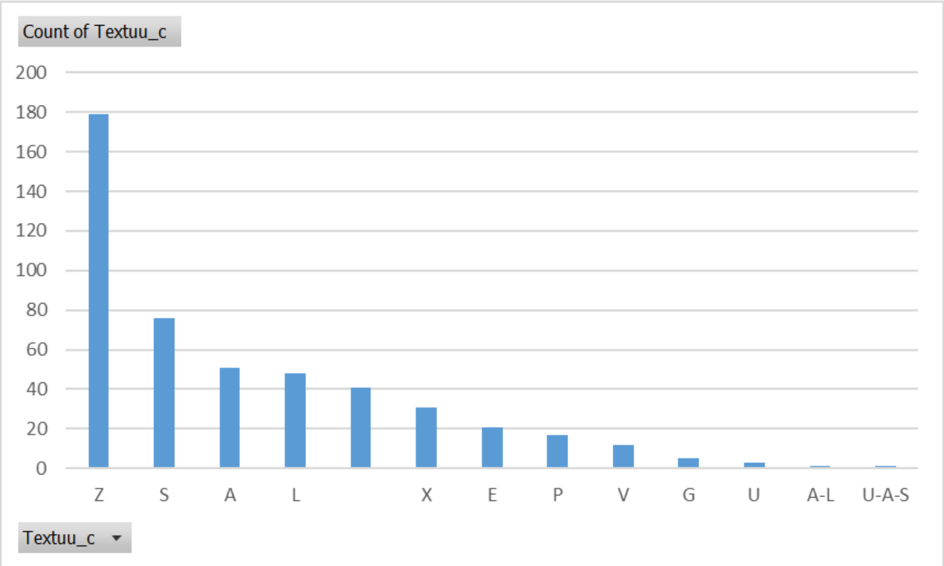


Figure 38 Occurrence of soil textural classes within the forest sampling locations selection

There was a rather uniform spread of the selected forest sampling locations across drainage classes.

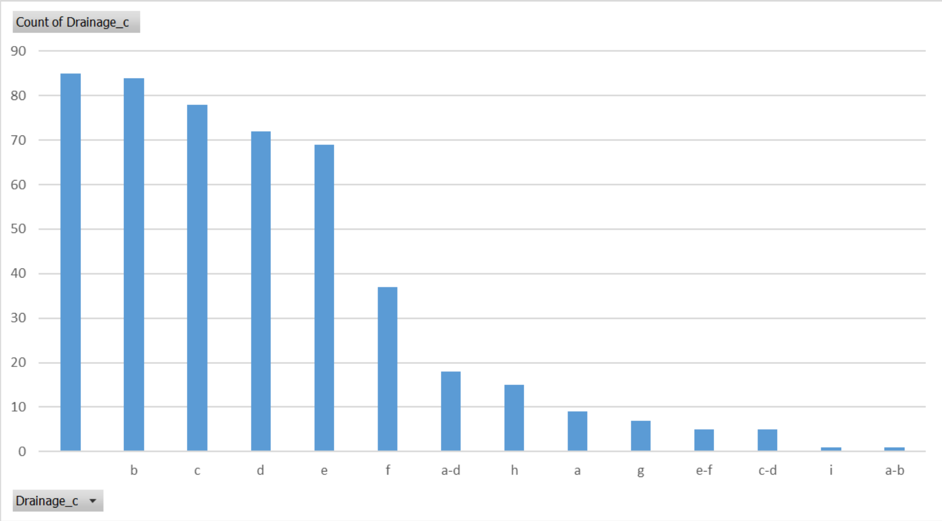


Figure 39 Occurrence of soil drainage classes within the forest sampling locations selection

2.2.5 Nature

Extra attributes for Nature

For Nature plots the just released updated digital '"Biologische Waarderingskaart en Natura 2000. Habitatkaart - Toestand 2020, 11-12-2020, Vlaanderen" (BWK22)' was linked to the GRTS-Nature selection. This map provides the best available information in 2018 on the distribution of Natura 2000 habitat types, the regionally important biotopes and the mapping units of the Biological Valuation Map. Following fields were joined from the BWK22 were added:

- **EVAL** = Indication of biological valuation (biologische waardering) based on the criteria of biotopic rarity, biological quality (diversity, rare species, etc.), general vulnerability and replaceability. Each mapping unit has a prescribed biological value, which can be deviated from with argumentation based on field info.
- **BWKLABEL** = Label of the biological valuation
- **EENH1, EENH2 and EENH3** = Mapping units for vegetation types, ground cover or small landscape elements (mapping unit 1, 2 or 3)
- **HAB1, HAB2, HAB3** = Natura 2000 habitat type or regionally important biotope in habitat mapping unit 1, 2 or 3

BWKLABEL	HAB1	HAB2	HAB3	EVAL	EENH1	EENH2	EENH3
hr + hu°	gh	6510,gh		w	hr	hu-	
hp* + hu + kbs	gh	6510,gh		wz	hp+	hu	kbs
hfb + alng	6430,rbbhf			z	hfb	alng	
hp* + kbp	gh			w	hp+	kbp	
cgb + que + bet	4030			z	cgb	que	bet
sz	gh			w	sz		
kh(sm)	rbbsm			z	kh(sm)		
hp*	gh			w	hp+		
n/kz + bet	gh			w	n	kz	bet
n + gml	gh			w	n	gml	
hr + sz	gh			w	hr	sz	
ce + ceb + cg + cmb	4010	4030		wz	ce	ceb	cg
hab° + ha + cra + fran + bet	gh	rbbha		wz	hab-	ha	cra
lhi	gh			w	lhi		
hacb + ni + pins	2330_bu	gh		wz	hacb	ni	pins
n/ko + hrb/ko + gml	gh			w	n	hrb	ko
sz	gh			w	sz		
hr	gh			w	hr		
ppmh	gh			w	ppmh		
hp + hp* + kbp°	gh			mw	hp	hp+	kbp-

Out of a total of 446 plots 213 were situated at sites judged as biologically valuable 'w' ('waardevol'); 100 as 'wz' ('complex van biologisch waardevolle en zeer waardevolle elementen') and 95 as 'z' ('biologisch zeer waardevol').

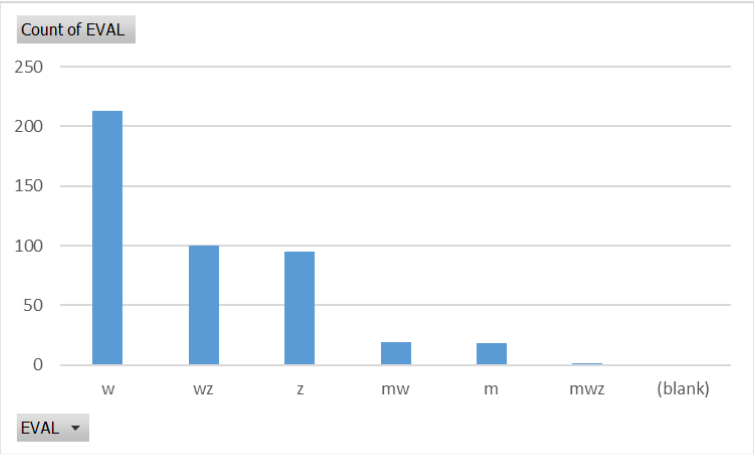


Figure 40 Occurrence of 'biologische waardering' classes within the nature sampling locations selection (derived from the 'Biologische Waarderingskaart')

The most prevalent (>10) mapping units ('karteringseenheden') were: hp* ('Soortenrijk permanent cultuurgrasland' – indicated as hp+), sz ('andere struwelen en kapvlaktes - Opslag van allerlei aard'), hr ('Verruigd grasland'), cg ('droge heide'), ku ('andere gekarteerde elementen'), cm ('Gedegradeerde heide met dominantie van pijpenstrootje') and hpr ('Weilandcomplex met veel sloten en of microreliëf').

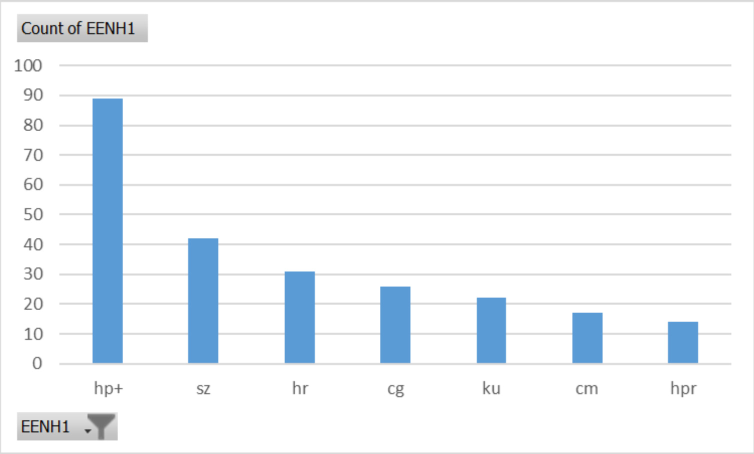


Figure 41 Occurrence of most prevalent ‘karteringseenheden’ within the nature sampling locations selection (derived from the ‘Biologische Waarderingskaart’)

For 296 points no ‘Natura 2000 habitattype of regionaal belangrijk biotoop’ was defined: ‘gh’ (geen habitat). In the below figure the order of prevalence of stated habitat types is presented. Main occurring habitat types were 4030 (‘Droge heide’), 2310 (‘Droge Heide op jonge zandafzettingen’), 4010 (‘Vochtige tot natte heide’), 1140 (‘Slik- en zandplaten die droogvallen bij eb’) and ‘Regionaal Belangrijke Biotopen’: rbbmr (‘rietland en andere vegetatie van het rietverbond’) and rbbhc (‘dotterbloemgrasland’).

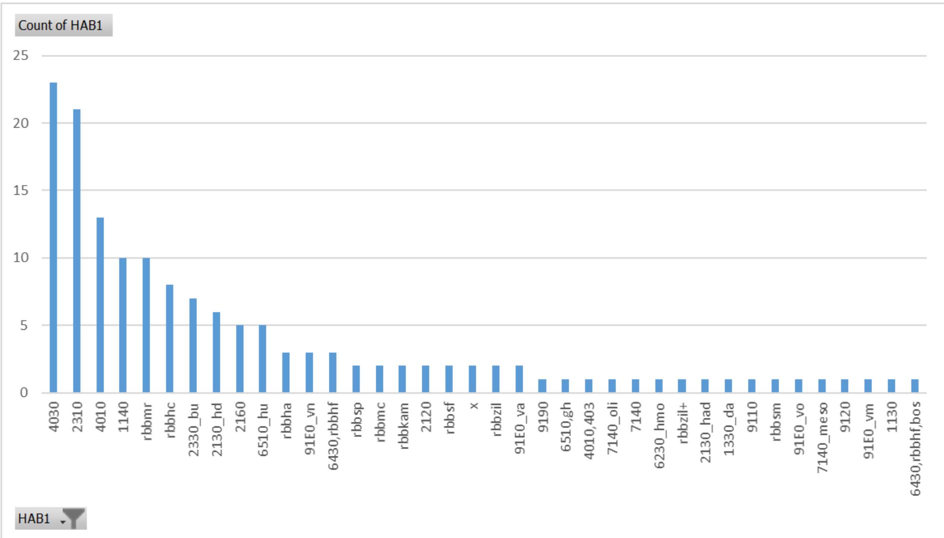


Figure 42 Occurrence of ‘Natura 2000 habitat type of regionaal belangrijk biotoop’ within the nature sampling locations selection in case they were not qualified by ‘gh’

Texture and drainage

For about half of the plots (228) no textural symbol was defined. Mostly symbol OB (bebouwde zone) was defined (in 128 cases), or ON (17 cases). For 30 sites symbol X ‘duinen’ was given. For 9 sites V – ‘veen’. Among the plots with soil textural symbosl defined, Z-sand (96) was most prevalent, followed by A (55), S (52) and L (35). Soils with insufficient – d (74), or moderately poor drainage – e (63) occurred most.

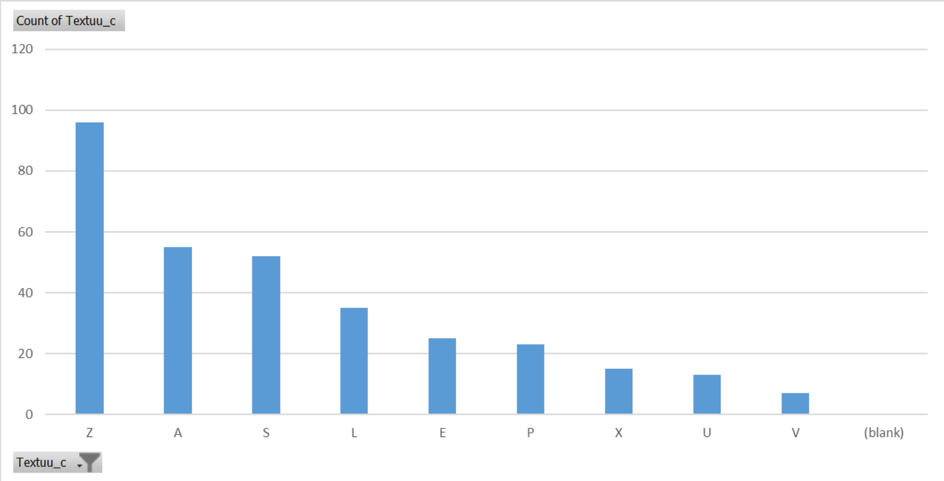


Figure 43 Occurrence of soil drainage classes within the nature sampling locations selection

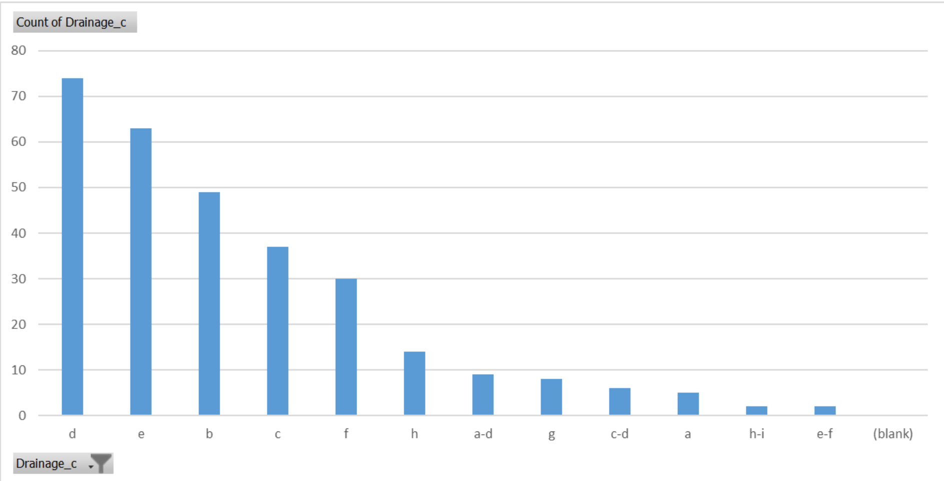


Figure 44 Occurrence of soil drainage classes within the nature sampling locations selection

2.2.6 Residential

The mean surface of a 'Garden' parcel (incl. buildings) was 123m², for 'Parcs & Recreational area' this was 581m².

Texture and drainage

There was an even spread of the residential sampling sites across soil textures, except for just few sites on clayey soils. The majority of sites had favourable (b) to moderately poor drainage (e). About a quarter of all sites (104) did not have a soil texture or drainage defined. Out of these, 76 had soil series OB, i.e. built-up land, as was to be expected for residential land-use.

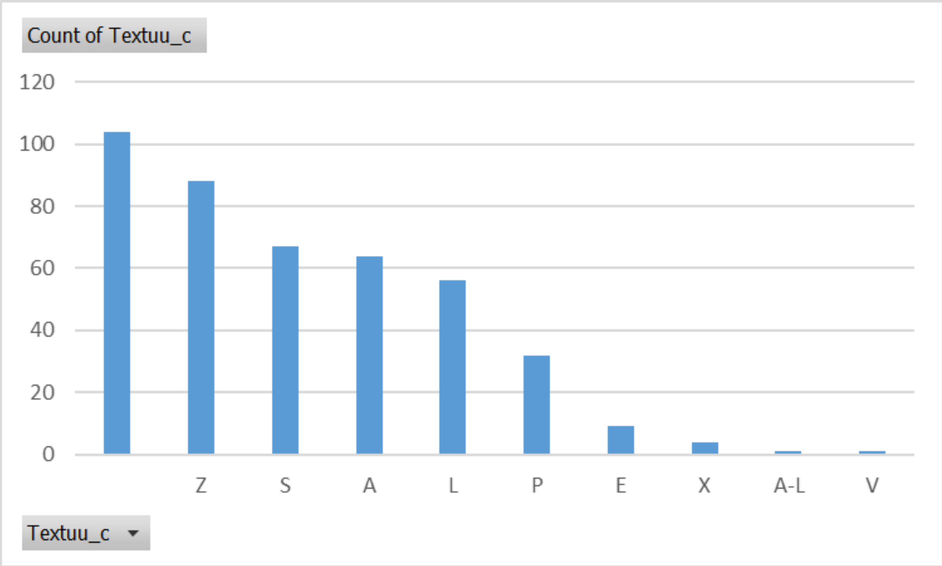


Figure 45 Occurrence of soil textural classes within the residential land-use sampling locations selection

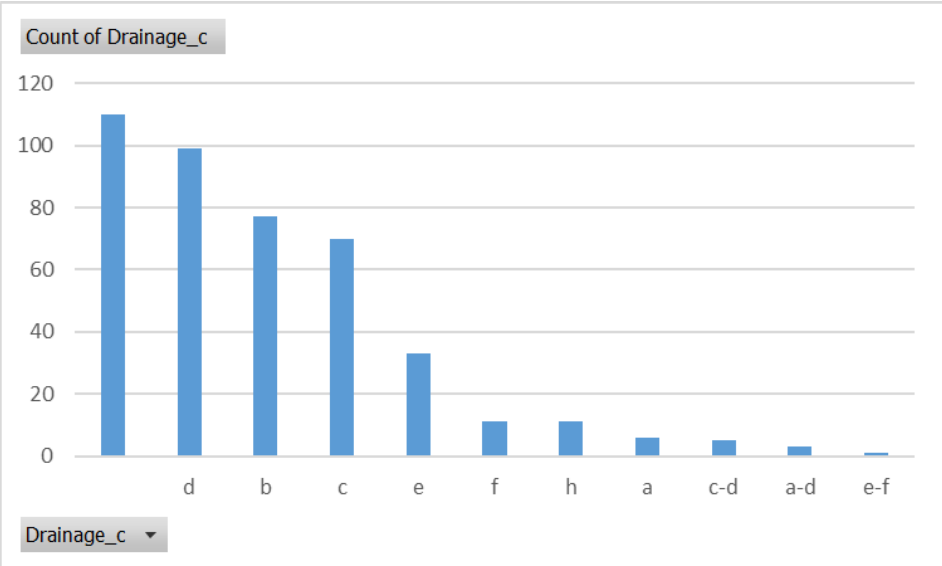


Figure 46 Occurrence of soil drainage classes within the residential land-use sampling locations selection

2.3 SAMPLING SITES TO DETECT SOC STOCK CHANGES RESULTING FROM LAND-USE CHANGE

2.3.1 Methodology

As explained in paragraph 1.6.1, a selection of plots with documented land-use-change are needed to ensure a balanced dataset for LULUCF reporting needs. In order to achieve this and in addition to the regular monitoring plots, 20 plots are added to each land use class (5 extra plots for LU change in one direction towards the 4 other land use classes) to ensure a balanced statistical design to compute SOC stock changes for all potential land use changes. This results in 100 additional plots (Table 22).

For the selection of these plots, we have to establish plots where recent land use changes occurred or would occur. Our approach is to overlay the two most recent versions of the VITO Ruimtemodel, adapted to the land use categories of the C-MON monitoring network. The latest version of the VITO Ruimtemodel (for the year 2019) will become available as of February 2021. For each grid cell, the 2016 and 2019 land use type can then be combined in order to determine the grid cells where a land use change occurred between these two years. This then allows to select sufficient grid cells with the desired land use change.

To illustrate the proposed methodology, an overlay was made between the currently available LU maps of 2013 and 2016 (Figure 47). Each grid cell either underwent a land use change, or stayed under the same land use. It is clear that certain land use changes were very exceptional, for instance cropland to forest occurred on 365 ha or nature to residential on 928 ha (Table 35). By overlaying this LUC map with the first ranked 10,000 plots of the GRTS grid, we selected plots that underwent land use change (Table 36). Strikingly, the number of plots under land use change from residential to cropland, forest, nature or grassland was surprisingly large. We will look into more detail at the individual plots of the GRTS grid in the next paragraph, by comparing the available orthophotos for the years 2009, 2012, 2018 and 2020. This should allow us to better interpret the detected land use changes.

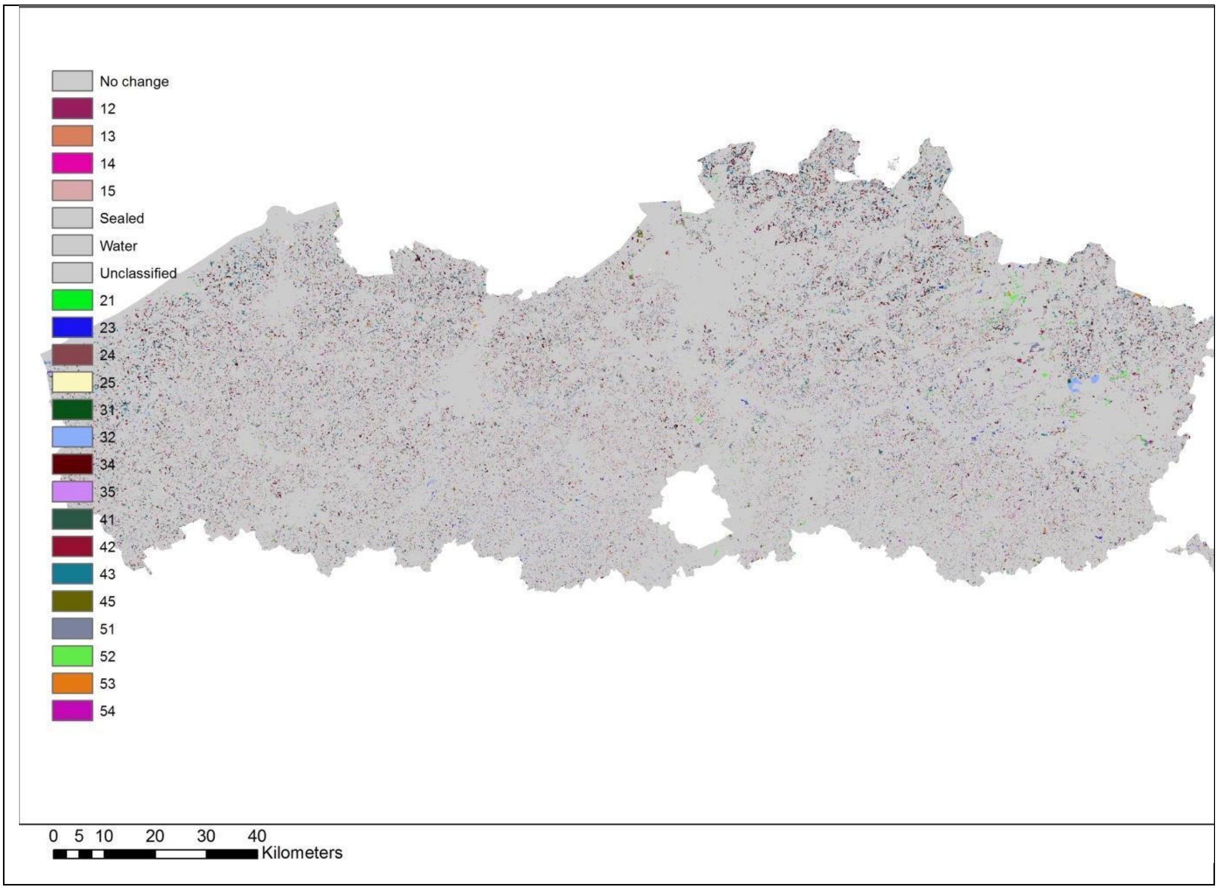


Figure 47. Land use changes between 2013 & 2016 (1=forest; 2=nature; 3=grassland; 4=cropland; 5=residential). Eg. '34' is a land use change from grassland (3) to cropland (4).

Table 35. Area (ha) of land use with or without land use change between 2013 and 2016. White = area without land use change; red = area under land use change < 1000 ha; light green = area under land use change > 1000 ha; dark green = area under land use change > 10,000 ha; grey = land use types not considered in the C-MON monitoring grid.

New LU → / **Orig LU ↓**	Cropland	Forest	Grassland	Nature	Residential	Sealed	Unclassified	Water
Cropland	373999	362	27055	564	15824	369	1246	82
Forest	557	125897	946	1778	703	203	404	155
Grassland	31585	944	193575	4741	14667	367	1765	329
Nature	624	1177	3005	48440	928	461	1837	354
Residential	8923	1834	10198	2219	183384	2418	30648	763
Sealed	129	54	117	76	746	154578	1298	30
Unclassif.	507	64	606	401	11435	2273	56420	303
Water	35	35	109	169	265	50	339	37493

Table 36. Number of C-MON plots (from a list of the first 10,000 plots) where a certain land use change occurred.

New LU → **Orig LU ↓**	Cropland	Forest	Grassland	Nature	Residential
Cropland		3	219	4	96
Forest	8		6	19	1
Grassland	232	8		34	110
Nature	1	9	21		5
Residential	59	14	83	20	

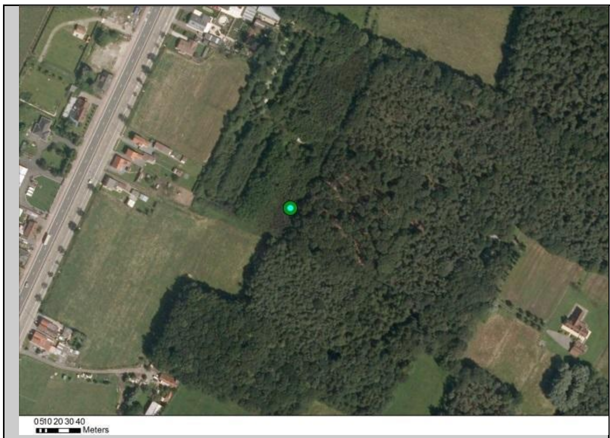
2.3.2 Land use change from cropland to other land uses (forest, nature, grassland, residential)

Only 7 GRTS points are located within grid cells with land use type cropland in 2013 and land use type forest or nature in 2016. When checking the orthophotos, none of them even appeared to have undergone an actual land use change. In most cases the plots are located at forest edges, or recently felled forest that has been misclassified as cropland in 2013, while being again classified as forest during the next survey, when reforestation had occurred (Figure 48). That is why the 2019 landuse classification can help in determining effective land use changes.

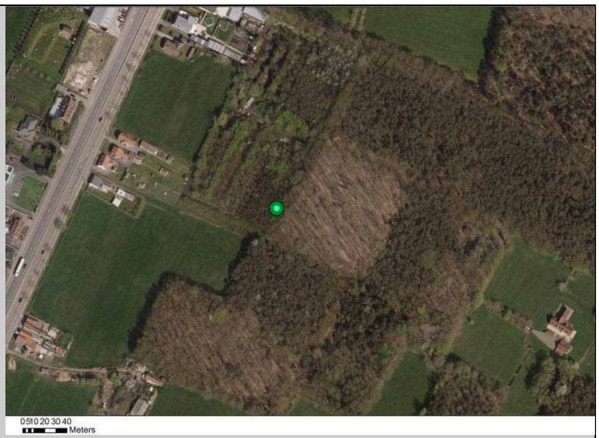
A change from cropland to grassland was detected at 219 GRTS plots. Checking the first 15 points yields 4 locations suitable for sampling. As illustrated in Figure 49, there are parcels that are sometimes crop and sometimes (temporary) grassland. In order to be certain, it will be necessary to consult the 'Landbouwgebruikspercelen', and possibly to contact the farmer in order to be certain that permanent grassland will be installed in the future.

96 C-MON grid cells displayed a change from cropland to Residential. This type of LUC is appeared very heterogeneous. Firstly, many locations fell on the edge of a parcel. Then often the change is was from cropland to 'niet geregistreerde landbouw' and it is unlikely that a real changes in land-use occurred (for instance P467e3dc and P3de7d93 in Figure 50). 'Niet-geregistreerde landbouw' is classified as residential area in the C-MON land use map. Of the first 52 locations, only five seemed to be interesting; e.g. P3de7d93 and P60ccc58 in Figure 50. Since soil sealing often occurs, it may be necessary and justifiable to move the plot in order to obtain the required minimum area for sampling (see 2.4 Sampling protocol).

Pb19fdc5 in 2012 (crop)	Pb19fdc5 in 2018 (forest)



P5810748 in 2012 (crop)



P5810748 in 2018 (forest)

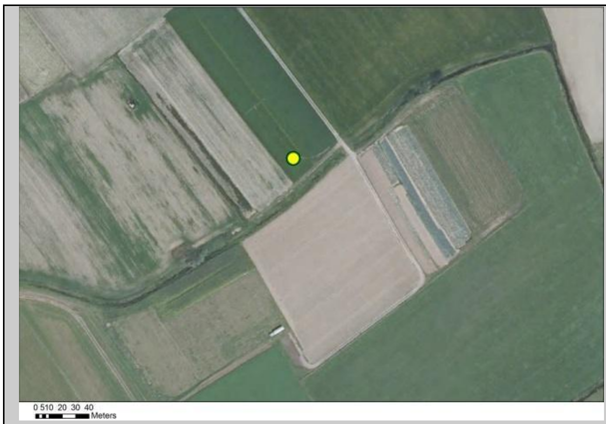
P67d81fe in 2012 (crop)

P67d81fe in 2018 (nature)

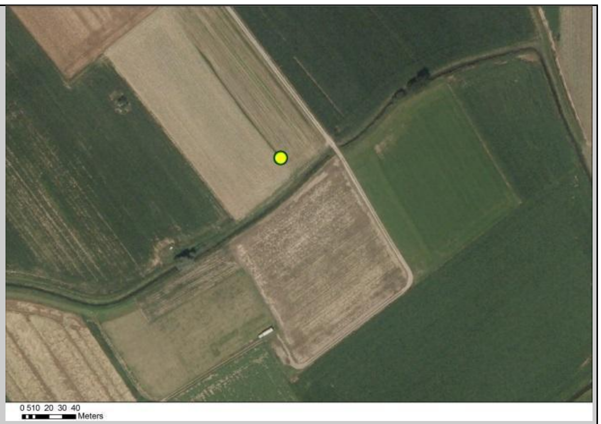
P95c9579 in 2012 (crop)

P95c9579 in 2018 (nature)

Figure 48. LUC crop to forest and crop to nature.

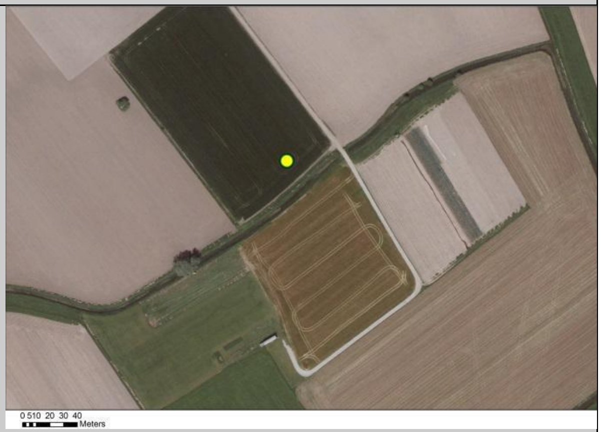


P6a9ddfc in 2009



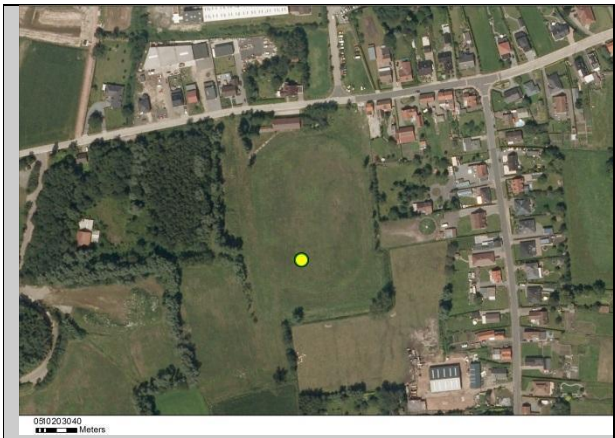
P6a9ddfc in 2012

P6a9ddfc in 2015



P6a9ddfc in 2018

Figure 49. Land use change crop to grassland: four consecutive orthophotos illustrate that the land use changes are in reality often crop rotations with crops and temporary grassland.



P467e3dc in 2012 (crop)

P467e3dc in 2018 (‘niet-geregistreerde landbouw’)

P3de7d93 in 2012 (crop)

P3de7d93 in 2018 ('niet geregistreerde landbouw')

P3de7d93 in 2012 (crop)

P3de7d93 in 2018 (residential)

P60ccc58 in 2012 (crop)

P60ccc58 in 2018 (residential)

Figure 50. Land use change crop to residential. Often a change of agricultural land to residential is in reality a change to 'niet geregistreerde landbouw' (see first two examples).

2.3.3 Land use change from grassland to other land uses (forest, nature, cropland, residential)

232 GRTS locations show a change from grassland to cropland. Checking the first 15 points yielded 3 locations suitable for sampling (e.g. P9e21e94 in Figure 51). From the orthophotos, once more no land use change seems to have actually occurred at the other locations. Similar to land use change cropland

to grassland, grassland was often found in rotation with crops. For a definitive selection of the plots, again 'Landbouwgebruikspercelen' map will have to be consulted and the farmer contacted.

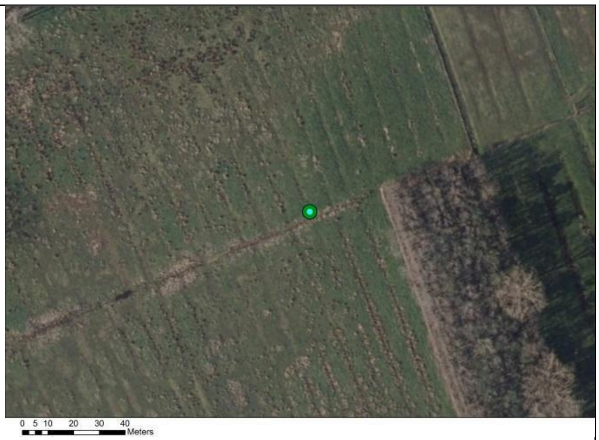
Grassland to forest LUC occurred at 8 locations, but none of these proved useful: as they were either situated at the borders between forest and grassland, or in relatively open forest, which in 2013 was misclassified as grassland and in 2016 as forest.

Grassland to nature LUC occured at 34 locations, where two out of the first 10 locations were useful (Figure 52, P4811720). The other locations consisted often of individual pixels in the borders of permanent grassland which were in 2016 classified as semi-natural grassland (see P76fc848 in Figure 52). This type of plot would not be suitable for long-term monitoring. It is clear that conversions from agricultural land use towards forest or nature often occur slowly and therefore the change may be difficult to detect over three years. It is again important to consult orthophotos whenever available to ascertain that an land use change effectively took place.

Similar to cropland, a change from grassland to residential (110 plots) was often a change from grassland to 'niet geregistreerde landbouw'. However, in the list of 110 plots, there were some plots that could be used for monitoring (for example P46cb8ee in Figure 53).

Figure 51. Land use change grassland to cropland .

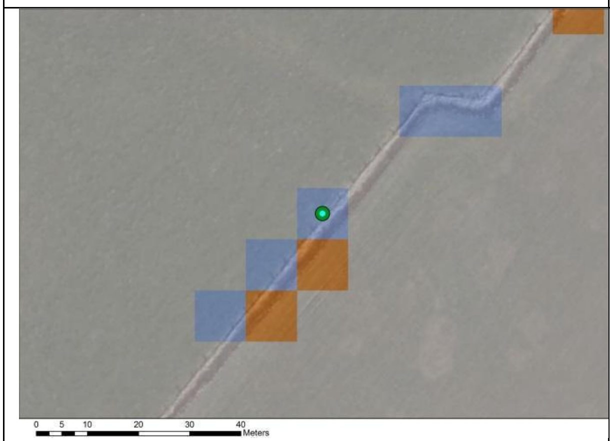
P4811720 in 2012



P4811720 in 2020

P76fc848 in 2012

P76fc848 in 2018



P76fc848 with LUC pixels grassland to nature in blue

Figure 52. Land use change from grassland to nature.

P46cb8ee in 2009 | P46cb8ee in 2018

Figure 53. Land use change from grassland to residential.

2.3.4 Land use change from forest to other land uses (cropland, nature, grassland, residential)

Forest changed into grasslands at 6 GRTS points, but none proved viable potential LUC plots when inspecting orthophotos. Most points were located at forest edges, which in 2013 were classified as forests but in 2016 as agriculture. In one occasion, there was effectively a clearcut, but there was no grassland installed, and presumably new forest would have been planted instead. Forests changed to croplands at 8 GRTS points, one of those locations could be used based on orthophotos. Most points were located in forest edges.

Forest changed to nature at 19 locations, of which two could be used of the first ten (one of them is P23ef814 in Figure 54). In most cases, the land use did not appear to have changed, although the classification apparently did (see P5a27c97 in Figure 54).

Land use change from forest to residential occurred at only one of the GRTS cells. This location could not be used though, since it was a point at a forest edge, that was classified as forest in 2013 and classified as “Overig Hoog Groen” in 2016.

P23ef814 in 2009 | P23ef814 in 2018

P5a27c97 in 2012	P5a27c97 in 2018

Figure 54. Land use change forest to nature. The first point could be used, while at the second location no land use change took place most likely.

2.3.5 Land use change from nature to other land uses (cropland, nature, grassland, residential)

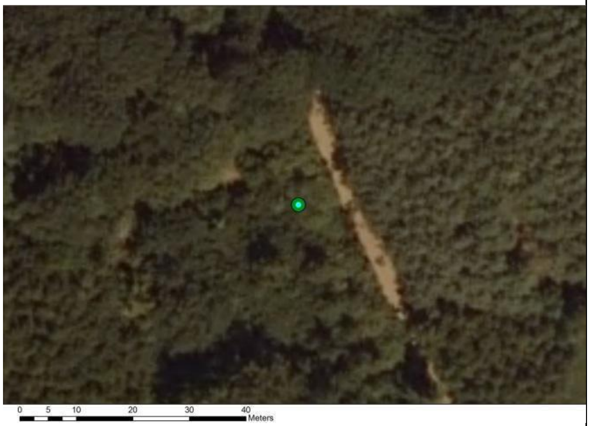
Nature changed to forest at 9 locations, of which possibly only one location yielded a valid land use change (Figure 55). The others were relatively open forest ecosystems which did not appear to have changed. However, it is to be expected that in three years' time, it is difficult to detect for instance natural reforestation of open semi-natural grassland or heathland.

Nature to grassland occurred at 21 locations. In some cases, there appeared to be a change from semi-natural grassland to intensive grassland (see Pc1282fa in Figure 56). We believe these cases should nevertheless be verified on available maps (e.g. landbouwgebruikspercelen) and orthophotos, as well as in the field to be certain that an actual land-use change took place. For most of the 21 locations, it seems quite obvious that nor the land use nor the land management changed (see e.g. Pa494c96 in Figure 56). A couple of locations were situated once more at field borders, which were more intensively used one year and more extensively the next (P71d6270 in Figure 56). Such grid cells would not be suited for long term monitoring of SOC stocks caused by land use changes, since their management changes from one year to the next.

Only one plot changed from nature to cropland, but the orthophotos showed no change on the ground.

At five GRTS-cells land use changed from nature to residential, but only one of them seemed relevant for monitoring C stock changes: P7ebac90 changed from semi-natural grassland to residential (Figure 57). Unfortunately, only part of the 10x10 m would in practice be available for sampling since a road was established. In this case one may consider moving the plot so that the required minimal area can be sampled. It also became apparent that on the 2016 VITO land use map, the categories 'overig hoog groen' en 'overig laag groen' may occur outside residential areas. These pixels are classified as residential, but in reality they represent isolated pixels with brushwood or trees. These cannot be used to monitor changes to or from residential land use.One of the five plots was deforested in 2009, then some low brushwood appeared (2012, classification 'nature') and then a combination of lawn and brushwood (2015, classification 'residential') was installed. This point could be used for a land use change forest to residential.

P2982f5a in 2009



P2982f5a in 2020

Figure 55. Land use change nature to forest.

Pc1282fa in 2012

Pc1282fa in 2018, spring

Pc1282fa in 2018, summer

Pc1282fa in 2020

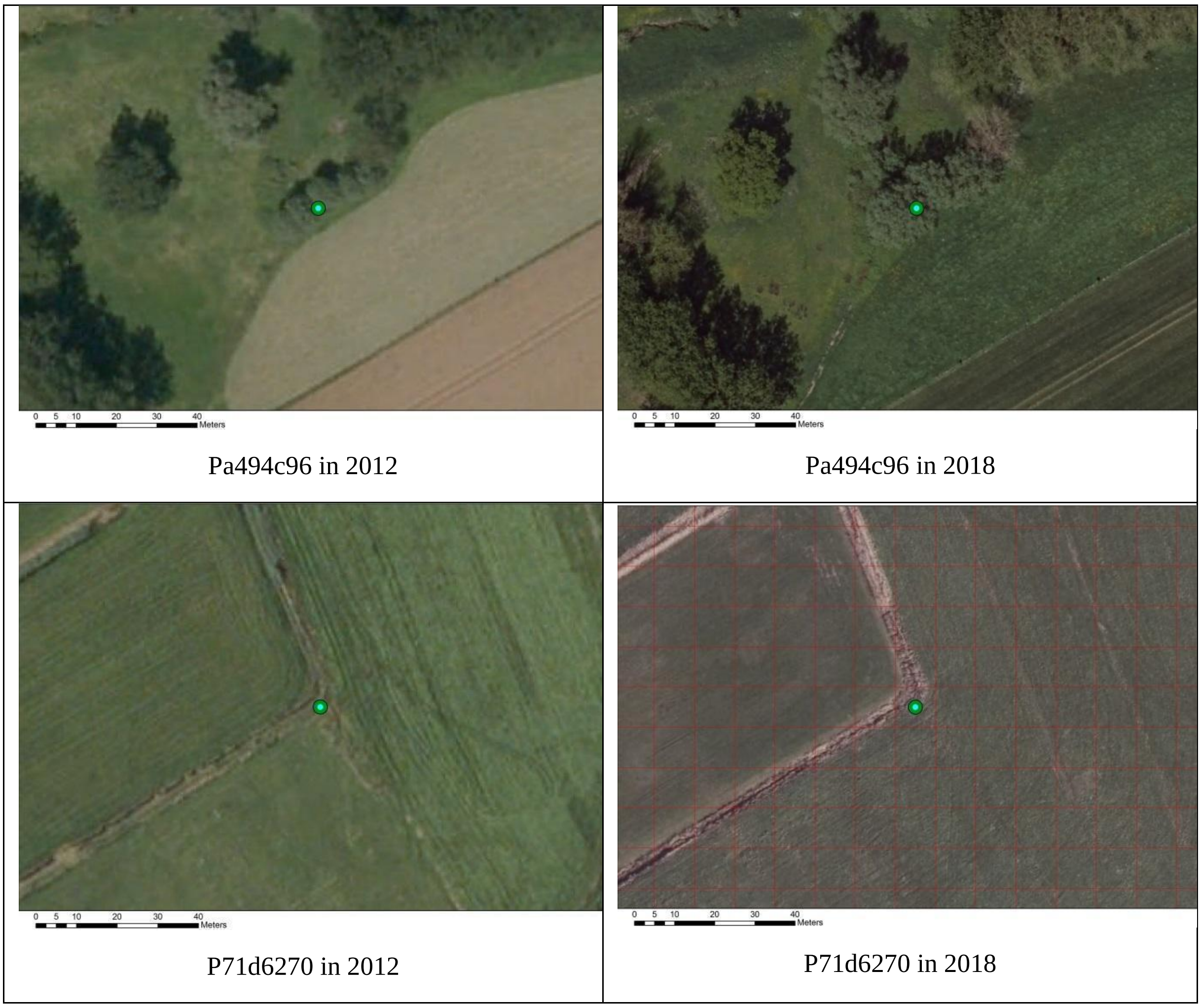


Figure 56. Land use change nature to grassland.

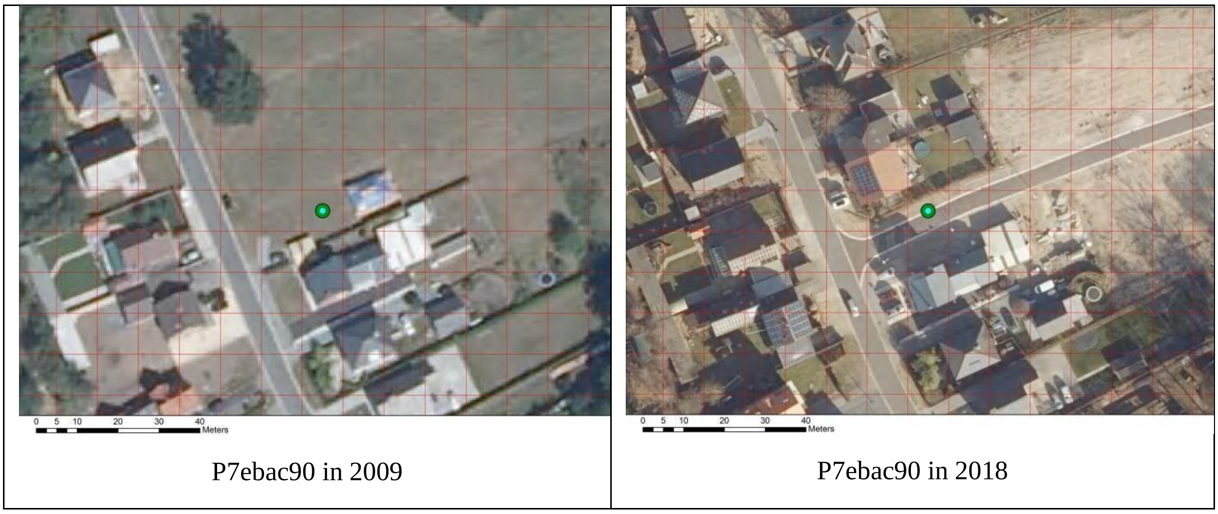


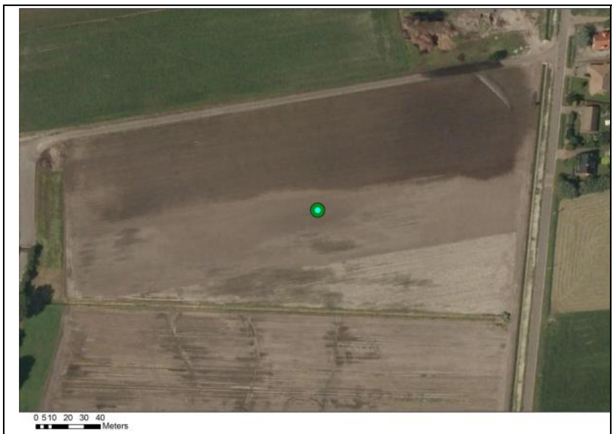
Figure 57. Land use change from nature to residential.

2.3.6 Land use change from residential to other land uses (cropland, grassland, forest, nature)

No plots were found with changes from residential to forest/nature. Although respectively 14 and 20 plots were indicated in Table 36, all of these changed from the category ‘overig hoog groen’ or ‘overig laag groen’ outside residential areas (but which is classified as residential) to forest or nature. So the plots were classified differently by VITO in 2013 and 2016, but no actual land use nor land management changes could be detected from visual inspection of the orthophotos. In some cases a change of ‘niet geregistreerde landbouw’ (= residential) to nature occurred.

A change from Residential to agricultural land use was found on a relatively high number of locations. However, we could not find locations were an actual change had taken place. It often concerned often changes of ‘niet geregistreerde landbouw’ (P241108f in Figure 58) or ‘Overig laag groen’ (Pa36daf0 in Figure 58) towards cropland or grassland. There was one exception: in this case the land use did appear to have changed from residential (garden) to permanent grassland (Paff7313 in Figure 58).

Question is, are these situations relevant? Do we want to monitor land use changes from residential to other land use type? This type of land use change is exceptional, and will probably not have a large impact on CO_2 fluxes to or from the soil.

 P241108f in 2012 (‘niet geregistreerde landbouw’)	 P241108f in 2020 (cropland)
 Pa36daf0 in 2012 (‘overig laag groen’)	 Pa36daf0 in 2018 (grassland)

Paff7313 in 2009

Paff7313 in 2018

Figure 58. Land use change from residential to agriculture.

2.3.7 Conclusions

For changes **from agricultural land** (cropland or permanent grassland) to forest or nature, overlaying the VITO LU maps yielded few results. This is probably not surprising, since this type of LUC often takes more than 3 years to be visible from the air. We propose to look for known sites where afforestation or natural management took place.

For changes from agricultural land to residential, we believe the approach with the subsequent VITO maps could be used. But if we want to find 5 locations for this land use change, we will need to check a large number of GRTS points to find locations where a ‘real’ land use change occurred. In that case, the first 10,000 GRTS locations proved insufficient. We also found based on a first analysis of orthophotos, that it may be necessary to relocate some plots, if soil was sealed on a substantial part of the 10x10m² plot during the LUC.

The VITO LU maps may also be used to select plots where changes between cropland and grassland occurred (in both directions). However, the ‘Landbouwgebruikspercelen’ maps will be needed to double check if the grassland was not part in rotation with arable crops (and therefore temporary). It may also be necessary to contact farmers in order to make sure that the newly installed grassland (or cropland) is expected to be permanent.

For changes **from forest** to agriculture (cropland or grassland) or nature, no plots or a very limited number of plots were found by overlaying consecutive VITO maps. It proved difficult to establish whether a real deforestation took place within the 3 year period between both VITO maps, or if reforestation is instead still under way. We believe it would be better to consult responsible authorities like ANB to more efficiently locate approved deforestation projects. The change from forest or nature to residential is very exceptional, therefore we propose to no longer consider this type of land use change.

For changes **from nature** to forest, we also propose to look for known projects (e.g. change in Natura 2000 habitat type). Plots where nature changed into cropland did not occur and it therefore seems pointless to further consider these forms of LUC. Likewise conversion from Nature to residential land use was very exceptional and could be disregarded. Plots where nature changed into grassland did occur. We propose to detect them with the VITO LU maps and also consult the Landbouwgebruikspercelen maps, in order to make sure that a real change in land use took place.

Land use changes **from residential** to crop, grassland, forest or nature were exceptional. The only land use change that proved less infrequent was a change from unregistered agriculture (‘niet geregistreerde landbouw') towards cropland or grassland, since C-MON classifies unregistered agriculture as residential. However, such a change is unlikely to bring about a change in management. We propose not to monitor LUC from residential to other land use types.

Table 37 summarizes the approach for the different types of land use change.

Table 37. Approach for selection of LULUC plots.

New LU → Orig LU ↓	Cropland	Forest	Grassland	Nature	Residential
Cropland	/	projects	VITO LU + landbgebrp	projects	VITO LU
Forest	projects	/	projects	projects	No
Grassland	VITO LU + landbgebrp	projects	/	projects	VITO LU
Nature	No	projects	VITO LU + landbgebrp	/	No
Residential	No	No	No	No	/

2.4 SAMPLING, ANALYSIS AND ARCHIVING PROTOCOLS

In C-MON soil organic carbon stocks will be determined on specific fixed depth intervals till a depth of 1m (i.e. LHF organic layer, 0-10, 10-30, 30-60 and 60-100cm) in 10 by 10m sampling plots. Key parameters for monitoring soil organic carbon stocks such as total organic carbon and bulk density will be analyzed. These analyses require specific methods of soil sampling, pretreatment and archiving. To standardize soil sampling and analysis during C-MON across the different land-use types, clear guidelines were combined in a sampling and analysis protocol (Annex 1; the protocol is presented in Dutch, in order to make it more practical and accessible to field technicians and lab personnel). This protocol compiles specific instructions for detecting the sampling location in the field, for sampling and analyzing both chemical (i.e. soil organic carbon and nitrogen, pH) and physical (i.e. bulk density and soil texture) soil properties and for archiving soil samples. Besides, special attention is given to the pretreatment of the soil samples before analysis. The protocol should be applicable across all land-use types that are present in C-MON.

The protocol as presented in this report is mainly based on existing protocols from ongoing soil surveys such as the European, periodic Land Use/Land Cover Area Frame Survey (LUCAS 2018; Orgiazzi et al. 2017) and Le Réseau de Mesures de la Qualité des Sols de France (RMQS; Jolivet et al. 2006), the Flemish compendium for soil sampling and analysis to comply with the regulations on land maintenance as set in the Common Agricultural Policy (Cross compliance, BOC 2017) and the ISO protocol on Pretreatment of samples for physico-chemical analysis (ISO11464:2006). Regarding the analysis of the chemical and physical soil properties, the protocol refers to existing and well defined ISO protocols (i.e. ISO 10694:1995, ISO 13878:1998, ISO 10390:2005, ISO 13320-1:1999, ISO 11272:2017). To ensure the quality of the lab analyses, the lab(s) that will become responsible for analyzing the C-MON samples should develop accreditation for those specific analyses and/or take part in a proficiency test (e.g. Amery et al. 2020). The guideline for sample archiving will be elaborated after further discussion with the steering group of C-MON.

Although soil organic carbon stocks clearly reflect the land-use and the management history (i.e. tillage, fertilization, crop rotation, etc.), an extensive survey by means of a questionnaire will not be organized among all land owners/mangers of sampling locations. This approach could be utilized in the Level-II plots but can be regarded as too labor-intensive if applied on all Level I plots. Furthermore, this type of study could unintentionally induce a change in soil management as land owners/managers become more aware of the conservation and enhancement of soil organic carbon. Therefore, a concise survey form was composed in which in situ observations will be compiled at the time of sampling (Annex 2). Besides general information on the sampling location, a set of terrain (e.g. slope, land cover) and soil (e.g. type, presence of peat) characteristics will be gathered. In addition, information on soil disturbance and management that can be observed at the time of sampling will be added. The information on the survey form will be used during the pretreatment of the samples (as explained in the sampling protocol) and during data processing.

2.4.1 Benodigd materiaal

2.4.1.1 Locatie proefvlak

- Kaart(en) met locatie van het staalnamepunt
- Handheld GPS (nauwkeurig tot op 1cm)
- Coördinaten subsamples (>16)
- Digitale hoekmeter (indien een slechte GPS-ontvangst verwacht wordt)
- markeringstokjes (minimaal 16) en lintmeters (minimum 25 meter)

2.4.1.2 Staalname

Strooisellaag (indien aanwezig; bos en (natuurlijk) graslanden)

- Metalen strooiselbak (roestvrijstaal, vierkant, 25 cm zijde)
- Veldweegschaal

Minerale/organische bodem

- Steekguts uit roestvrij staal met een nuttige lengte van 30 cm en een binnendiameter van 30 mm, met markering op de guts per 10 cm
- Steekguts uit roestvrij staal met een nuttige lengte van 30 cm en een binnendiameter van 25 mm met markering op 60 cm
- Steekguts uit roestvrij staal met een nuttige lengte van 40 cm en een binnendiameter van 20 mm met markering op 100 cm
- Veenboor (indien verwacht wordt dat de traditionele steekguts niet zal voldoen)
- Zuigerboor (indien verwacht wordt dat de traditionele steekguts niet zal voldoen)
- Hamer met kunststof slagkop
- Spatel
- Minimaal 4 mengemmers (minimaal 5l) met aanduiding van het diepte-interval
- Recipiënt om bodemstaal te verzamelen in het veld en te transporteren naar het labo (vb. plastic zakje, plastic bakje)
- Bidon met water
- Schoonmaakdoek om materiaal schoon te maken

Bodemdichtheid

- Core sampler met aanduidingen op 16,5; 23,5; 41,5; 48,5; 76,5; 83,5 cm
- Metalen ringen (5cm diameter, 100 cm^3volume)
- Aardappelmes
- Vouwmeter met leesbare centimeteraanduiding en mm schaal
- Edelmanboor (diameter > 5cm)

Transport

- Koelbox en koelelementen

Overige

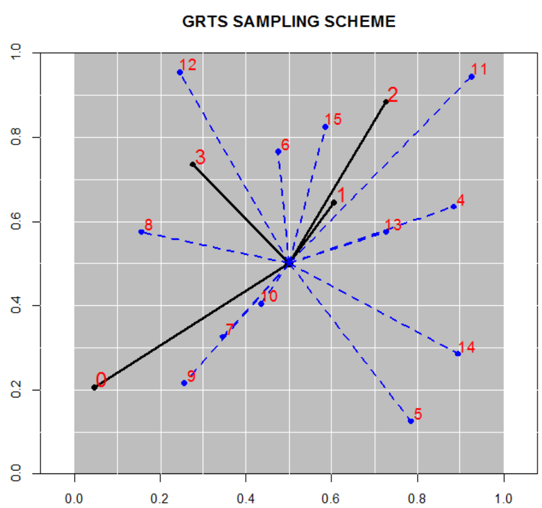
- Voorgedrukte (zelfklevende) etiketten (met proefvlakcode)
- Fototoestel (met correcte datum- en uurinstelling) of Smartphone
- Opnameformulier C-MON en schrijfplank
- Schrijfpotloden

2.4.2 Staalname

2.4.2.1 Locatie staalname

De staalname en metingen gebeuren binnen de perimeter van een proefvlak van maximaal 10mx10m. De locaties van de proefvlakken zijn vooraf geselecteerd. Het proefvlak werd vooraf opgedeeld in 100 x 100 = 10.000 blokjes van 1 dm^2 en hieruit werden met behulp van GRTS[1] software 32 random blokjes van 1 dm^2 geselecteerd voor het nemen van de **subsamples**. Deze staan in volgorde van prioriteit (rank). De eerste 16 worden bemonsterd als subsamples. Indien om één of andere reden bemonstering niet mogelijk is in een blokje (vb. wegens een obstakel zoals mestopslagplaatsen, bietenhoop, boom, tuinhuis,…), dan wordt het volgende blokje geselecteerd totdat 16 subsamples bemonsterd kunnen worden.

<table>
<tr><td>1</td><td>De coördinaten van de subsamples worden op het terrein gezocht met behulp van een hand-GPS en worden gemarkeerd met een markeringstokje. Het uitzetten stopt wanneer 16 subsamples zijn gelokaliseerd en geschikt bevonden voor staalname.</td></tr>
<tr><td>2</td><td>Indien de ontvangst van de GPS onvoldoende blijkt (bvb. bos) om de locaties van de subsamples te achterhalen wordt gebruik gemaakt van een digitale hoekmeter (type total station). De locaties voor het nemen van de 16 subsamples worden bepaald vanuit het centrum van hetplot. Vanuit het centrum worden de geselecteerde cellen omgerekend in polaire coördinaten zodat elke locatie een hoek (t.o.v. het centrum) en een afstand krijgt. De punten worden op die manier gelokaliseerd en gemarkeerd met een markeringstokje.



</td></tr>
</table>

Let op

1. Indien een deel van het proefvlak van 10mx10m niet kan bemonsterd worden omwille van de aanwezigheid van een extremiteit (vb. mestopslagplaatsen, bietenhoop, boom, tuinhuis, (weg)verharding…) wordt enkel verder gegaan indien 50% van het proefvlak bemonsterbaar blijft. Voor wegbermen geldt een minimum van 20% (1/5 van de oppervlakte fysisch bemonsterbaar).
2. Indien het volledige proefvlak niet kan bemonsterd worden op het moment van staalname door de aanwezigheid van een tijdelijke extremiteit (vb. diepe insporing, bietenhoop, mestopslag, net geploegde of bewerkte akker) wordt de staalname opgeschoven in de tijd. Bij een permanente extremiteit (vb. gebouw, verharding) wordt het proefvlak geschrapt en wordt een volgend proefvlak geselecteerd.
3. Indien een proefvlak verspreid ligt over twee aangrenzende percelen, tuinen,… worden de subsamples in beide percelen, tuinen,… bemonsterd. De GRTS sampling garandeert een aselecte en evenredige verdeling van staalnamepunten tussen de aangrenzende percelen (nog af te stemmen met de stuurgroep).

2.4.2.2 Voorbereiding grondoppervlak voorafgaand aan staalname minerale bodem

Vooraleer van start te kunnen gaan met de staalname van de minerale bodem dient het grondoppervlak vrijgemaakt van organische resten en dient een eventuele aanwezige O-horizont (bv. in bos en (natuurlijk) grasland apart bemonsterd te worden.

3	**De bodem** wordt rond de plaats waar er geboord zal worden, eerst **lichtjes aangetrapt**. Vooraleer de gutsboor in de grond wordt geduwd, wordt de **oppervlakte vrijgemaakt van organische resten** zoals plantenresten (bovengrondse plantendelen zoals grasssprieten, gewasresten of resten groenbedekker) en resten van organische bemesting (vb. compost, stalmest,…). Er mag nooit op een plant bemonsterd worden.
4	Bij aanwezigheid van een strooisellaag of viltlaag (OL, OF, OH) wordt eerst op elk van de 16 staalnamelocaties de strooisel-/vilt laag bemonsterd met een strooiselbak (25 cm zijde). De OL laag wordt verwijderd en wordt niet bemonsterd. De OF en OH laag worden samen verzameld en de netto massa (versgewicht) wordt op elk van de 16 locaties gemeten met de veldweegschaal en genoteerd.

Let op

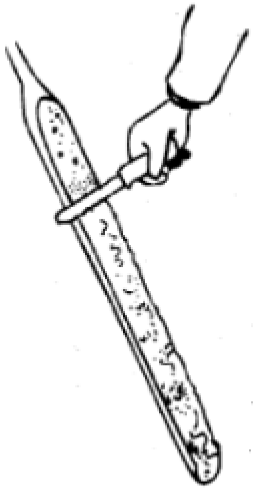
1. Bij meerjarig/oud grasland en/of natuurgrasland kan er na het verwijderen van het gras bovenaan nog een 'viltlaag' aanwezig zijn van meerdere centimeters (minimaal 1cm dik). Deze viltlaag is moeilijk te onderscheiden van levende materie en zal net zoals bij een strooisellaag (en volgens hetzelfde protocol) in bos voor elk van de 16 staalnamelocaties apart bemonsterd worden vooraleer van start te gaan met de bemonstering van de minerale bodem.

2.4.2.3 Staalname minerale bodem

Vervolgens kan van start gegaan worden met de staalname van de minerale bodem. In het proefvlak worden de volgende lagen volgens vaste diepte bemonsterd. Hiervoor wordt gebruik gemaakt van gutsboren met een verschillende diameter naargelang de diepte waarop bemonsterd wordt. Ook het aantal substalen hangt af van de bemonsteringsdiepte. Slechts 4 van de 16 substalen dienen bemonsterd te worden tot 1m diep en dit op de eerste vier locaties die door de GRTS-routine werden aangeduid. Indien op één van deze locaties niet kan bemonsterd worden tot 1m diep (door bvb. de aanwezigheid van stenen) wordt overgegaan naar de volgende locatie.

- *strooisellaag indien aanwezig (16 substalen, door middel van een strooiselbak met 25 cm zijde) zie stap 4*
- **0-10 cm** (16 substalen, door middel van een gutsboor)
    - diameter gutsboor: **30mm**
- **10 - 30 cm** (16 substalen, door middel van een gutsboor)
    - diameter gutsboor: **30mm**
- **30 - 60 cm** (4 substalen, door middel van een gutsboor)
    - diameter gutsboor: **25mm**
- **60 - 100 cm** (4 substalen, door middel van een gutsboor)

diameter gutsboor: **20mm**

5	Duw de boor **loodrecht t.o.v. het maaiveld** in de bodem tot op de vereiste diepte. De boor wordt 1 omwenteling **in wijzerzin gedraaid** en dan omhoog getrokken met de opening van de guts van de persoon weg. Het is hierbij belangrijk om geen grondverlies te hebben. 
6	**Grond die zich buiten het boorlichaam (guts) bevindt wordt afgeschraapt met de spatel**. Je duidt met de spatel de te bemonsteren diepte-intervallen aan op het materiaal in de boor door dit lichtjes in te snijden (in het geval van de lagen 0-10 en 10-30 cm). Los de volle boor door met de spatel (de bolle kant boven) het monster uit de gutsboor te duwen. 

Let op

Bij bemonstering van de bovenste minerale bodemlaag mag, in tegenstelling tot bij de andere lagen, de eerste twee cm staal **NIET** verwijderd worden uit de guts. Duidelijk zichtbare bovengrondse plantendelen (vb. grasprieten) mogen verwijderd worden.

7	Voor de laag 30-60 cm en 60-100 cm wordt hetzelfde boorgat als voor de 0-30 cm laag gebruikt. De laag 30-60 cm en de laag 60-100 cm worden afzonderlijk bemonsterd. De boor voorzichtig in het boorgat brengen (probeer hierbij te vermijden dat losse aarde in het boorgat terecht komt), en naar **beneden duwen tot aan het merkteken voor -60 cm of -100 cm.** De boor in wijzerzin rond draaien en voorzichtig uit het boorgat trekken met de opening van de guts van de persoon weg.
8	**Grond die zich buiten het boorlichaam (guts) bevindt wordt afgeschraapt met de spatel**. **De bovenste 2 cm wordt tevens uit de guts verwijderd met de spatel.** Los de volle boor door met de spatel (de bolle kant boven) het monster uit de gutsboor te duwen.

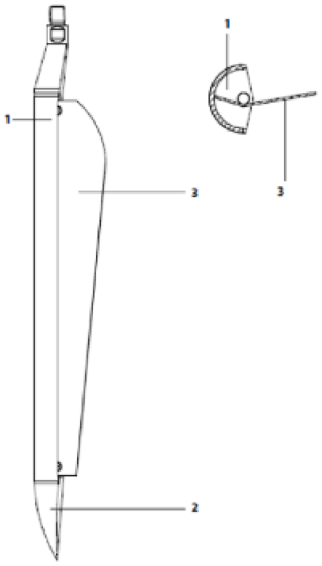
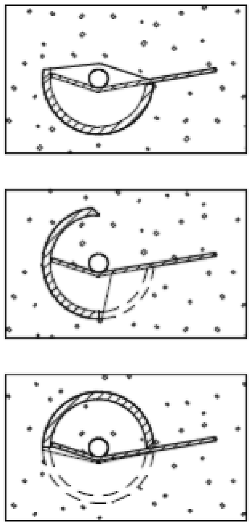
Let op

Tussen 2 boringen wordt de boor goed afgeschraapt met de spatel. Na de bemonstering van het perceel worden boren en spatel met een stoffen doek afgekuist. Indien vereist wordt hiervoor water gebruikt.

Indien bij een boring het boorlichaam niet volledig gevuld is (indien > 2cm van de totale lengte geen bodem bevat) wordt de boor leeggemaakt naast het recipiënt en wordt een nieuwe boring uitgevoerd net naast het originele boorgat. Indien dit tot driemaal toe mislukt wordt overgestapt naar een ander type boor (**zie verder bij 5'->9' en 5''->9''**). Het type boor dient vermeld te worden op het opnameformulier.

9	Verzamel al het bodemmateriaal per diepte-interval in het daartoe bestemde mengemmertje/plastic bakje/plastic zakje. Voorzie ieder recipiënt van een etiket waarop minimaal de code van het proefvlak , de staalnamedatum en de staalnamediepte wordt weergegeven Het bodemstaal wordt **ofwel ter plaatse ofwel in het labo** manueel verkleind en gehomogeniseerd en ontdaan van stenen, levende wortels of andere plantendelen, rhizomen, verse houtsnippers of compost,…. Voor kleiige stalen wordt het sterk aanbevolen om reeds te verkleinen ter plaatse.

In venige bodems zal gebruik gemaakt worden van **de veenboor**.

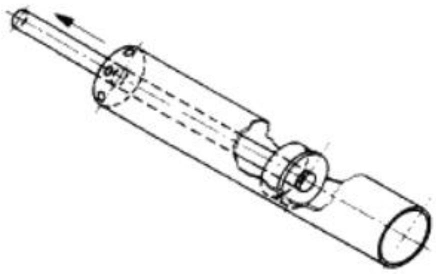
5’	**Draai de vin zodanig dat deze het gutsgedeelte volledig afsluit**. De uitstekende zijde van de vin moet hierbij tegen de platte, niet-snijdende rand van het gutsgedeelte liggen. Steek de **boor vervolgens rechtstandig, dus zonder te draaien, in de grond of onder water tot de gewenste diepte**. De vin sluit het gutsgedeelte af zodat dit leeg blijft. De massieve punt duwt de (zachte) grond aan de kant. De snijdende kant van de vin snijdt daarbij door de grond (Figuur 5 bovenaan).  Figuur 4: Veenboor, zijaanzicht (links) en dwarsdoorsnede (rechts). (1) Half-cilindrisch bemonsteringsgedeeltje; (2) Massive punt; (3) Een om de booras scharnierende gehoekte vin.  Figuur 5: Staalname met een veenboor
6’	**Aangekomen op de gewenste diepte, wordt de boor een halve slag (180°) rechtsom gedraaid.** Het gutsgedeelte draait hierdoor een halve cirkel, met als draaias de scharnierpunten van de vin. De vin blijft tijdens het draaien door zijn weerstand in dezelfde positie in de grond staan. Na een halve draai heeft het gutsgedeelte zich door de grond gesneden en is het volledig gevuld met grond (zie onderstaande figuren). De vin sluit het monster in de boor (Figuur 5 onderaan).
7’	**Haal de volle boor rechtstandig omhoog**. De vin sluit het volle gutsgedeelte volledig af, waardoor geen vermenging optreedt met de bovenliggende bodemlagen. Gebruik eventueel het trek-/drukstuk wanneer de handgreep op een ongunstige hoogte zit.
8’	Zodra het boorlichaam boven het maaiveld uitsteekt, wordt de boor zodanig gekanteld dat het gutsgedeelte onderop, en de vin bovenop komt te liggen. Houd de boor horizontaal. Om het monster bloot te leggen, wordt de vin een halve slag

	gedraaid. Deze schraapt het monster uit het gutsgedeelte, waarna het nauwelijks-geroerde monster op de vin komt te liggen.
9'	**Ledig de veenboor** door handmatig het bodemmateriaal over te brengen op het plastieken zeil. Plaats een vouwmeter naast het uitgelegd boormateriaal. Verzamel al het bodemmateriaal per diepte-interval in het daartoe bestemde mengemmertje/plastic bakje/plastic zakje. Het bodemstaal wordt ofwel ter plaatse of in het labo manueel verkleind en gehomogeniseerd. Ook stenen, levende wortels of andere plantendelen worden verwijderd. **Veenmateriaal, houtskool en stukjes black carbon blijven in het monster!**  Figuur 6: Resultaat staalname met veenboor tot 50 cm  Figuur 7: Ledigen van de veenboor op zeil

Let op

Met deze techniek kunnen enkel de diepte-intervallen 0 -10 cm, 10-30 cm en 30-40 cm bemonsterd worden.

In weinig cohesieve gronden zoals bvb. nat zand beneden de grondwaterspiegel of bodems met een permanente hoge grondwaterstand zal gebruik gemaakt worden van de **zuigerboor**.

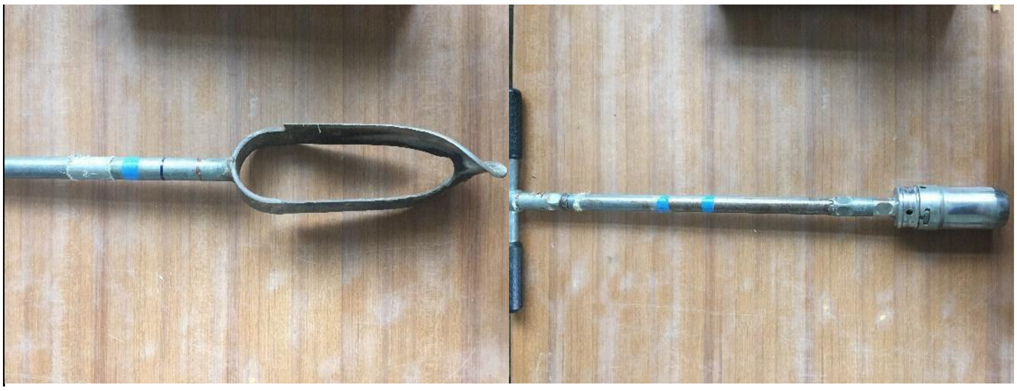
5’’	Plaats de boor op de bodem van het boorgat. De zuigerstang dient hierbij in de onderste stand te blijven! Door de zuigerboor enigszins te schudden zal de zuigerstang in de onderste stand zakken. Trek met het touw de zuigerstang licht schoksgewijs omhoog, zodat een lichte onderdruk onder de zuiger ontstaat. Druk tegelijkertijd de buis met constante druk omlaag.  
6’’ **7’’** **8’’**	Druk de volle buis even aan en trek hem weer uit het boorgat omhoog. Om het monster in de buis te houden, moet de zuigerstang in de bovenste positie blijven en het touw dus strak gehouden worden (knoop het eventueel aan de handgreep). Houd de zuigerstang altijd parallel met de boorstang om lekkage van de zuiger (en dus monsterverlies) tegen te gaan. Wanneer het hoogteverschil tussen maaiveld en waterspiegel in het boorgat te groot is, kan het monster uit de buis lopen. Vul het boorgat met extra water om dit te voorkomen.
9’’	Los het monster door de zuigerboor op het maaiveld te leggen, met de zuigerstang het monster uit de buis te drukken en tegelijkertijd de zuigerboor naar je toe te trekken. Door de zuigerboor enigszins te schudden, wordt het uitdrukken vergemakkelijkt. Verzamel al het bodemmateriaal per diepte-interval in het daartoe bestemde mengemmertje/plastic bakje/plastic zakje. Het bodemstaal wordt ofwel ter plaatse ofwel in het labo manueel verkleind en gehomogeniseerd. Ook stenen, levende wortels of andere plantendelen worden verwijderd

Let op

Vermits de werkzame lengte van de boor 75 cm is, kunnen enkel de diepte-intervallen 0-10 cm, 10-30 cm, 30-60cm en 60-75cm bemonsterd worden.

2.4.2.4 Staalname ongestoord bodemmonster voor de bepaling van de bodemdichtheid

Na de staalname van de minerale bodem worden de stalen genomen voor de bepaling van de **bodemdichtheid**. De **ongestoorde bodemmonsters** worden genomen in de **4 verschillende bodemlagen (0-10cm, 10-30cm, 30-60cm en 60-100cm**) en dit op **4 locaties**. Er wordt telkens bemonsterd in het midden van de laag, dit wil zeggen resp. op 2,5 cm, 17,5 cm, 42,5 cm en 76,5 cm diepte. De 4 locaties stemmen overeen met de 4 substalen waar de minerale bodem werd bemonsterd tot op een diepte van 1m. De ongestoorde bodemmonsters worden genomen met behulp van metalen 'Kopecky' ringen (5cm diameter) met een gekend volume (100 cm³).

10	**Naast de boorschacht van de boring tot 1 m wordt opnieuw geboord, ditmaal met de core sampler (foto links) en de edelman boor (foto rechts)**. Doel is een zo ongestoord mogelijk bodemmonster in de metalen ring te krijgen en dat per vaste diepte. 
11	Voor het onverstoorde bodemmonster in de **0-10cm bodemlaag** kan onmiddellijk gebruik gemaakt worden van de core sampler. Vooraleer de core sampler in de grond wordt geduwd, wordt de **oppervlakte vrijgemaakt van organische resten** zoals plantenresten (gras, oogstresten of resten groenbedekker), resten van organische bemesting (vb. compost, stalmest,…) en strooisellaag. Er mag nooit op een plant bemonsterd worden.
12	Steek een metalen ring in de steekhuls van de core sampler. Duw de core sampler in de bodem en hamer eventueel lichtjes

Let op

Laat de core sampler **niet verder dan 8cm in de bodem dringen (of laat niet meer dan 2cm bodem in de headspace van de core sampler dringen).** Op die manier wordt vermeden dat er verdichting van de bodem optreedt in de core sampler en metalen ring.

13	De core sampler wordt 1 toer **in wijzerzin omgedraaid** en dan voorzichtig omhooggetrokken. Het is hierbij belangrijk om geen grondverlies te hebben.
14	Haal voorzichtig de metalen ring uit de steekhuls en de ringhouder en **verwijder het overtollig bodemmateriaal met een aardappelmes**. **Noteer** tevens **de diepte** van de ondergrens van de gestoken ring in de boorschacht.
15	Duw alle (!) bodem uit de metalen ring en verzamel de inhoud van alle ringen per proefvlak en per diepte-interval in het bestemde plastic bakje/plastic zakje. Vermeld de proefvlakcode en diepte-interval op ieder recipiënt.
16	**Voor de overige bodemlagen (10-30, 30-60 en 60-100cm) dient met behulp van de edelman/riverside of boor/core sampler de boorschacht voorgeboord en afgevlakt te worden** tot op een diepte van ongeveer 4 à 5 cm boven het midden van de bemonsterde bodemlaag. Herhaal vervolgens stappen 12 tot en met 15.

2.4.3 Opnameformulier

17	Vervolledig voor, tijdens en na de staalname het opnameformulier (Annex 2).Hier wordt algemene info over het proefvlak en terrein- en bodemstaalkenmerken gedocumenteerd. Neem tevens minimaal één overzichtsfoto van het proefvlak. Vermeld bij de naamgeving van de foto's steeds de proefvlakcode.

2.4.4 Transport en bewaring van de bodemstalen

18	De bodemmonsters worden tijdens de staalnamedag en het transport naar het labo **bewaard in koelboxen met koelelementen** om te vermijden dat de temperatuur in het monster significant zou stijgen t.o.v. de bodemtemperatuur. De monsters worden afgeleverd in het labo en opgeslagen in de koelruimte bij <4°C. **Stalen mogen maximaal 5 dagen in de koelruimte bij <4°C bewaard worden vooraleer ze naar de droogstoof kunnen verhuizen.**

2.5 LABORATORY ANALYSIS PROTOCOLS AND ARCHIVING

2.5.1 Labo-analyse

2.5.1.1 Staalvoorbereiding minerale bodem

Eens de stalen aankomen in het labo kan de staalvoorbereiding aanvangen.

19	Na het manueel verkleinen, homogeniseren en verwijderen van stenen, levende wortels of andere plantendelen, rhizomen, verse houtsnippers of compost,…. (MERK OP: veen, houtskool en black carbon mogen NIET verwijderd worden) wordt via de kwartiermethode een **representatief deelstaal van tenminste 750g verse bodem** overgebracht in een **recipiënt en in de droogstoof geplaatst bij 40°C**. Het bodemmonster mag de dikte van 5 cm niet overschrijden. Indien dit wel het geval zou zijn, dan wordt het monster verdeeld over twee recipiënten teneinde een voldoende snelle droogtijd te bekomen. De droogtijd is afhankelijk van het initiële vochtgehalte, de dikte van de laag materiaal in het recipiënt, bodemtextuur en ventilatiesnelheid van de droogstoof. Om een voldoende droog bodemstaal te garanderen, **dienen de stalen 7 dagen in de droogstoof te blijven.**

Vervolgens wordt een onderscheid gemaakt tussen volledig minerale bodemstalen en bodemstalen die geheel of gedeeltelijk organisch zijn (stalen van de strooisel- of viltlaag behoren tot de organische stalen). Stalen die niet volledig mineraal zijn krijgen geen routinebehandeling maar worden aangeduid als '(gedeeltelijk) organisch' en moeten samen met de laboverantwoordelijke/coördinator bekeken worden tijdens de voorbehandeling. Dit gebeurt in een van de volgende gevallen:

- Op basis van de bodemkaart is er een vermoeden dat er in het bodemprofiel venige materialen kunnen zitten;
- Op het opnameformulier werd aangeduid dat er tijdens één over of meerdere boringen veen, houtskool, black carbon werd aangetroffen.

In deze gevallen moeten alle dieptes door de laboverantwoordelijke/coördinator bekeken worden.

Bij volledig minerale bodemstalen verloopt de verdere staalvoorbereiding volgens stap 20. De vermoedelijk (gedeeltelijk) organische stalen worden verwerkt volgens de richtlijnen in stap 20'.

20	Het gedroogde staal wordt vervolgens gebroken en gezeefd over een zeef van 2mm. Wat van bodem niet onmiddellijk door de zeef gaat, even voorzichtig mortieren om de bodemaggregaten te breken, en terug over 2mm zeven tot alle bodem door de zeef is gegaan. Steentjes groter dan 2mm en plantenresten/wortels langer dan 2mm die op de zeef blijven worden bewaard in een goed gelabeld afgesloten zakje of potje.
20'	Het gedroogde staal wordt vervolgens gebroken en gezeefd over een zeef van 2mm. Wat van bodem niet onmiddellijk door de zeef gaat, even voorzichtig mortieren om de bodemaggregaten te breken, en terug over 2mm zeven tot alle bodem door de zeef is gegaan. Steentjes groter dan 2mm en duidelijk identificeerbare verse plantenresten/wortels langer dan 2mm die op de zeef blijven worden bewaard in een goed gelabeld afgesloten zakje of potje. Veen, houtskool, black carbon dat eveneens op de zeef blijft liggen wordt gescheiden van verse plantenresten/wortels op de zeef en verkleind. . Na verkleinen (hard crushen, snijden of knippen) wordt deze koolstofrijke fractie gewogen en

	bij het bodemmateriaal gevoegd en in het labosysteem wordt duidelijk aangegeven dat laboranten het staal extra goed moeten opmengen voor analyse. Stalen die als volledig organisch worden beschouwd, gaan onmiddellijk naar de snijmolen (2mm).

21	Het staal kleiner dan 2 mm wordt verder opgesplitst in deelmonsters voor (i) analyse in het labo (minimaal 100g) en (ii) archivering. Hiervoor wordt gebruik gemaakt van een **statische spleetverdeler**. Hierbij wordt het gedroogde bodemstaal verdeeld in twee even grote deelmonsters door het te spreiden over een verdeler met voldoende spleten (minimaal 6). Eén van de twee deelmonsters wordt aan de kant gehouden, het andere deelmonster moet indien nodig opnieuw op dezelfde manier worden verdeeld totdat een deelmonster van de gewenste grootte bereikt wordt. 
22	Het deelmonster voor het labo wordt nogmaals onderverdeeld in **3 deelmonsters voor de bepaling van pH, TOC & TN en textuur.**
22	Indien de testportie of analyseportie voor TOC en TN analyse kleiner is dan 2 g, wordt conform ISO11464 het ganse deelmonster gemalen tot een deeltjesgrootte < 250 µm met een kogelmaalmolen. Daarbij wordt gedurende 2 x 1 minuut (2 draairichtingen) vermalen bij 400 toeren per minuut. Met deze instellingen is het staal voldoende verkleind (< 250 µm).

2.5.1.2 Staalvoorbereiding onverstoorde ringmonsters

23	De onverstoorde bodem van de ringmonsters wordt overgebracht in een recipiënt en gedroogd bij 105°C voor een periode van 48h (ISO 11272:2017 – core method). Na het drogen worden de aanwezige stenen (>2mm) uit het staal verwijderd. Indien de fractie stenen meer dan 2-3% bedraagt (op volumebasis) dient de fractie stenen gewogen en dient het volume ervan bepaald te worden.

2.5.2 Labo-methodes

De labo-analyses en de bepaling van de verschillende parameters verlopen volgens onderstaande ISO-normen.

- **TOC:** ISO 10694:1995 Soil quality – Determination of organic and total carbon after dry combustion (elementary analysis) – drogen bij 40°C – vochtrest altijd bepalen
- **TN:** ISO 13878:1998 Soil quality — Determination of total nitrogen content by dry combustion – drogen bij 40°C
- **pH-KCl**: ISO 10390:2005 Soil quality – Determination of pH
- **Bodemtextuur**: ISO 13320-1:1999 Particle size analysis – Laser diffraction methods – Part 1: General principles en ISO 13320:2009 Particle size analysis – Laser diffraction methods
- **Bodemdichtheid**: ISO 11272:2017 – Soil quality – Determination of dry bulk density (core method)

2.5.3 Archivering

Tussen de 400 en 500g ovengedroogd (40°C) en gezeefd (2mm) bodemstaal wordt overgebracht in een plastic recipiënt met goed sluitend deksel, beschermd tegen stof en licht, en correct gelabeld en bewaard in een geconditioneerd bodemarchief (donker, stabiele temperatuur, lage luchtvochtigheid).

3 PHASE III SUPPORT WITH CONTROL AND PROCESSING OF MEASUREMENT DATA

3.1 CONTROL AND PROCESSING OF MEASUREMENT DATA

The actual execution of the baseline measurement was foreseen to be started during Phase III (M18-36) of the applied science project OMG/VPO/BODEM/TWOL/2017/1. Several actions as foreseen in the original tender could not be initiated because actual monitoring was delayed. Some general remarks on the originally foreseen actions in phase III are presented in this section.

3.1.2 Feedback on sampling protocols

Based on their experiences with execution of the zero survey the grid manager and field workers would have been able to provide first feedback to further adjust site sampling protocols. At time of writing the start-up of C-monitoring in Flanders has not been decided yet. Nevertheless, during the parallel C-Gar study already 132 sites in residential areas had been sampled for their 0-1m SOC stock, by the current project consortium. In dialogue with the C-Gar steering group this resulted in practically robust sampling protocols – presented in 2.4. The project consortium can in the future still further provide advice, should there be a need for their further optimization of sampling protocols.

3.1.3 Statistical tests on measurement data

In case of operationalisation during Phase III, a first step would have consisted of deriving distribution functions for SOC stocks and performing statistical tests to compare means between the discerned land-uses and explore changes in time. Obviously the C-MON design in fact assumes paired sampling after at least 10 years but it would be interesting to already during the zero survey explore temporal trends in SOC stocks.

As described under Phase II, site sampling will be phased, due to practical feasibility constraints. Such tiered sampling has the major advantage that a first analysis of SOC stock changes can already be made from the second monitoring year onwards. From the C-Gar study it was however clear that SOC concentration and apparent bulk density can be expected to be non-normally distributed. For selected subcategories of residential land use, log-transformation proved useful to normalize the data, but not always. Moreover, often the variance of independent groups differed as well so that the condition of homoscedasticity was not met. As a result, it is likely that for the initial surveying years it will be necessary to compare SOC stocks among years and strata with non-parametric statistical tests. The larger number of observations in a fully-fledged monitoring network will later on ensure that violation of these conditions will no longer impede the use of parametric statistical analysis as such.

For the first monitoring years comparison of SOC stocks would need to be done by means of an independent samples t-test or by means of ANOVA or non-parametric analogues: the sampled sites between the years would not be paired. Because of slow changes in SOC stocks and the only limited number of measured SOC stocks after the first survey years (e.g. for grassland just 40 SOC stock measurements are foreseen per year) it seems likely that significant changes in SOC stocks will not be detected yet. It will then be relevant to know the power of the statistical test used for comparison of means. Such information can be drawn from a post hoc power-analysis, i.e. in which the achieved statistical power is estimated based on the given significance level, sample size and effect size. In this way the decision to maintain the zero hypothesis (i.e. no change in SOC stock) can be properly nuanced.

3.1.4 Sampling locations

3.1.4.1 Spare locations

In Phase II measurement locations were set using GIS and GRTS. However, only at the start of the fieldwork will it become clear whether all measurement locations are usable. In practice, planned measuring points are sometimes not available for sampling after all (e.g. in case of refusal of an owner to his/her plot, due to recent land use change, permanent obstacles etc.). Based on experience in previous assignments, this number is thought to quickly rise above 10%. For the C-Gar project 32 gardens needed to be sampled. Because of a low response of private owners to a request to sample their garden the initial GRTS draw of 75 potential garden plots proved insufficient and had to be further expanded with 50 spare plots. Positive **response rates** for other subcategories of land take (verges, parks) were much better though.

To remediate loss of sampling sites, for each land-use and stratum parallel sets of spare measurement points were foreseen. For Cropland there were 2225 spare points; for Grassland 1323 spare points; for Forest 503 spare points; for Nature 405 spare points; for Residential land use 2824 spare points. Selection of these spare locations must be as per their GRTS-rank. E.g. if from the current selection of 486 selected forest sampling sites 48 would prove unavailable then Forest ranked sites 487-537 should be used as replacements.

3.1.4.2 Final screening of sampling sites

The sampling sites sets were produced using queries on recent geo-datasets in GIS. However, specific extra considerations remain for final selection of the sampling locations. For residential land-use extra pre-screening of the anticipated sampling sites will be required because it was not possible to perform final draws for different subcategories of residential land use using the VITO-Space model. Also for cropland and grassland an updating of the presented final selection may be required.

Gardens

To date no specific geo-dataset exists of private owned gardens (incl. from enterprises). For final selection of private owned gardens the following procedure, used in the C-Gar study, can be used:

1° The 'residential' GRTS draw is used as first step to randomly select points in Flanders that cannot be allocated to any of the other four land-uses.

2° Grid cells classified as recreational areas or public domain are excluded. The VITO space model defines such land-use by level 2 qualifiers 2-Park; 4-Golfterreinen; 6-Sportterreinen; 7-Campings; 8-Overige Recreatie.

3° Only remaining GRTS-points coinciding with VITO Space model level 2 value '12 - Residential' and selected other categories like 32 – 'Horeca', 37 – 'Zelfstandigen' , etc. are further considered.

4° Sampling a garden section inside a 10x10m GRTS cell would often lead to a very small area per garden section (e.g. the ornamental garden). Moreover it is well possible that for many 10x10m cells several private plots are located within the GRTS cell, which would make field sampling practically difficult. Selecting only GRTS-cells that are entirely within the perimeter of a single garden on the other hand would lead to a biased selection of larger parcels only. It was then during completion of C-Gar decided that for gardens not a 10x10m cell but the entire garden perimeter should be considered as test area. The private owned parcel containing the middle of the GRTS cell is selected by overlay of the GRB-Adp vector layer with in steps 1-3 derived GRTS garden raster.

5° The retained GRB polygon acts as a base surface for a second internal GRTS drawing. Only on site are the sampling sites (in ascending GRTS grade) assigned to a garden section. Non-sample locations (house, driveway, paths, ...) are ignored. There will be no distinguishing between different parts of the garden: lawn, hedges and ornamental garden parts are all sampled.

Figure 47 Combination of the GRB with the soil cover map appeared insufficient to determine the exact garden perimeter. An internal GRTS draw is carried out on the entire perimeter of the cadastral plot and is also used to set out random sampling points within the garden (taken from Sleutel et al., 2020).

6° Vegetable gardens are considered as separate stratum as per C-Gar's conclusions. Vegetable gardens could be sampled along if present in a parcel was selected for sampling of its lawn+ornamental garden. A total of 32 vegetable gardens is to be sampled and so yearly 2 or 3 vegetable gardens need to be sampled. To select these 2-3 gardens in an unbiased way the lowest possible GRTS-ranked garden sampling plots are taken for every particular year. A dedicated sampling scheme is used to assess the SOC stock in the vegetable garden i.e. with 16 samples taken only inside the vegetable garden.

The above presented methodology was used for the C-Gar study but was no definite decision was takes as to adopt this procedure for the entire C-MON zero survey. For instance the impact of not considering vegetable gardens separately would not hold a large impact on the achieved MDD and so practically it could equally be decided to considers any non-sealed part of a garden as potential sampling spot. Also, it should be noted that the dimensions of a cadastral parcel may change over time.

Verges

As explained in 2.1.6.2 random selection of GRTS-cells pre-classified as verges is impossible given that no 10x10m raster data layer exists with any potential verges of roads, waterways and railways. The current selection of potential sampling locations for verges was therefore pragmatically taken as all residential GRTS-cells which could not be assigned to neither 'Gardens' nor to 'Parcs & Recreational areas'. From the C-Gar study it is, however, clear that in doing so verges from roads outside of residential areas (e.g. motorways and large parts of railroads and waterways) are a priory excluded. Moreover, many verges from small roads (bikeways, earth roads) are still included, although as agreed upon with the C-Gar steering group they are not considered fit for the C-MON grid because of their small dimensions and because they do not qualify as 'manageable verges'. Specific procedures set out in the in the C-Gar study based on buffer operations with (rail)road maps, maps of waterways and selected VITO Space model level 1 qualifiers will need to be used to finally select the **53 foreseen sampling locations on verges**. Such exercise was, however, out of scope of this assignment. As with gardens, for each of these sampling locations a within-plot GRTS-draw will also be needed to ensure unbiased field sampling.

Grassland & Cropland

As 'Landbouwgebruikspercelen' polygon surfaces do not precisely match year by year, some thin elongated 'parcels' ended up in the derived 'permanent grassland' raster map used for the grassland GRTS draw (Figure 22). In a final visual check such 'misclassified' permanent grassland sampling plots would need to be ruled out. This might be done by setting an arbitrary minimum dimension of a valid 'permanent grassland'. Or otherwise, the occurrence of the grassland sampling point inside the most recent available 'Landbouwgebruikspercelen' map could be used as criterion. The same applies to croplands: the presence of the targeted sampling location inside a cropland will need to be verified by the most recently available 'Landbouwgebruikspercelen' map.

As a general rule it is important to use the geo-data closest to the time of soil sampling in order to obtain the lowest possible noise in the dataset. This implies that the characterisation of the points sampled in a given year is best done with the GIS data of the same year. With a foreseen 10-year period to sample all points such updating of the data in the produced .shp files for the various land-uses will be pertinent.

3.1.5 Quality control

At the moment it is not yet known which and how many institutions will be responsible for field sampling and lab analysis. Regular performance of a ring test will guarantee that all measurements are reliable. During operationalizing following questions still need to be addressed: which samples (e.g. from which strata) are used for quality control? Quality assessment of the field work (standardised sampling) in combination with quality assessment in the lab. What is an acceptable deviation between field surveys and between labs (in terms of repeatability and reproducibility)? In this context, Wouters et al (2008a) formulated recommendations for evaluating the measuring network itself:

1. By independent experts via a formal audit -> thorough but time and money consuming

2. By publishing results in scientific journals -> much cheaper than an audit, but data is analysed in greater depth, making the scope and any shortcomings in the data set clearer. However, this may only be a partial aspect of the monitoring network.

3. By making data available to research institutions -> researchers 'automatically' critically examine the data and signal bottlenecks to the monitoring network manager.

The C-Mon parties can in future advise on a 'peer review' procedure and interpret any criticism together with the commissioning party.

3.2 MONITORING SCENARIOS

3.2.2 Number of sampling locations

Wouters et al. (2008a) stated: "*During the start-up phase of a monitoring network, the network designer makes a number of assumptions that are necessary, for example, to calculate the required sample size. These assumptions will not always correspond sufficiently with the final measurements. As a result, the original calculations of the sample size may no longer fully apply (overestimation or underestimation). This obviously has consequences for the results of the monitoring network. It is the task of the monitoring network operator to check, at predetermined evaluation moments, whether an adjustment of the monitoring network is necessary*". We accordingly give some reflections on necessity for re-evaluation of the proposed monitoring design:

The allocation of numbers of measuring points over different strata (1.6 and 2.1) was based on assumptions based on currently available but partly dated SOC data. During execution of the present project for example already 3x required numbers of sampling locations per stratum were recalculated as 'improved' figures on SOC stock variation and areas of strata became available. If variation on SOC stock data deviates significantly from initial expectations, this will have implications for the number of points to be further sampled. In particular the variability of SOC stocks in 'Nature' is poorly known. Due to the at present large assumed variability of soil OC stocks under 'Nature', the optimization algorithm allocated a disproportionally large number of sampling points to this land use. The current MDD and required number of sampling sites for 'Nature' may thus well prove optimistic or pessimistic. This will only become clear when the actual zero sampling starts. When optimistic, then a relocation of sampling locations to other land-uses should be considered: at present the density per unit area is about 4.5 fold in nature compared to cropland (1 site per 680 ha cropland vs. 1 site per 154 ha 'nature'). **The survey design allows such relocation during 2021-2031, and this flexibility results from the phased sampling over several years, with in any year an unbiased sample guaranteed for all individual strata.**

Calculations to optimize allocation of sampling sites to various strata were based on 0-30cm SOC stock data due to lacking data for deeper layers. Hence it was assumed that variation of the 0-100cm SOC stock would correspond to that at 0-30cm. However, in the C-Gar study (Sleutel et al., 2020) it was seen that the coefficient of variation on the OC stock in soils under residential land-use increased with the size of the intended depth interval: s/m was 0.35, 0.38 and 0.44 for 0-30cm, 0-60cm and 0-100cm, respectively. We do not expect the same picture for SOC stocks under cropland though, as then usually a relatively smaller part of the SOC is at 60-100cm. But actually at this stage we may only speculate how the coefficient of variation for 0-30cm and 0-100cm OC stocks relate in cropland and the other land uses. Incoming measured SOC stocks after the first years of the zero survey will allow a more reliable re-evaluation of the overall survey design.

3.2.3 Sampling depth / soil density

We strongly recommend to measure **SOC concentrations** in all cases up to 1m depth at least during the zero survey. This allows to detect changes in SOC stock at changing land use of measurement points and facilitates comparability of SOC stock estimates between different soil/land uses. First measurement results will show how variable SOC levels are in deeper soil layers within strata. Despite their low OC content, according to Rumpel and Kögel-Knabner (2011), the deeper soil layers contain more than half of the total BOC stock. Sleutel et al. (2011) came to similar conclusions. It was also decided: Depth extrapolation of the OC% by means of a pedotransfer function appears to introduce unacceptably large errors on the SOC stock, especially for arable land. For grassland there is a slightly better relationship between the OC% of the surface layer and deeper (>30cm) layers. However, re-sampling does not necessarily have to take place at this depth for all locations. If inner-stratum variation in SOC in deeper layers is limited, it can be decided not to take deep samples during re-sampling. From the C-Gar study it was clear that a considerable part of the 0-100cm SOC stocks is in the 30-100cm layer. The OC levels at 30-60cm and 60-100cm also differed within subcategory 'Parks and recreational areas' and 'Verges'. It was therefore deemed necessary to always carry out OC measurements up to 1m deep for the monitoring of residential land-use. In fact from 1.6 it became apparent that costs to sample OC at 60-100cm would not strongly lift total costs.

For soil **bulk density** the situation is different as its field measurement is far more labour intensive; for this reason also only at 4 locations per plot are undisturbed soil cores taken. If density in an underlying layer correlates well with soil density in the upper layer the precision of depth extrapolation can be evaluated. This can possibly lead to the recommendation to measure no/less soil densities under e.g. 60cm depth in a follow-up a resampling campaign. From the C-Gar study it was concluded that, at least for land take it would be possible to determine bulk density at only 0-10cm, 10-30cm and 30-60cm. The bulk density of the 60-100cm layer can be equated with that of the 30-60cm layer (no statistical difference). But it makes no sense to measure fewer samples at 30-60cm depth than at 0-10cm or 10-30cm, as BD was found equally variable at all depths.

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Part IV annexes

5 ANNEXES

Annex 1. Shapefiles with sampling site locations

Details on sampling sites for the five discerned land-uses are bundled in separate ESRI shape-files:

CMON_Cropland.shp

CMON_Grassland.shp

CMON_Forest.shp

CMON_Nature.shp

CMON_Residential.shp

Each file consists of following fields:

PlotID & PlotNR	unique identification code of the test surface from GRTS draw
c_LB72X & c_LB72Y	Lambert1972 X and Y coordinates
LUCMon	Overall Land-use category (1 Forest; 2 Nature; 3 Grassland; 4 Cropland; 5 Residential; 6 Sealed; 7 Water; 8 Unclassified)
GRTS_Rank	Ranking of the sampling location within the GRTS-draw
Nature_Ran, Forest_r…	Ranking of the sampling location within the specific GRTS-draw for the concerned land-use
sel	letter code indicating selection for the zero-survey. Rows with no value indicated represent spare sampling locations – see 2.2.1.
Bodemtype; Bodemser_C; Textuu_c; Drainage_c; Profontw_c	Soil type; soil series; textural symbol; drainage symbol; profile development symbol according to the digital soil map
niveau1_vl; niveau2_vl; niveau3_vl; niveau4_vl;	Land-use specified according to VITO Space model 2016 on 4 levels
DHMVIIDTMRAS25m	Elevation in m extracted from the DHM - Vlaanderen, raster, 25m geoTIFF 6.0 (.tif) file
BBKVl1	Code according to the ‘Bodembedekkingskaart Vlaanderen 2015 - 5m’
CAPAKEY	Key ‘kadastraal perceel’ (land registry parcel)
OPPERVL	Surface of the ‘kadastraal perceel’ as registered in GRB – Adp (in m^2)

Ancillary fields for separate shapefields are defined in 2.2.

Annex 2. Draft SURVEY FORM (Dutch)

C-MON: OPNAMEFORMULIER

ALGEMENE INFO PROEFVLAK

Identificatiecode van het proefvlak:		**Plaats (hoofdgemeente en/of toponiem):**
Landgebruik:		**GRTS rank:**
Datum:		**Beginuur:**
Staalnemer(s):		
GPS meetpunt en/of centrum coördinaten:		
	Latitude/LambY	Longitude/LambX
WGS84 Lambert72		
Beschrijving bereikbaarheid en ligging proefvlak:		
FotoIDs (minimaal één overzichtsfoto van het terrein en het proefvlak):		

TERREINKENMERKEN *(Omcirkel of vul aan)*

Landgebruik zoals verwacht?	ja/neen
Landbedekking (Teelt, Boomsoort, Vegetatietype,…)	…………………………………………………………………………………………
Weersomstandigheden tijdens monstername	Helder - Gedeeltelijk bewolkt - Bewolkt - Mist - Buien (wisselvallig) - Regen - Smeltende sneeuw - Sneeuw
Voorafgaande weersomstandigheden	Geen regen in afgelopen maand Geen regen in afgelopen week Regen maar zonder hevige buien afgelopen week Hevige regen - of sneeuwval afgelopen week Zeer natte periode of smelten van sneeuw
Bodemtoestand	Normaal - Waterverzadigd - Bevroren - Overstroomd - Uitgedroogd
Macroreliëf: Helling: Positie:	Vlak - Depressie (droog/nat) - Helling - Top - Plateau Convex - Lineair - Concaaf Onder - Midden - Boven

OBSERVATIE BODEMVERSTORING EN –BEHEER *(Omcirkel of vul aan)*

Bodemverstoring	Geen Betreding door de mens (omschrijf: …) Bodemverwonding (bv. plaggen, bosexploitatie,.....................................) Vergraving (bvb. greppels, ophoging,..) Natuurlijke verstoring (bv. windworp, vossenburcht, ligplaats reeën, woelactiviteit van everzwijnen,……………………………………………….) Erosie (tekenen runoff, geultjes, ravijnen) Afzetting sediment colluvium/alluvium Diepe insporing door berijding Vertrappeld door dieren (voederplaats, weide(door)gang,……………….) Recent geruimde bietenhoop Recent geruimde mesthoop
Beheer	Begrazing / Maaien / Mulchen Recent bewerkt, specificeer:……………………………………………….. Recent bemest, specifieer:………………………………………………… Recent bekalkt Andere, specifieer: ....

OBSERVATIES OP BODEMMONSTERS *(Kruis aan indien aanwezig of vul aan)*

	Strooisel/vilt	0-10cm	10-30cm	30-60cm	60-100cm
Matrixtype (M=mineraal, O=organisch, M&O)					
Reductie					
Grind (D<6cm)					
Stenen (D>6cm)					
Schelprestanten					
Houtskool, Black Carbon, Veen					
Baksteenfragmenten					
Compacte laag					
Artefacten *Indien ja, specifieer:*					
Dikte bouwvoor (cm)					
Diepte grondwater (cm)					

BIJKOMENDE INFO/OPMERKINGEN