Agricultural Residues in the Netherlands and Their Role in the Soil Carbon Cycle

Are Residues Available for Bioenergy?

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Summary

The current food production system is important for the surviving and thriving of mankind. It currently feeds and supports the livelihood of around 200 million people on this planet. Because of that, it is one of the core interests of study of the Intergovernmental Panel on Climate Change (IPCC). Moreover, it will be increasingly affected by projected future climate change. Through increasing temperatures, changing of precipitation rates, land degradation and increasing frequency of extreme events, climate change is effecting on food security. It is essential to maintain the land/soil quality of our agricultural land in order to protect food security. Soil Organic Matter (SOM) is one of the most important soil content that has the most widely recognized impact on soil quality (Doran and Parkin, 1996). SOM is one of the most important preconditions for soil formation as well as an essential element for the preservation of the soil fertility (Körschens, 2010).

One of the major sources of SOM in agricultural practice is returning the agricultural residues to the land. Therefore, although there have been talks about utilizing residues as a feedstock for second generation biofuel, it is essential, because of the reasons stated before, that these residues are going to be used to balance SOM. In this research, soil organic carbon (SOC) is used instead of SOM, with a SOC;SOM ratio at about 1:2. The Netherlands and its agricultural system is used as a case study.

This research aim to determine:
1)What is the amount of residues available in the country, and their organic carbon composition, from different agricultural practices and farm types? and
2) How much of the residues will need to be returned to the land in order to satisfy the need for maintaining a stable soil organic carbon level without compromising food productivity of the land?
A SOC balance model was made to answer these questions.

This leads to concluded that almost all the residues in the Netherlands are needed for keeping the balance of SOM in the soil, and the system as it is now is more or less self-contained. There is little to no residue left available as second generation biofuel feedstock. Although the model in this study has its short comings, but it provides a clear indication that a cautious approach should be taken when accessing the residue availability., and for specific regions and areas, the issue should be analysed individually and thoroughly.

List of Abbreviations

CBS - Central Bureau of Statistics of the Netherlands

CIVE - *Les Cultures Intermédiaires à Valorisation Énergétique (French)*; Intermediate Cropping with Enhanced Biomass Production for Energy Porpose

EOC - Effective Soil Orgainc Carbon

EOM - Effective Soil Organic Matter

EY – Exploitable Yield

ha – Hectare

HC - Humification Coefficient

HI - Harvest Index

LSK - *Landelijke Steekproef Kartering* (Dutch); National Sample Mapping

NOAA - National Oceanic and Atmospheric Administration

RDR- Relative Decomposition Rate

RSR - Root to Shoot Ratio

SOC - Soil Organic Carbon

SOM - Soil Organic Matter

TLA – Total Land Area

1. Introduction

1.1 General Introduction

The current food production system is important for the surviving and thriving of mankind. It currently feeds and supports the livelihood of around 200 million people on this planet (IPCC, 2019a). Because of that, it is one of the core interests of study of the Intergovernmental Panel on Climate Change (IPCC). Moreover, it will be increasingly affected by projected future climate change (IPCC, 2019a). Through increasing temperatures, changing of precipitation rates, land degradation and increasing frequency of extreme events, climate change is effecting on food security, (IPCC, 2019a).

Land degradation is one of the major threats to land quality, adversely occurs over a quarter of the Earth's ice free land mass (IPCC, 2019b). Agricultural lands in particular, have inherent severe ecological perturbations that are coursed by the conversion of native perennial vegetation to crops. They are most vulnerable to soil degradation that is exacerbated by, and as a result of, climate change (IPCC, 2019b). It is essential to maintain the land/soil quality of our agricultural land in order to protect food security.

Soil acts as a carbon stock in the form of soil organic carbon (SOC), and SOC is key to maintain land productivity by keeping soil structure intact (IPCC, 2019b). In turn, by preserving SOC levels of the agricultural land, not only the greenhouse gas (GHG) will be limited, but the productivity of the land will also be maintained, which is essential for food security.

1.2 Soil quality in relation to carbon

1.2.1 Soil Quality and Soil Organic Carbon

To the scientific world, as well as to the farmers, that soil quality and its function are essential for the productivity and the sustainability of the farming practices in a long run. Scientists use soil quality indicators to assess soil function/quality because soil functions/quality is often not able to be directly measured. Measuring soil quality is an exercise to identify soil properties that are responsive, influential, or related to environmental outcomes, and can be accurately measured under certain technical and economic constraints. Soil quality indicators can be qualitative (e.g., draining quickly or slowly) or quantitative (Nutrient N P K level etc.)(Doran and Parkin, 1996). There are three main types of soil indicators defined by Doran and Parkin (1996): chemical, physical and biological. The overall definition of soil quality is an attempt to integrate all three types of indicators but on one hand, typical soil tests focus only on chemical indicators. Historically speaking, chemical indicators such as nitrogen, phosphors and potassium have been a main focus of improving soil quality in Europe, and even up till now they are important for agriculture because they are required by plants at relatively large concentrations (El-Ramady et al, 2014).

Soil Organic Matter (SOM), on the other hand, transcends all of the three indicator categories and, has the most widely recognized impact on soil quality (Doran and Parkin, 1996). SOM is associated with all three categories of soil functions. It affects other indicators such as aggregation stability which is a physical indicator; nutrient retention and availability which is a chemical indicator; and nutrient cycling which is a biological indicator; also, it is itself an important indicator of soil quality (Doran and Parkin, 1996). SOM is one of the most important preconditions for soil formation as well as an essential element for the preservation of the soil fertility (Körschens, 2010). On the global scale, SOM plays an important role as a large carbon storage affecting the carbon balance (Conijn and Lesschen, 2015). SOM contains more than 3 times as much carbon, when compared with either the atmospheric carbon or the carbon stored by terrestrial vegetation (Schmidt, 2011).

SOM is the major source of Soil organic carbon (SOC). SOC refers only to the carbon component of organic compounds which is measurable. SOM is difficult to measure directly, so in practice laboratories and scientists tend to measure and report only SOC (Hoyle, 2013). In different researches, the ratio of SOC to SOM differs from 0.5 to 0.67 (Conijn and Lesschen, 2015; Jones et al., 2012; Hoyle, 2013).

1.2.2 Carbon Cycle and Soil Organic Carbon

Soil and plant organic carbon cycles, alongside with the atmospheric carbon cycle play an important role for the global carbon cycle and balance (Conijn and Lesschen, 2015), which in term is affecting the course of climate change (IPCC, 2019a). The anthropogenic carbon emission every year is “only” about 10% compared to the total amount of carbon that are cycling naturally in the system (Conijn and Lesschen, 2015). Any major change in this cycle can have rather dramatic effects in a long period on the atmospheric carbon concentration and balance (Conijn and Lesschen, 2015). Previous studies have suggested that 50% of the soil carbon is stored in the upper 30 cm of the soil where the other 50% is stored from 30 to 100 cm of the soil (Conijn and Lesschen, 2015; Mann, 1986).

In general, when any organic matter is applied to the soil, soil microbes start to decompose the matter, utilizing and transferring the carbon into the atmosphere and the soil, participating in the carbon cycle (Conijn and Lesschen, 2015). During this process, less stable carbon molecules will react and are emitted into the atmosphere as CO_2, while the more stable part will remain in the land (Conijn and Lesschen, 2015). **This contributes to the SOC stock of the soil and agricultural residues and slurries is one of the major carbon source on agricultural land hence they are required and important for maintaining the SOC balance of the land** (IPCC, 2019b; Conijn and Lesschen, 2015; Monforti et al., 2015).

There are, however, rising concerns regarding the reduction of SOM in the soil, not only in Europe, but also globally (Conijn and Lesschen, 2015; Griffin et al., 2013). Decreasing of SOM in certain areas is on the page of emergency for various stakeholders ranging from farmers to people working in biodiversity conservation (Conijn and Lesschen, 2015). Generally speaking, as mentioned before, SOM has a positive influence on soil quality in terms of soil fertility, and hence, plant productivity because when SOM decomposes, a variety of nutrients will be released (Conijn and Lesschen, 2015). Also, SOM in the soil acts as an agent that absorbs excess nutrients which will then prevent these nutrients from leaching into the water system and are lost from the soil (Conijn and Lesschen, 2015). SOM also improves the structure of soil, making soil more resistant to erosion, and have better infiltration when water is applied, as well as also acts as water storage with high water holding capacity (Conijn and Lesschen, 2015). Meanwhile, the decomposition of the SOM is a major source for the soil micro biota, which has an impact on the soil biodiversity as well as the quality of the soil (Conijn and Lesschen, 2015; Smith et al., 1998).

It is worth mentioning that the scientific world has not yet come up with a critical or an optimal SOM which could be indicated as a threshold (Conijn and Lesschen, 2015). Jones et al. (2012) reported 3.4% SOM, which is around 2.3% SOC, could be a threshold in which the soil will perform and function optimally, while others like Zwart et al. (2013) have a much lower value of 1.5% SOM. Conijn and Lesschen (2015) suggested a threshold of 1.5% SOC level which was concluded by utilizing different models and studies. Therefore Van Camp et al. (2004) conclude that it is simply not possible to define a single standard for every climate, soil type and soil use. However, as mentioned before, the losing and possible loss of SOM is one of the major threats regarding soil degradation, and has been one of the main threats to soils in Southern Europe (Van Camp et al, 2004). It has been reported that around 45% of the mineral soil in Europe has low SOM, even lower than the 3.5% SOM threshold proposed by Jones et al. (2012).

1.2.3 Carbon stock of Dutch agricultural land, and concerns

The agricultural environment and system is extremely dynamic in terms of diversity. As the interest of study, there are numbers of different soil types in the Netherlands, a huge proportion of the land in the Netherlands is dedicated to agriculture purposes, which includes arable land and grassland, as Figure 1 shows (Conijn and Lesschen, 2015).

Figure 1. Land use map of the Netherlands indicating grasslands, arable lands (cropland) and natural lands from year 2012 Others includes housing area, urban area and cities(Conijn and Lesschen, 2015)

The Landelijke Steekproef Kartering (LSK) was a national sample survey of soil map units (Finke et al., 2001; Finke, de Gruijter and Visschers, 2001), who have been studying different soil chemical parameters, including the SOM content of the soil for different soil types.

In the Netherlands, although the declining of SOM is not common in the country, there are areas (sandy soils with continuous maize) which could be considered as high risk areas (Hanegraaf et al., 2009; Reijneveld, Kuikman, and Oenema, 2010), and possibly some grassland fields. It is stated by Conijn and Lesschen (2015) that the status quo of the majority of the Dutch soil system is in a healthy situation, with the farming practice stays business as usual for croplands, but areas like dune sand areas are already below 1.5% SOC threshold, although in most of the clayey soil areas the balance is positive, the rest of the croplands are in negative which could be considered as risk (Conijn and Lesschen, 2015). In the current practice, sawdust and wood chips are constantly added to the slurry or directly to the land by the farmers (Wageningen UR Livestock Research, 2014). As for the grasslands, they are mostly on a positive balance (Conijn and Lesschen, 2015).

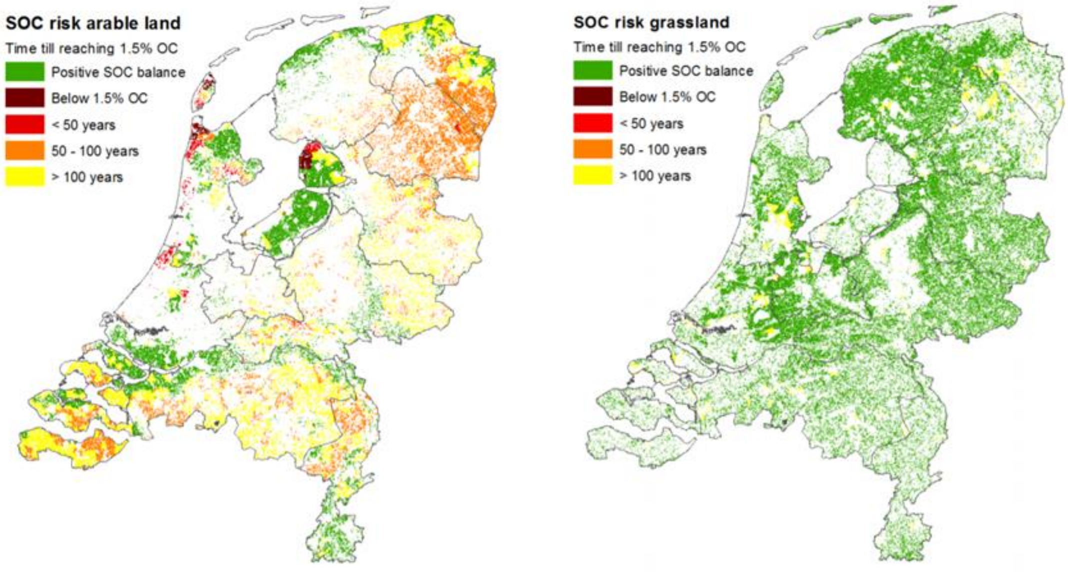

Figure 2. Soil Organic Carbon risked area in the Netherlands and the time of these places would take to pass 1.5% Organic Carbon threshold. (Conijn and Lesschen, 2015)

However, the stability of Dutch SOC over the years is just an overall representation of the situation nation-wide, and there will be a difference locally in different regions. Some regions of the country have a relatively poor soil quality in terms of SOC and the quality hence needs to be improved (Conijn and Lesschen, 2015). Also, for the coming decades, it is estimated that an overall 2.5% increase in productivity per year should be achieved to meet the demand of increasing population (Lal, 2005). Therefore it is essential to increase SOC, or to keep it at the historical level to say the least.

Historically farmers have been burning the residues after harvest and returning the ashes back into the ground in the effort of restoring carbon and nitrogen back into the soil. Although researches suggests that the difference in SOC would be minor by applying this method, other means and more advanced measurements could be taken in terms of treating the residue and restoring the carbon, like putting the crop residues back to the land directly, which is an utilization of agricultural residues in practice (Conijn and Lesschen, 2015). In cases of dairy farms, cow manure is often the form of the residue. Therefore it is crucial to use agricultural residues to fulfill the need of SOC of the soil (Monforti et al., 2015).

1.3 Agriculture and Energy

The idea of building a bio-based economy, mainly bioenergy, has been a hot topic in Europe and around the world for the past decade (van Hasselt, 2013). One of the most essential components of the bio-based economy which have received a huge attention in policy is biofuels (Vander Meulen et al., 2011). Biofuels are one of the main focuses of this field and one of the main products that can be made from biological resources, mainly agricultural products (McCormick, 2010).

The majority of the sources which are used to produce biofuels in the Netherlands are mainly from the agricultural sector, ranging from agricultural products such as energy crops, as well as the residues and residues of the agricultural activities such as leaves and straw (van Hasselt, 2013). Wood chips and natural fibres from forestry could also be used as sources for biofuels (van Hasselt, 2013). The scale of the agricultural sector in the Netherlands means there are likely more sources for biofuel.

Generally speaking, agriculture, grassland and horticulture combined together account for about two third of the surface land use in the Netherlands, and this sector generates an extensive export value of over 20 billion Euros on a yearly basis hence it is important for the country. Although the scale and the quantity of this sector are seemingly high enough, production is still increasing in volume. This growth is still slower than the past because of the policy reasons such as environmental regulations. Moreover, the number of farms is declining. While there is a trend in which farms are increasing in scale and size rapidly (Department of Agriculture, 2019).

Although being a sound idea, the fact is that implementation of dedicated biomass production for bioenergy purpose would increases the competition for land with food and could potentially pose serious consequences for food security and land degradation which are already under threat (IPCC, 2019b). That is true for first generation biofuels as they use agricultural products (most of them food products) as the feedstock of biofuels production. Therefore the second generation biofuels come in to the play with a significant importance as they do not use. Food crops as feedstocks. The majority of their feedstock came from residues from different sectors, including the agricultural sector. The only time the food crops can act as second generation biofuels is if they have already fulfilled their food purpose. For instance, waste vegetable oil is a second generation biofuels because it has already been used and is no longer fit for human consumption. Virgin vegetable oil, however, would be a first generation biofuel. **The process of making the residues into biofuels is that the carbon content of that residue will end up in the biofuel, and therefore compromise the amount of the carbon which would otherwise be returned back to the land.**

1.4 Research Questions

The energy sector considers that the agricultural residues for bioenergy are infinite and would not be used for other purposes. Based on what was discussed in the previous sections, this optimistic assumption of residues availability, regardless their other application, might results in potential depletion of soil organic carbon (Monforti et al., 2015).

The Netherlands is a country that agricultural production is essential to the country's economy, It was picked as case study for this assessment due to the data availability and the relative huge impact if the agricultural production is to be compromised due to the lack of enough carbon input, because the carbon sources are used for other purposes such as energy. Because of the scale and the scope of the research, the system boundary will be set to focus only on the soil organic carbon cycle using residues, in the representative environments of the Netherlands, therefore other cycles such as the nitrogen cycle, will be ignored in this study.

In this study, all the processes of residues should be done locally, and the process will be drastically simplified. The assumption is that no treatment of the residue is needed therefore carbon from the residue will be applied into the land naturally. The installation of the residue treatment facilities, as well as the transportation and actual treatment of the residues will be neglected.

This system will be analysed on an annual basis; other sources of production of carbon will not be take into consideration, if applicable. Such sources can include kitchen waste, municipal wastes, as well as industrial waste.

Therefore, **the research focus of this paper is to assess at the proportion of the residues in the Netherlands which would have to be returned back to the land, to satisfy the need to sustain a stable SOC level, or even to improve it.**

These following questions could be asked:

What is the amount of residues available in the country, and their organic carbon composition, from different agricultural practices and farm types?

How much of the residues will need to be returned to the land in order to satisfy the need for maintaining a stable soil organic carbon level without compromising food productivity of the land?

What are the other methods of increasing overall carbon production and how would these methods help in terms of maintaining/improving soil organic matter quality?

The answer to these questions could help identify whether the residues available in the agricultural sector could be even considered for second generation biofuel production in the Netherlands.

2. System Analysis

2.1 Dutch Farming system

2.1.1 General Information about the Dutch agricultural system

The Dutch agricultural system has been regarded as one of the best agricultural producers in the world, exporting a large amount of vegetables, fruit, flowers, meat and dairy products on an annual basis (Department of Agriculture, 2019; Statistics Netherlands, 2019a). The Netherlands in general have the second largest agricultural exports in the world just behind the United States (Holland Trade and Invest, 2018).

According to EuroStat (2008, 2013), as well as the Central Bureau of Statistics of the Netherlands (CBS), during the census of gathering land use information, it is normal to define the Dutch agricultural land usage into two basic systems according to the land-use difference, which are arable land and grassland (Statistics Netherlands, 2019b). Arable land refers to the growing of crops in the open, usually for industrial processing (Statistics Netherlands, 2019c), which undergoes the crop rotation and other advanced farming methods, normally on an annual basis (Lamers et al., 1986). The results of the rotation systems are often less fertilizer usage and higher yield potential (Nevens and Reheul, 2001). As for the grassland, the main uses of the grassland in the Netherlands usually serve as fresh forage (Statistics Netherlands, 2019d). In the Netherlands, although variations of livestock range from sheep to cattle, the majority of the livestock is indeed cattle (Statistics Netherlands, 2019e).

2.1.2 General Information about Croplands

There are dozens of crops and vegetables cultivated in the Netherlands, ranging from hemp to linseed (Statistics Netherlands, 2019f). According to the CBS, the top three major products in the Netherlands are wheat, potatoes, and sugar beets (Statistics Netherlands, 2019f; 2019g). This data also provides the information about annual gross yield of each crop.

As the description by the CBS stated, the land area data about harvested crops were categorised into two different types, area under cultivation and harvested area (Statistics Netherlands, 2019h). Harvested area means in principle it should equal to the area under cultivation. However, based on information from experts on expected crop failure, it is possible to make estimations of area that probably will not be harvested. When this is the case the harvested area will be smaller than the cultivated area. The figures in the table are based on already harvested areas and areas expected to be harvested later on. These are the areas which production has taken place effectively. Due to circumstances (for example flooding), this (surface) area can be smaller than the original (surface) area used for cultivation (Statistics Netherlands, 2019h).

Wheat:

Includes spring wheat and winter wheat. Grass of the genus *Triticum*.

Potatoes:

Includes ware, seed and starch potatoes. Plant of *S. tuberosum.*

Sugar Beets:

Root of a variant of the plant *Beta vulgaris,* which contains a lot of sugar.

The productivity of these crops during the past 10 years and their average is shown in table 1 (Statistics Netherlands, 2019h).

Table 1, total Dutch crop production yield for wheat, potato and sugar beets in past 10 years, with an average (Source: Statistics Netherlands, 2019h).

	Crop Production		
	Total Wheat	**Total Potato**	**Total Sugar Beets**
Year	**Gross yield per ha (1000kg)**		
2009	9.30	46.30	78.90
2010	8.90	43.60	74.80
2011	7.80	46.10	79.90
2012	8.60	45.20	78.90
2013	8.70	42.20	78.20
2014	9.20	45.70	90.80
2015	9.10	42.70	83.30
2016	8.00	42.00	77.80
2017	9.10	46.00	93.30
2018	8.80	36.60	76.40
Average	8.75	43.64	81.23

Wheat

Table 1 show that productivity of the wheat crop is changing during the years. The highest productivity appeared in year 2009 with a gross yield per hectare of 9.3 per year, and the lowest at year 2011 with a gross yield per hectare of 7.8 per hectare per year. This is maybe because of the variation of rainfall and other climate conditions differs year to year (Seiler, Kogan and Guo, 2000).

Potato

It is clear that, the gross yield per ha of potato varies from year to year, same as the wheat plant. The highest of the gross yield per ha was in year 2010, which has 46.3 tonnes of gross yield per ha, and the lowest being year 2018 with only 36.6 tonnes of gross yield per ha. Although this can be considered an anomaly as year 2018 is one of the driest years for Europe and the Netherlands (NOAA, 2018), and therefore the potato production was smaller than usual. Therefore, year 2016 with the gross yield of 42.0 tonnes per ha is the more reasonable representative of the lowest productivity of potato.

Sugar beets

The highest productivity for sugar beet is in year 2014 with 90.8 tonnes per hectare, and the lowest is in year 2010 with a productivity of only 74.8 tonnes per hectare. The productivity of sugar beets varies a lot when compared with potato or wheat.

In the preliminary estimate the yield of cereals (wheat, barley, oats, rye and triticale) are defined as the gross weight of the harvested grains. The definite estimate is the weight in the situation where each grain would contain 16 percent moisture (Statistics Netherlands, 2019h). Root plants gross weight is normally defined as harvested roots (Statistics Netherlands, 2019h). Potatoes normally have a moisture content of 80 percent when harvested (Nonhebel, 1995). Sugar beet has a moisture content of 77 percent (Nonhebel, 1995).

Normally in the Netherlands, in practice, a good crop rotation chosen gives maximum assurance that pests and diseases could not accumulate and grow rapidly, therefore the pesticides use would be as small as possible as well (Meijer, 2010). If a crop rotation system is to be designed with wheat, potato and sugar beet, a simple approach would be grow and rotate each crop on an annual basis.

2.1.3 General information about Grassland

The major product of grassland is actually grass, primarily for the feeding of cattle. This is especially true when the cattle and cows are in free range and roam around the land to get feed.

Table 2 shows the total size of the grassland in the Netherlands for the period 2009-2018, in which the total grassland includes pasture and meadows (Land with herbaceous forage crops, through cultivation (sown) or naturally (self-seeded), that has not been included in the crop rotation on the holding for at least 5 years), rough grazing (Land with herbaceous forage crops, through cultivation (sown) or naturally (self-seeded), with low yield (less than 5 tonnes of dry matter/ha) and unimproved by fertiliser, cultivation, reseeding or drainage for several years) and temporary grass (Crop rotation is the practice of growing different crops in the same area to avoid build-up of pathogens and depletion of soil nutrients. Land with herbaceous forage crops, through cultivation (sown) or naturally (self-seeded), that has not been included in the crop rotation on the holding for a maximum of five years) (Statistics Netherlands, 2019i). Overall the total land area of grassland has been decreasing over the past 10 years.

Table 2. Annual and average size of Specialist grazing livestock, mixed livestock holdings and mixed crops/livestock cattle farms on Grassland (Pasture and meadows, Rough Grazing and Temporary Grass) in the Netherlands in general. (Statistics Netherlands, 2019i)

	Grassland, total			
	Specialist grazing livestock	**Mixed livestock holdings**	**Mixed crops / livestock**	**Total**
Year	**Ha**			
2009	903,568.84	24,942.48	23,073.70	951,585.02
2010	883,993.98	23,017.87	22,341.16	929,353.01
2011	878,282.42	20,740.01	23,258.53	922,280.96
2012	879,520.32	18,107.70	21,845.92	919,473.94
2013	881,130.87	15,705.82	20,707.29	917,543.98
2014	894,210.47	14,998.57	20,077.75	929,286.79
2015	903,890.68	14,941.31	17,580.76	936,412.75
2016	879,463.24	14,478.69	17,294.38	911,236.31
2017	863,509.51	13,956.29	19,965.89	897,431.69
2018	832,798.25	13,675.62	19,594.39	866,068.26
Average	880,036.86	17,456.44	20,573.98	918,067.27

There were three different types of grazing land for cattle in the data provided by Statistic Netherlands, namely specialist grazing, mixed livestock holdings and mixed crops and livestock (Statistics Netherlands, 2019i). All these land types are used for the grazing and farming of cattle therefore should all be counted into the total land area used for cattle. Specialist grazing livestock, mixed livestock holdings and mixed crops/livestock are general farm types that are operated on the grassland, with a standing cattle population (Statistics Netherlands, 2019i).

Standing cattle population is also measured in the same manner and classification as the size of the grassland, as table 3 shows. It is clear that the cattle population during past 10 years have merely changed, the total number of cattle have been rather stable. However, there is a constant decreasing of cattle in mixed livestock holdings, and the number of cattle in specialist grazing livestock area has changed somewhat drastically, with a difference of nearly 400 thousand between pick and bottom.

Table 3. Annual and average cattle population in Specialist grazing livestock, mixed livestock holdings and mixed crops/livestock cattle farms on Grassland (Pasture and meadows, Rough Grazing and Temporary Grass) in the Netherlands in general. (Statistics Netherlands, 2019j)

	Grassland Cattle			
	Specialist grazing livestock	**Mixed livestock holdings**	**Mixed crops / livestock**	**Total**
Year	**individual**			
2009	3,672,513	130,615	87,040	3,890,168
2010	3,680,916	125,526	88,035	3,894,477
2011	3,614,232	110,899	83,808	3,808,939
2012	3,631,947	94,835	81,233	3,808,015
2013	3,761,555	88,896	74,614	3,925,065
2014	3,825,079	91,542	80,685	3,997,306
2015	3,886,161	96,219	82,849	4,065,229
2016	4,002,544	91,618	90,854	4,185,016
2017	3,843,765	90,141	100,635	4,034,541
2018	3,659,226	81,597	92,816	3,833,639
Average	3,757,794	100,189	86,257	3,944,240

The density of the cattle in general in the Netherlands is given by a dairy farm research. On average there are 108.7 cows on a 62.4 ha of farm land (Fokkert, 2014). This is only true for dairy farms.

On this grassland, there is in general, roughage growing as animal feed. The typical roughage in the Netherlands mainly consists of grass silage, hay, maize silage and meadow grass (Statistics Netherlands, 2012). According to Cornelissen et al. (2015), a typical Dutch Farm would have around net yield potential of 15.4 ton DM ha^{-1}/yr, when the conditions are optimal, as well as the lost during exporting of the animal feed and grazing loss. However it is not the case since environmental and soil conditions are different throughout different parts in the Netherlands (Cornelissen et al., 2015). Therefore it was stated that there are different categories of land condition, and they would have different yield (Cornelissen et al., 2015):

- G1: Grassland for cultivation of cow feed and thus with optimal conditions, estimated at 50% of total Land area (TLA) and a potential of 100% of exploitable yield (EY);
- G2: Grassland under fertilization restrictions, 12.5% TLA and 90% EY;
- G3: Grassland under drought limitations, 12.5% TLA and 80% of EY;
- G4: Grassland with poor drainage conditions, 12.5% TLA and 70% EY;
- G5: Grassland that serve other purposes next to agricultural production, 12.5% TLA and 60% EY.

Table 4 states the area proportion of different categories of land and their responding yield. It is concluded by Cornelissen et al. (2015) that all things considered, on average, Dutch grassland have an output of grass yield of 15.75 ton DM ha^{-1}/yr.

Table 4. Area proportion of different categories of land and their responding gross exploitable yield for different land types (G1 to G5) (Cornelissen et al., 2015)

Type	Land Area Proportion	Gross exploitable yeild (1000kg/ha)
G1	0.500	18.0
G2	0.125	16.2
G3	0.125	14.4
G4	0.125	12.6
G5	0.125	10.8
Total		15.75

2.1.4 Catch Crops

Catch crops, or in other words, cover crops are used for reducing nutrient leaching of the soil, transferring nitrogen to the next major crop, improving or maintaining the soil quality and structure and, sometimes contributing to the overall production of the biomass (Peltonen-Sainio et al., 2015). The mode of the catch cropping practice is largely dependent on the climate conditions and their respective aim (Peltonen-Sainio et al., 2015). As an example, the French CIVE (Les Cultures Intermédiaires à Valorisation Énergétique; Intermediate cropping with enhanced biomass production for energy porpose) scheme catch cropping program is specifically aiming at improving the biomass producing of the croplands (Marsac et al, 2018; Laboubee, 2018), and then utilize them for the production of biofuel. The reason of using this French scheme instead of a Dutch one is because of its dedication on using the catch crops for energy, and it is already in use at a certain scale, therefore the data is more realistic and can provide good information on energy catch cropping in the Netherlands, although there might be difference because of the agricultural environment differences between two countries. In this CIVE scheme, oat, triticale and barley are used as catch crops. They are grown in the winter period between major productions periods hence would not effect on the production of main crops. Table 5 provides the dry mass production of different crops at different harvesting times.

Table 5. The dry mass production of different catch crops (oat, triticale, barley and mixed) planted during winter, at different harvest times in year 2017 from the French CIVE scheme (Les Cultures Intermédiaires à Valorisation Énergétique) (Marsac et al, 2018; Laboubee, 2018).

	Harvest Date		
	20-Mar-17	**5-Apr-17**	**20-Apr-17**
	ton dry mass/ha		
Oat	3.17	4.90	7.92
Triticale	3.01	4.21	6.65
Barley	2.85	4.55	5.16
Mixed	1.37	3.01	5.05

2.2 Residues Availability

2.2.1 Residues from Croplands

During the harvesting period, not everything harvested is useful as effective yield, the waste materials such as straw which will eventually be residues are also harvested and calculated as the final gross yield. The residue fraction is normally calculated with the harvest index of the crop. The harvest Index (HI) is often defined as the yield of actual consumable products presented as the fraction of aboveground/underground total biomass production (the parts that has been harvested) on a dry matter basis. The harvest index gives insight of the proportion of residues to products (Nonhebel, 1995; Jing et al., 2016).

Because often HIs are measured in dry matter, it is important to understand the relationship between dry matter and the freshly harvested crops and products. This is where the moisture content comes into play. The moisture content indicates the ratio of water in the specific plant, their product as well as the residues of the product, which differs from plant to plant.

- Normal Residue

Wheat plants in general have a moisture content at harvest of 13.5% (Jing et al., 2016), with a HI of 0.46 (Conijn and Lesschen, 2015). The remainder/residue of the wheat is straw, which usually has a moisture content of 15% (Conijn and Lesschen, 2015).

Potatoes in general have a moisture content of around 82.5%, with a HI of 0.69 (Conijn and Lesschen, 2015). This moisture content can also be applied to the leaf and stems of potato. The residues are the leaves and stems of the potato (Nonhebel, 1995).

Sugar Beet has a leaf and stem moisture content of 79%, and the HI is 0.69 (Conijn and Lesschen, 2015). The residue products are leafs and tops of the sugar beets.

- Additional Residue

Because the harvest data and index only include what is aboveground, therefore what's left over in the soil was normally not accounted for (Jing et al., 2016; Nonhebel, 1995). This is especially true for wheat as the rooting system of wheat can be fairly large in size when compared with the whole plant (Palta, 2011).

The root to shoot ratio (RSR) is the index used to define the portion of the root and the rest of the plant mass. It can be expressed by using the following calculation:

Dry weight for roots/dry weight for top of plant = root/shoot ratio

The value of RSR could be used to determine the dry weight of the root when the weight of the aboveground harvest is determined (Fageria and Moreira, 2011).

Wheat

For the wheat plant, the RSR is normally ranging from 0.13 to 0.17 from the top 30cm of soil (Palta, 2011).

Potatoes

As for the potato, which is an underground product itself, there is no need of calculating the root to shoot ratio, because in farming practices people are essentially harvesting the root.

Sugar beets

The situation for sugar beets is the same as for potato.

2.2.2 Residues from Grasslands

Manure is the main product of grassland as the purpose of the grasslands in the Netherlands is often for cattle raising, the cattle are mainly dairy cow. There are housing periods and grazing periods for the cattle in the country, the cattle spend fair amount of time both indoors and outdoors. During the housing period the amount of manure can be calculated because it is removed on a regular basis. Manure production during grazing periods, is based entirely on estimations based on past experiences. For cattle it is estimated that manure production during the summer housing periods is 15 percent higher than during the grazing period since the 90s, as the amount of manure that ended up in the housing facilities during the grazing period would be counted in the housing period because of statistical reasons (Statistics Netherlands, 2012). In general, a dairy cow can produce a total amount of 26,000 kg of manure per year (Statistics Netherlands, 2012). The manure is in the form of slurry. Because this value is estimation rather than a real measurement, so the amount of manure produced is stable throughout the years with little to no change.

Because the animal feeds produced on grasslands will normally be fed to the animals, the left over parts can then be considered as residues. Therefore the amount of the grass and silage products that are fed to the animals can be used to estimate the grass products that would otherwise end up in the land or for other purposes. Table 6 is the total amount of grass products been fed to animals yearly. There is no clear pattern in terms of change during the decade from year 1999 to year 2008.

Table 6. Annual total amount of three major animal feeds in grassland that are fed to the animals measured in dry weight. (Statistics Netherlands, 2012)

	Total Amount fed to Animal			
	grass silage	grass hay	maize silage	Total
Year	mil kg dry weight per year			
1999	4,147.00	294.00	2,650.00	7091
2000	4,263.00	393.00	2,790.00	7446
2001	4,090.00	318.00	2,613.00	7021
2002	3,885.00	168.00	2,850.00	6903
2003	4,697.00	427.00	2,737.00	7861
2004	4,326.00	374.00	2,875.00	7575
2005	3,778.00	583.00	2,845.00	7206
2006	3,829.00	321.00	2,992.00	7142
2007	4,339.00	227.00	2,936.00	7502
2008	4,715.00	108.00	3,078.00	7901
Average				7364.8

2.3 Soil Organic Matter and Organic Carbon

2.3.1 Soil types and carbon stocks of the Netherlands

The soil type in general is important because the stock of different soil types differs, however for general review the land usage alone is enough. In the Netherlands there are varies of different soil type which have their own SOM content which differs for each soil type. This difference was taken into consideration and concluded by Conijn and Lesschen (2015) into as per land use type. Table 7 shows a detailed carbon content in C ha^{-1} of the top 30cm soil for different Dutch land uses, which only include arable land, grassland and natural land in 2001, and in this table, the amount of the carbon in soil is calculated by applying the portion of carbon (in %, mentioned before) to the total weight of the soil from top 30cm layer (Conijn and Lesschen, 2015; Finke, de Gruijter and Visschers, 2001).

Table 7. Soil organic carbon content (ton C ha^{-1}) and total amount (Mton C) in the top 30 cm per major land use type for the Netherlands in 2001. (Conijn and Lesschen, 2015)

Land use	Area (km^2)	ton C/ha	Mton C
Grassland	12229	123	150
Cropland	9379	94	88
Nature	4417	98	43
The Netherlands	26026	108	282

On average, Dutch soil has a carbon content of 108 ton C ha^{-1}, although different studies showed different numbers, because of the different parameters considered, as well as the differences in system boundary (Conijn and Lesschen, 2015).

2.3.2 Effective Soil Carbon, SOC Inflow, SOC Outflow and Carbon Availabilities of Residues

Effective Soil Carbon

As stated before, when any organic matter is applied to the soil, which is the main method of adding carbon artificially to the land, soil microbes start to decompose the matter, utilizing and transferring the carbon into the atmosphere and the soil (Conijn and Lesschen, 2015). During this process, less stable carbon molecules will react and are emitted into the atmosphere as CO^2, while the more stable part will remain in the land (Conijn and Lesschen, 2015). The part that has effectively remained in the land is called effective soil organic matter (EOM), and the fraction of this EOM is defined as the Humification Coefficient (HC) (Conijn and Lesschen, 2015). Effective Soil Organic Carbon (EOC) can be calculated from EOM, by taking a ratio. In the paper of Conijn and Lesschen (2015) the ratio is of EOC to EOM is 0.5. Table 8 shows the HC for general residues.

Table 8. Overview of Humification Coefficients of different residues from different sources

Source	Hendriks, 2011	Janssen, 2002	van Dijk et al., 2005	Velthof, 2004	INAGRO, 2011	Kolenbrander, 1969	Conijn and Lesschen, 2015	Bonten et al,2014	van Dijk, 1980
Crop residues (aboveground); green biomass		0.2				0.2			0.2
Sugarbeet (leaves+top)	0.22				0.22				
Cabbage	0.25				0.25				
Tree branches(Wood)								0.75	
Grass (leaves?)	0.25				0.26				
Green manure, incl. roots	0.3	0.3			0.3	0.25			0.25
Cereals (straw?)	0.31	0.35			0.31	0.35			0.35
Belowground crop residues	0.35	0.4			0.3	0.35			
Slurry	0.4							0.7	
Bovine slurry			0.7	0.45	0.4		0.47		
Pig slurry			0.33	0.3	0.4		0.42		
Poultry slurry			0.33	0.44	0.4		0.46		
Manure (stable?)	0.5		0.6		0.5	0.5			
Leaf residues		0.55							
Kitchen compost (Gft)	0.86	0.75	0.75	0.85	0.86		0.76		
Compost	0.91		0.5	0.8	0.91		0.42		
Green compost	0.96				0.95		1.06		

Table 8 shows that the HC values vary, for example the HC for bovine slurry varies from 0.7 to 0.4 from different studies. The categorization in table 10 has limitations, because some of the more common residues are not included, such as solid manure. The researches on this topic are relatively scarce and limited to mainly Dutch scholars with a certain tie to Wageningen University.

SOC Inflow

Studies have identified three major input flows of carbon into the soil (Conijn and Lesschen, 2015): 1) Crop and grass residues; 2) Animal manure; and 3) Compost. Figure 3 shows that the input of the grassland is different from the input of the arable land, in amount (Mton EOM y-1), as well as the categories, where there are more carbon put in the grassland and less carbon into the arable land (Conijn and Lesschen, 2015).

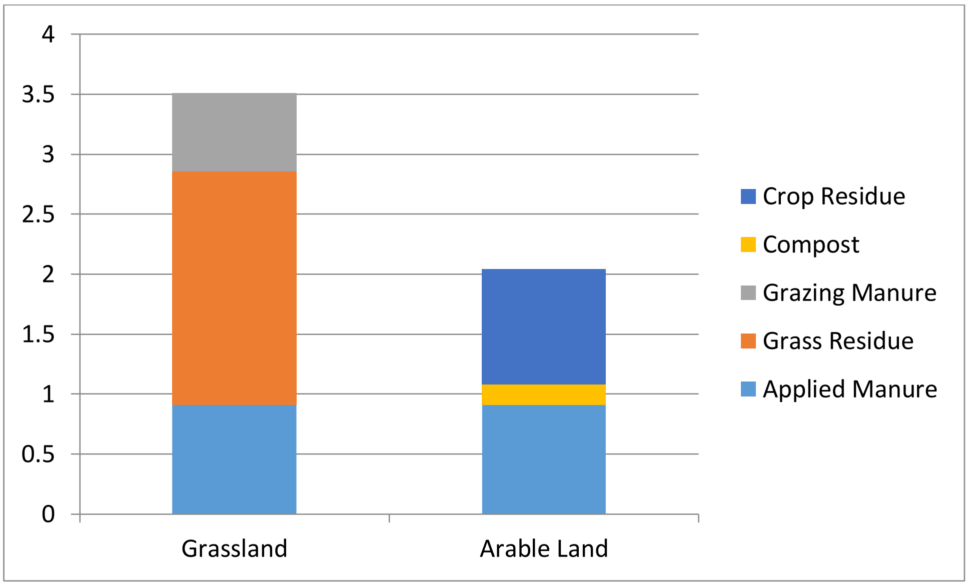

Figure 3. The effective organic matter (EOM) input (Mton EOM y^{-1}) of grassland and arable land from different sources, when applied manure is evenly distributed (Source: Conijn and Lesschen, 2015)

SOC Outflow

There are three main ways that Soil Organic Matter (SOM) gets lost throughout the years, which are 1) the respiration effect of the SOM in the soil, which is lost by been transformed to CO2, 2) SOM like any other nutrient in the soil, is lost by leaching, 3) SOM could also be lost by erosion (Conijn and Lesschen, 2015).

According to the work of Yang (1996), an equation to describe the decomposition of SOM as well as other organic materials was developed. Another tool that has been used by soil scientist regularly is the Roth-C model, which considers the carbon stock of the soil not as one universal stock, but rather as different stocks which would have different carbon integration and degradation processes, as well as interactions between different stocks (Coleman and Jenkinson, 1996). It is clear that to conclude from these two models, the rate of SOM loss is a relative rate, which is dependent on the size of the initial stock. A simplified losing rate was also developed for the Netherlands, accounting the different on land uses and soil types (Kolenbrander, 1969). The suggested rate is 2.0% on an annual basis (Conijn and Lesschen, 2015; Kolenbrander, G.J., 1969). In that research, the 2% is a national average for the Netherlands taking the soil type difference of the country into consideration. The SOM loss rate depends on the soil type and varies from 1.8% for sandy soil to 3.2% for clay soil. Also, in different studies, different methodologies and assumptions were applied which could also lead to a difference in the value, for example, when the depth of the soil accounted is different than top 30cm, there will be a difference (Conijn and Lesschen, 2015).

Carbon Availabilities of Residues

Crops

The carbon available from the crop and the residues can be determined by looking at the carbon content of the respecting parts. It is worth noting that the carbon content of all types of vegetation is rather constant across a wide variety of tissue types and species. The C content of biomass is almost always between 45 and 50% (by oven-dry mass) (Dyer et al., 2004). The term humidification coefficient is the fraction of the amount of the organic matter that has been converted to SOM after one year (Bonten, Elferink and Zwart , 2014), which accounts for all the organic input of all the residues and plants, therefore the carbon content of the plant should be calculated first. According to Penning de Vries (1983), Table 9 gives the carbon content of different plant parts for different types of crops.

Table 9. Carbon content in ratio to the total dry weight of different plant parts of different types of crops (Penning de Vries, 1983).

	Glucose	Carbon Fraction
Vegetative organs non-legminous and non-rice crops		
Leaves	1.463	0.461
Stems	1.513	0.408
Roots	1.444	0.406
Vegetative organs rice crops		
Leaves	1.326	0.408
Stems and roots	1.326	0.365
Vegetative organs leguminous crops		
Leaves	1.687	0.79
Stems	1.603	0.54
Roots	1.534	0.537

Manure

The water, nutrient and organic matter contents of manure varies greatly depending on the specific cases (Manitoba Agriculture, 2015). It was concluded by Manitoba Agriculture (2015) that fresh slurry with a water content of 73.1% would have a carbon proportion of 8.9%, which could provide an indication for the organic content in the slurry (Manitoba Agriculture, 2015; Larney et al., 2006).

2.3.3 Example Crop Rotation Scheme and Residue Return Rate

According to the hand book of soil and fertilization (Handboek Bodem Bemesting, 2019), soil organic matter is regarded as one of the important aspect of soil quality, hence needs to be maintained and intergraded into the normal crop rotation system during the farming practice. The hand book provided a rotation scheme and the corresponding effective organic matter input over 4 years as an example of a typical Dutch farming system, as Table 10 shows.

Table 10. A four year crop rotation scheme and the correspondent EOM input (Handboek Bodem Bemesting, 2019)

Year	Crops	Effective Orgainc Matter (kg/ha)
1	Potato	875
	20 ton/ha Pig Manure	280
		1155
2	Sugar Beat	1020
	Chicory Root	120
		1140
3	Wheat	1640
	20 ton/ha Pig Manure	280
	Black Spanish Radish	875
		2795
4	Onions	150
	Carrots	350
		500
	Total EOM for 4 years	5590
	Annual Average EOM	1400

To maximize the EOM input, it is suggested by the hand book of soil and fertilization (Handboek Bodem Bemesting, 2019) that, leaving the straw from the wheat results in an EOS supply of 2630 kg per ha instead of 1640 kg, or 990 kg per ha extra. On average over the four years that is almost 250 kg per hectare extra. The EOM supply then rises from 1400kg to 1650 kg per hectare per year. In addition, if a pig slurry donation is replaced by 40 tons of cattle slurry per ha, this results in an EOM supply of 1800 kg per ha instead of 280 kg. The EOM supply therefore increases by 1520 kg per ha. On average over the four years that is 380 kg per ha, or an increase from 1650 kg to 2030 kg EOM per ha per year.

2.3.4 Exploring Soil Organic Carbon Outflow Calculation

As mentioned before, there are varies means of calculating the SOC outflow rate. Although it was conclude that using an annual 2% outflow rate of the carbon stock is a more practical approach for the purpose of this paper, but it is also interesting to look into other methods of calculating this rate. In the practical soil carbon balance tool for farmers developed by the University of Wageningen as part of a Producschap Akkerbouw project, Kor et al. (2013) stated that the calculation of the decomposition of soil organic carbon in the Netherlands is based on an experimental study conducted by Wadman and De Haan (1997). In that research, Wadman and De Haan (1997) took 36 different soil samples from different soil types across the Netherlands and recorded their soil organic matter decomposition for 30 years, and in the end the records were compared with results of model. It was concluded by Wadman and De Haan (1997) that all three of the modelling methods they used were tested as valid for the purpose of imitating the decomposition of soil organic matter, and the work of Janssen (1984) is regarded as one of the most elegant one (Wadman and De Haan, 1997). This could be explored and discussed further as supplementary of the simpler on average 2% outflow rate which were regarded as valid by Conijn and Lesschen (2015). In the paper if Janssen (1984), there is a concept of 'apparent initial age' which is different for different types of soil, and it is important for the calculation of the organic carbon ratio. The number of 'apparent initial age' is always greater than 0 and could vary from 0.99 of green matter to 13.62 of a certain kind of peat (Jassen, 1984).

3. Method

3.1 General Information about the Calculation

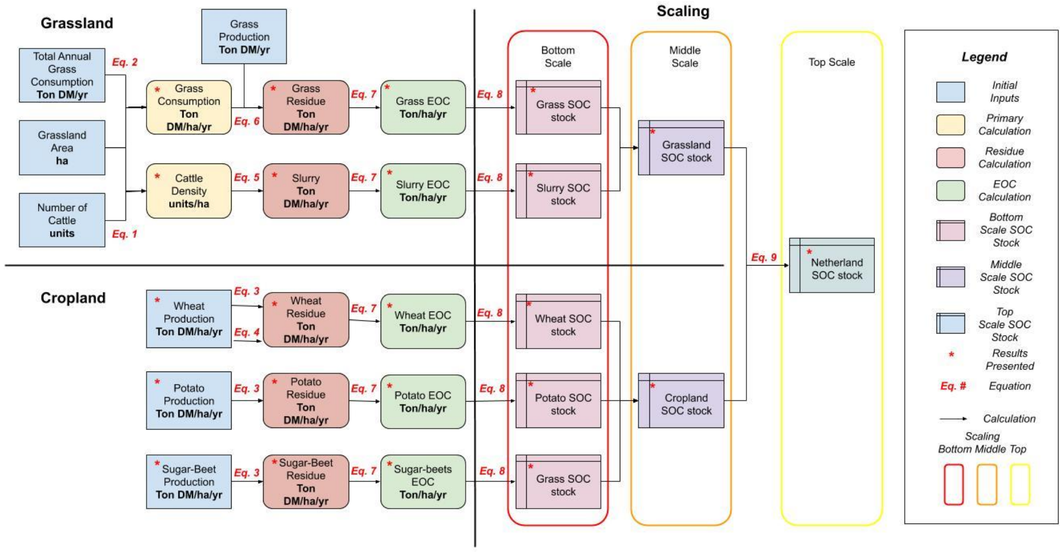

Figure 4. A scheme of the steps and calculations in this paper, where EOC stands for Effective Organic Carbon and SOC stands for Soil Organic Carbon. Agricultural productions are categorized into grassland which contains grass and slurry, and cropland which contains wheat, potato and sugar beets.

Figure 4 shows the basic setup of this paper. All the agricultural productions are categorised into two categories, grassland and cropland, depending on their characteristics. Then their production and corresponding residue are calculated. The effective organic carbon input are deducted from the amount of residue and then used as a carbon input to calculate with the corresponding stock size. Individual agricultural products are used to demonstrate the change of SOC at the bottom scale; these products are then combined according to their production place, grassland or cropland, again as the input to represent the middle level of the carbon stock; in the end grassland and cropland are integrated together to present the situation in the Netherland in general.

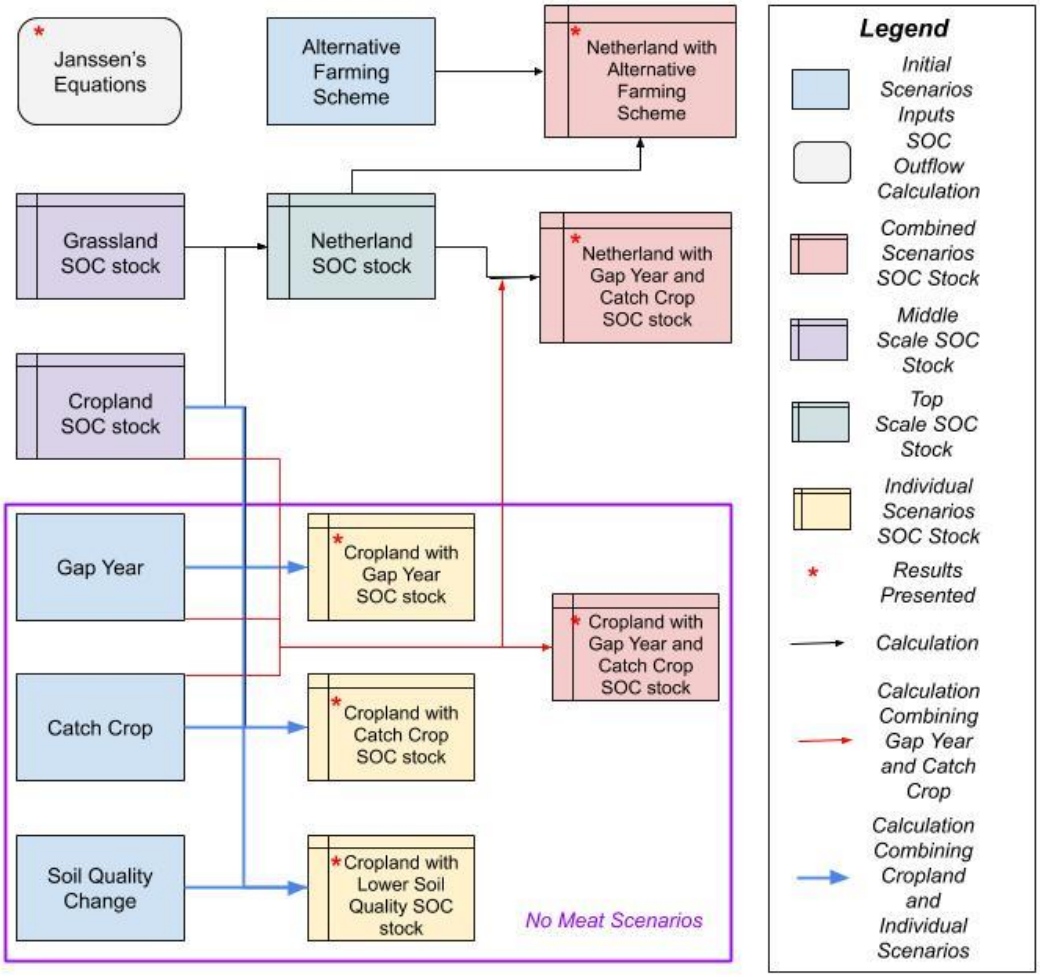

Figure 5. A scheme with all the scenarios assumed in this paper, the combination of these scenarios with each other, as well as their combination with the cropland and Netherlands results from the previous steps.

Figure 5 shows the later scenarios that are based on the calculations from the previous steps. Scenarios are calculated individually as well as in combination with cropland and Netherland SOC stocks. Also, another method of calculating the SOC outflow rate which is the Janssen's equation is also explored here.

3.2 Production Inventory

3.2.1 Gross yield of Crops

According to the CBS, the top three major products in the Netherlands are wheat, potatoes, and sugar beets (Statistics Netherlands, 2019f).This data (Statistics Netherlands, 2019f) also provides the information about annual gross yield of each crop. It is important to know the crop yield per ha in order to calculate the residue availability. To eliminate any extreme year with higher or lower production compare to normal years, the average of 10 years from year 2009 to 2018 will be used for the final result of Gross yield per hectare. Because of reason stated in the system analysis, for example, floods, can cause part of the crop to be left un-harvested. Therefore to determine an effective gross yield of each crop, the harvested area should be used instead of area under cultivation. This is also normally done by CBS (Statistics Netherlands, 2019f). This process will be repeated for wheat, sugar beets and potato.

3.2.2 Grassland Inventory

Density of cows

There were three different types of grazing land for cattle in the data provided by Statistic Netherlands, namely specialist grazing, mixed livestock holdings and mixed crops and livestock (Statistics Netherlands, 2019i). All these land types are used for the grazing and farming of cattle therefore should all be counted into the total land area used for cattle. The density of the cattle is calculated by dividing the land area by the cow population. The study calculated the average annual cattle density of 10 years over the period from year 2009 to 2018.

The density of the cattle (Density, Cattle) over 10 years in this study is calculated as follows (Statistics Netherlands, 2019e; 2019j):

$$Average\ Densit\ of\ Cattle\ over\ 10\ years = \left(\sum \frac{Number\ of\ Cattle\ on\ Farms}{Total\ Area\ of\ Grassland\ as\ Farm}_{year\ 1-10}\right)/10 \qquad \textbf{Eq 1 .}$$

Grass Production and Consumption

The amount of grass produced in dry weight is directly taken from the data mentioned before, which is around 15.75 ton DM ha^{-1}/yr (Cornelissen et al., 2015), and the annual amount of grass consumed as animal feed is around 7365,106 kg per year on average of 10 years (Statistics Netherlands, 2012), the size of the accounted grasslands is around 918,067 hectares of an average of 10 years (Statistics Netherlands, 2019i). The average grass consumption per land area over 10 years is calculated:

$$Average\ Grass\ Comsuption\ over\ 10\ years = \frac{Average\ annual\ Grass\ Consumption}{Average\ Total\ Area\ of\ Grassland\ as\ Farm} \qquad \textbf{Eq 2.}$$

3.3 Residue Calculation

3.3.1 General

When the residues are calculated, for wheat it is assumed that there is an aboveground part which is the part that has been calculated into the yield database, and there is also an underground part which will be calculated using other method because it is not shown in the yield database. As for potato and sugar beets, only the underground part is calculated because the harvest data already include the major residues like the roots and leaves. The residue production of grassland is only represented by slurry, because the slurry is the major residue product of the grassland and other the other residues like grazing grass is deducted from the calculation of the productivity of the grassland already (Cornelissen et al., 2015).

3.3.2 Cropland Residue

In order to determine the residues, the Harvest Index will be used to calculate the portion of the harvested crops which is consumable, and what are left will be the residues. In general, the plant is not completely dry when harvested at site The HI works on a dry matter basis, so that when the yield is calculated, the moisture content at harvest will be used to ensure that the harvest will be on a dry matter basis.

The residue can be then calculated utilizing the dry yield, which is determined by deducting the moisture of the crop from the gross yield:

$$\begin{aligned} &Normal\ Residue\ Yield \\ &\quad = [Gross\ Yield\ per\ ha\ \times (1 - Moisture\ Content\ at\ Harvest)] \\ &\quad \times (1 - Harvest\ Index) \end{aligned}$$

Eq. 3

Using this method, the general residue produced per ha for each crop can be calculated accordingly. This part is considered as the normal residues because they are deducted directly from the yield data, and requires no additional step.

Wheat

As for wheat, the moisture content at harvest is 0.135 and the HI for wheat in general is 0.46. This will determine the above ground residue for wheat as the HI and the gross yield data would only account for what is harvested aboveground.

Wheat has roots which will be left in the ground after harvest. Therefore root residues also contribute to the carbon input of the land. It becomes important to calculate the root that was left over in the ground. Root to shoot ratio (RSR) can be used to calculate the amount of root left in the ground. Because the RSR is determined by the ratios of dry weight of root and dry weight of the aboveground biomass of the plant, the dry weight of the root, i.e. the $Residue_{Additional}$, can be calculated by using the ratio:

$$Residue_{Additional} = RSR \times Gross\ Yeild$$ ***Eq 4.***

Wheat on average has a RSR of 0.15 (Palta, 2011).

The total amount of residue of wheat is the sum of the normal residue combined plus the additional residue underground.

Potato

The general method for normal residue applies, as the residues for potato can be calculated only using the yield data and there is no additional residue beside that. Potato has Moisture content at harvest of 0.825 and a HI of 0.69 (Nonhebel, 1995).

Sugar beets

Sugar beets will apply the same method as potato because it is underground crop as well. Sugar beets have Moisture content at harvest of 0.79 and a HI of 0.69 (Nonhebel, 1995).

3.3.4 Grassland Residue

Slurry

The estimation of the cattle manure will be based on the land area instead of the actual numbers of cattle in the country. However, because of the grazing nature of the farming practice, annual manure production by grazing animals is always very difficult to measure, because of a large number of grazing animals actually spend the summer season grazing in pasture.

There are no measurement data for the manure produced per animal during housing periods. Therefore, calculations of manure production per animal were based on the dry weight and nutrient content of ruminant slurry collected in during the housing period. For calculations of cattle manure volumes (excluding suckler, feedlot and grazing cows), slurry was always assumed, not taking solid manure production into account because that would be double counting as it has been counted as slurry in the dataset (Statistics Netherlands, 2012i).

One dairy cow can produce 26,000 kg of manure in the form of slurry per year, as mentioned before (Statistics Netherlands, 2012). There are around 4.3 cows per hectare of the accounted land (Statistics Netherlands, 2019j). It was concluded that the water content of slurry is around 0.739 (Manitoba Agriculture, 2015), therefore the dry residue per ha is calculated. The following equation can be used to calculate the annual dry slurry production per hectare, and the average of the cattle number is used, but the manure production is the same since it did not change (Statistics Netherlands, 2012) over the accounted years:

$$Dry\ Residue_{Slurry} = (Annual\ Slurry\ per\ Cattle\ \times No.of\ Cattle\ per\ ha_{average\ of\ 10\ years}) \times (1 - Moisture\ content)$$

Eq 5.

Grass

The amount of grass residue produced can be determined using the annual grass production as animal feed, as well as the annual grass consumption. Because both of these two data are in dry weight already, therefore the moisture content can be ignored. Calculate the amount of grass left as follows:

$$Annual\ Grass\ Residue\ = Annual\ Grass\ Producrion\ - Annual\ Grass\ Consumption$$ ***Eq 6.***

3.4 Carbon Availability from Residues

The nature of organic carbon in the soil is not stable, therefore the carbon containing molecules will degrade once left in the soil. The part which will remain after one year is determined by a ratio, which is called Humification Coefficient (HC), which gives the amount of organic carbon that's still left in the ground after one year. The part that has effectively remained in the land is called effective soil organic carbon (EOC). A general equation can be concluded for all kinds of residues:

$$EOC = Residue \times Humification\ Coefficient \times Carbon\ Ratio \qquad \textbf{\textit{Eq 7.}}$$

Wheat

Because the wheat crop has two types of residues which have their own different HC, so the calculation of the total EOM of wheat crop will be made separately with the above ground part (straw) have a HC of 0.33 on average and carbon ratio of 0.494. The root has a HC of 0.35 and a carbon ratio of 0.467 (Penning de Vries, 1983).

Potato

The residues of potato are mainly leaves and top of the potato plant, which have a HC of around 0.22 and carbon ratio of 0.459 (Penning de Vries, 1983).

Sugar beets

The residues of sugar beets are mainly leaves and top of the plant, similarly to potato which have a HC of around 0.22 and carbon ratio of 0.459 (Penning de Vries, 1983).

Slurry

The slurry of cattle would always contain a decent amount of water, which makes the remainder of that slurry the effective input of organic carbon. And the slurry has a HC of 0.4 and a carbon ratio of 0.089 (Manitoba Agriculture, 2015).

Grass

The grass in general has a HC of 0.25 and a carbon ratio of 0.459(Penning de Vries, 1983).

3.5 Calculation of the Carbon Stock

The calculation above has determined the possible annual input of organic carbon to an initial stock. The initial size of the stock is different for different land uses and soil types On average in the Netherlands the arable land has a stock of 94 ton/ha for the top 30cm, and the grassland has 123 ton/ha (Conijn and Lesschen, 2015). The national average is 108 ton/ha. The outflow of the carbon stock is estimated at around 2% on average of the original carbon stock, which will be different for different land type (Conijn and Lesschen, 2015). This number is used to determine the rate of carbon outflow because of the simplicity of the method is suitable for the general purpose of this research and the range 1.8% - 3.2% are used later in the sensitivity analysis. There are equations and method developed to better represent the real situation of the carbon outflow on an annual basis, as mentioned in system description.

This equation can be used to determine the stock size at the end of the first year cycle, and every following year will be applying a different initial stock size:

$$Stock\ at\ end\ of\ first\ year = Initial\ Stock + EOC\ Inflow - Initial\ Stock\ \times Annual\ Lost\ rate$$

$$Stock\ at\ end\ of\ following\ year = Stock\ of\ previous\ year + EOC\ Inflow - \ Stock\ of\ previous\ year \times Annual\ Lost\ rate$$

Eq 8.

The SOC stocks are going to be explored at different levels. First at the bottom level, all the single crops and product will be considered individually as independent systems; next at the middle level, cropland with a rotation system of wheat, potato and sugar beets, and grassland with slurry and grass residue would be considered together; At the top scale, grassland and cropland will be merged together to make a single system, namely Netherland, which is representative for the Dutch agricultural situation; a no-meat scenario would be add in considering a cropland only system with gap years between production years, then a cropland only system with catch cropping, also a cropland only system with lowered soil quality, and in the end a cropland system combining catch cropping and gap years; at last, an single system considering catch cropping and gap years would combined with the top scale Netherland system to explore the theoretical maximum carbon production from the land. Figure 6 is a representation of different scales and scenarios.

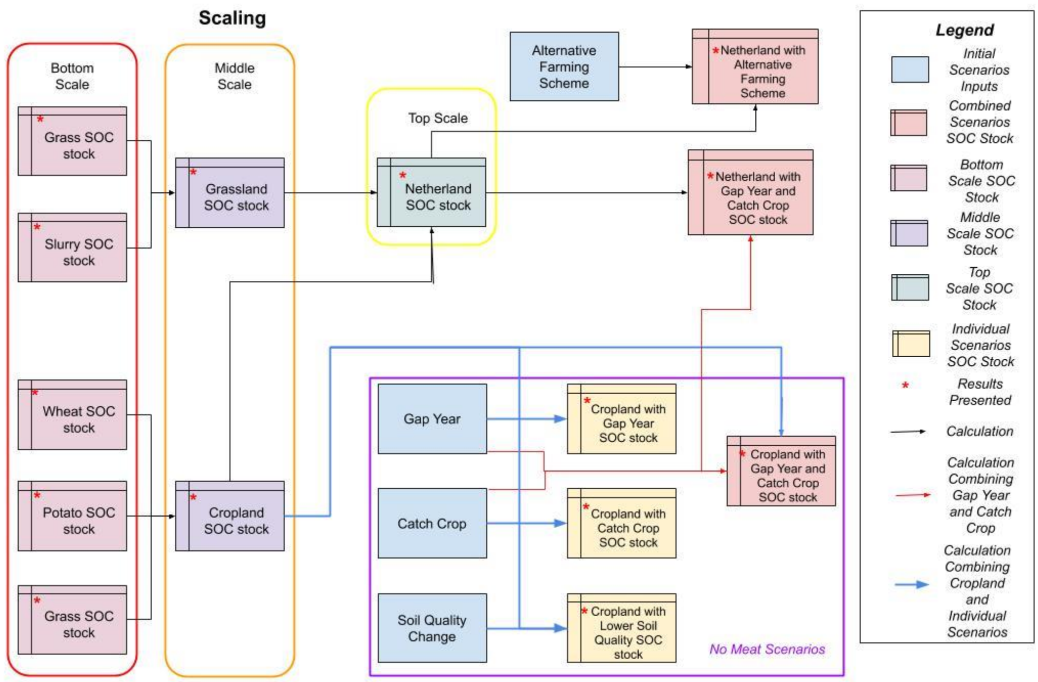

Figure 6. Design of different scales and scenarios of the carbon stock of different agricultural system.

The stock size in the scenarios are assumed unchanged except the inflows and outflow, excluding the erosion of the land and other possible effects which may lead to the change of carbon stock. Figure 7 is a overall representation of the system without any exact value. The exact starting stock size, inflow amount and outflow rate will be clearly stated later when the scenarios and scaling are talked in detail.

Figure 7. The carbon cycle system with the inflow and outflow, where only the Effective Organic Carbon (EOC) is considered in inflow, with the Soil Organic Carbon (SOC) as the stock and Carbon (C) loss which is a percentage of the SOC stock on annual basis.

3.5.1 Scaling

Bottom Scale

Firstly the individual products of both crop and grasslands will be considered individually, assuming the product of the system will only have one type. In general all the individual systems contain a stock of soil organic carbon, as well as the inflows and outflows, to complete as a carbon cycle within the small system. The only source of input will be determined by the land use and their respective crop/ residue type. Any other inflow therefore is neglected, and the input of the crop is stable across the years. The outflow of carbon is assumed to be at a constant rate of 2% annually. The stock is assumed to be 123 ton C/ha for grassland, and 94 ton C/ha for cropland (Conijn and Lesschen, 2015). Wheat, potato and sugar beets having the initial stock size of 94 ton C/ha which is general for croplands. Slurry and grass will have an initial stock size of 123 ton C/ha which is for grassland. The average of all kinds of land in the Netherlands is 108 ton C/ha. In general the Dutch SOC stock is large compare to other countries because of the amount of peat in the country and they contribute heavily in terms of SOC stock (Conijn and Lesschen, 2015).

The size of the stocks is then recorded as result to present and illustrate the effects of the inflows on the stock. The assessment will be made for 20 years period and during the cycles the record of the size of the stock will be presented as a result, as well as the final stock size relative to the initial size. **It would be obvious to conclude a decreasing/increasing trend by looking only at the first 20 years, and the trend will determine whether the SOC can reach a balance or not, therefore there is no point look into the results for longer period. This is also true for other scales.** Figure 8 is a visual representation of each product.

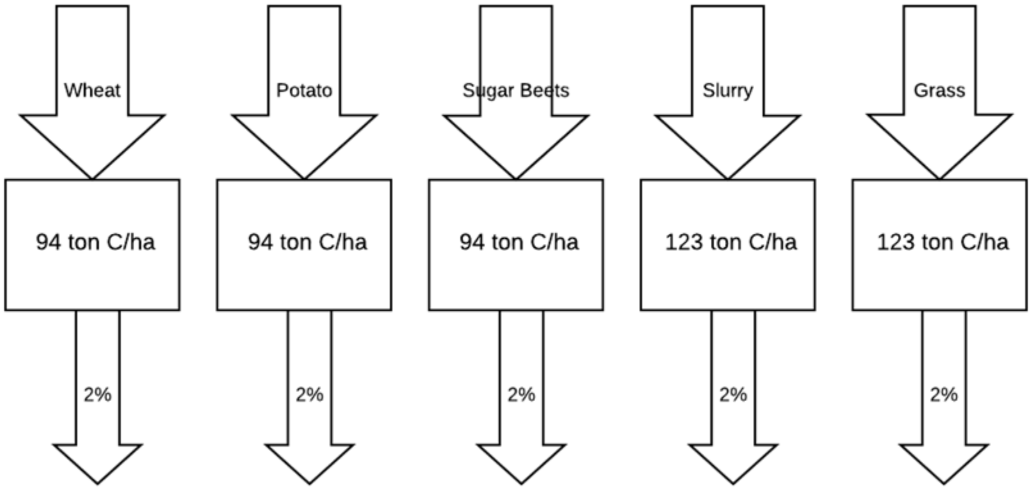

Figure 8. Bottom scale, individual residue types on their respective land.

Middle Scale - Cropland with Rotation and Grassland with All Residues

In this scale, a simple crop rotation of wheat, potato and sugar beets in three year of each crop in one year is assumed, to represent a general situation with crop rotation in the Netherlands. Initial stock size of 94 ton C/ha (Conijn and Lesschen, 2015) which is general for croplands will be used. The crop rotation, to avoid any complication, is represented by taking an average of three residue input for each year. The outflow will be 2% (Conijn and Lesschen, 2015). As for the grassland, because the land use for grass production and slurry production are not conflicting with each other, therefore the inflow will be a sum of grass and slurry. The outflow rate will be the same. The stock size of the grassland is 123 ton/ha (Conijn and Lesschen, 2015). Figure 9 is a representation of this middle scale.

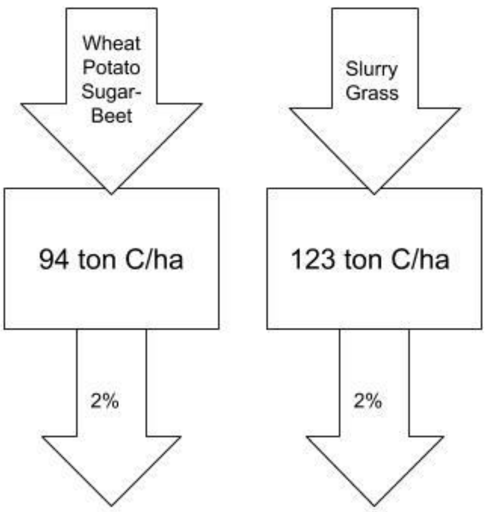

Figure 9. Middle scale, Including crop rotation as carbon input for cropland and slurry + grass input for grassland.

A sensitivity analysis will be performed by using the maximum and the minimum value of the values of outflow rate, 1.8% and 3.2% (Conijn and Lesschen, 2015), which are possible outflow rate for different soil types for more extreme situations. But these values are only used in the sensitivity analysis to show the possibilities with more extreme scenarios.

Top Scale - The Netherland System

This scale level will be built on the base of scenario 2 to include grassland in the mix. It is stated that in the Netherlands, there are 12,229 km^2 grassland and 9,379 km^2 cropland, so that the grassland covers 57% and the cropland 43% of the total agricultural land. This ratio will be applied to the residue inputs so that an overall input per hectare of the Netherland can be made. The following calculation is used to calculate the total annual Dutch residue inflow:

$$\begin{aligned} &Dutch\ Residue\ Inflow \\ &\qquad = \%\ of\ Grassland\ \times Grassland\ Inputs\ per\ ha + \%\ of\ Cropland \\ &\qquad \times Crops\ (avrage\ of\ three\ crops) Residue\ Inputs\ per\ ha \end{aligned}$$

Eq 9.

In this level, a Dutch average of 108 ton C/ha is used as the initial stock size (ref). Again, a constant 2% annual outflow is assumed. A sensitivity analysis will be performed by using two other different values of outflow rate, 1.8% and 3.2%, which are possible outflow rate for different soil types. Figure 10 is a representation of the top scale (Netherland System).

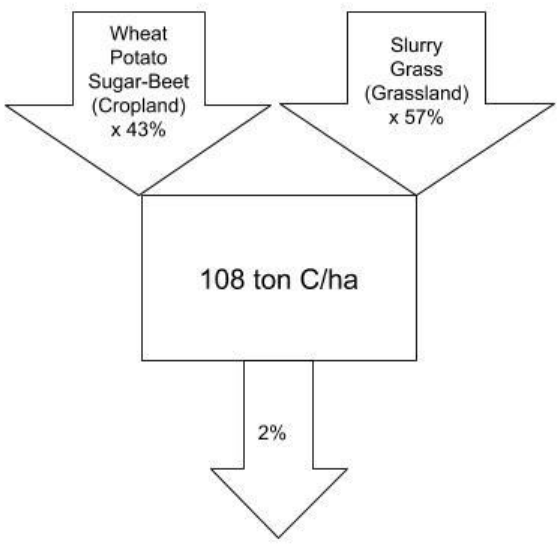

Figure 10. Top scale – the Netherlands, with relative residue input.

3.5.2 No-Meat Scenarios

There are ideas nowadays that the meat production and consumption is one of the worse branches of production in our agricultural sector (Hedenus, Wirsenius and Johansson, 2015). This is because of the relatively high requirement of water and other resources that are needed during the production of meat, also with higher pollutions (Tuomisto and Teixeira de Mattos, 2001). The water footprint of meat, especially beef is indeed high due to the water consumed during the production phase (Tuomisto and Teixeira de Mattos, 2001). Therefore food systems that are based purely on crops and vegetable have been promoted very often hence it is interesting to look into the system from a SOC balance perspective, to see if it is possible to balance a pure crop based agriculture system.

The goals of these scenarios are to explore the possibility of having only crops and plants in the system, different to the situation for the Netherlands, which have animal in the mix. This system should ideally be in a balanced soil organic carbon cycle without compromising too much on the quality of the soil, or the productivity of the soil. In other words, this means that the soil organic carbon should be balanced. Normally the change of crop rotation system itself would not have any significant effects on the soil carbon (Mogollón et al., 2005).

In these scenarios there are different approaches that are used in order to achieve the goal of a balanced soil carbon cycle, and all of them are running for around 200 cycles, in order to allow the carbon stock develop and reach a relatively stable level. The carbon stock is relatively stable after 200 years. The following approaches will be considered in this session: 1) introducing a 'gap year' between production years; 2) introducing a catch crop between the off-seasons of normal production; 3) lower the soil quality in order to achieve a lower carbon outflow; and 4) combination of 'gap year' and catch crop with the current cropland system.

'Gap year' between the production years

In this scenario, a 'gap year' will be introduced in between production years in order to make up for the carbon losses. During this gap year, although technically nothing will be grown artificially in the field, the nature will always take over. Therefore it is logical to assume that during this year, grass and shrubs will grow naturally in the field. The grass data from grassland can be used during this period. Because of the lack of fertilization and maintenance, under natural condition the productivity of the grass will be less than it is under cultivation, however in this scenario the assumption is the productivity of the gap year wild grass will be the same as normal year of grass production. Also it is assumed that all of the grass biomass will be put back to the land as green manure and not used for any other reasons. To calculate the EOC of the gap year, equation 7 can be used.

Catch crops between production seasons

Because the production of the primary crops would not take up the whole year, there are still gaps that can be used to grow catch crops between the primary production rounds, the biomass that are contributed by the catch crop can be considered and accounted as another source of input. Therefore in this scenario, a mixed catch cropping system proposed by the CIVE scheme (Marsac at al., 2018) is used, and this mix considers oats, barley and triticale as the catch crop. There are three major harvest times for the catch crop, the longer the cultivation time, the more biomass they will produce. In this scenario the assumption is that all the parts of the catch crop will be left on the land

and nothing will be taken for any other purpose. Also it is assumed that the catch crops are grown to the longest time so that the biomass output will be at maximum. The EOC of the catch crops can be calculated using equation 7, along with the catch cropping data proposed by CIVE program (Marsac at al., 2018).

Lower soil quality

The rate of the outflow of the carbon stock is directly related to the size of the carbon stock, therefore to achieve a lower outflow that could be sustained by the regular annual carbon input from a normal rotation pattern, the stock size needs to be smaller. The normal rotation pattern is a rotation on a three year basis where potato, wheat and sugar beets will be cultivated in each year. Different soil types generally have different carbon contents that would lead to a difference in the carbon stock, hence in this scenario, the soil type 'Kalkhoudende zandgrond' (calcareous sandy soil) is chosen and it has the lowest carbon stock at 52 ton/ha in the top 30cm layer of the soil. In relation to the change of the soil type, the rate of outflow which is dependent on the soil will be set at 1.8% yearly as this is the rate for sandy soil. 'Kalkloze zandgrond' (Lime-free sandy soil) with a carbon stock of 75 ton/ha with the same outflow rate of 1.8% will also be tested in this session (Conijn and Lesschen, 2015).

Combination of 'gap year' and catch crop with the current cropland system

The production of the catch crop and the concept of the 'gap year' would not affect each other, therefore they can be combined together in order to produce more biomass which could contribute to the organic carbon input. This idea will be tested in this scenario to minimize the 'gap year' because the 'gap years' would damage the overall output of food crops produced. In this scenario the mixed catch crop from the catch crop scenario will be used, with again 2 to 5 gap years.

3.5.5 Netherland System with Catch Cropping and Gap Years

It is essential to find the ideal system for the Netherlands, therefore this scenario is built by introducing the gap year and mixed catch cropping into the original Netherland System. Because the gap year and the catch cropping are only conducted in the cropland normally, therefore they will only be counted into the inflow of the cropland portion of the overall system, which is around 43% of the land, where the grassland will be around 57%. The inflow of carbon of the grassland will stay the same compared with the Dutch System mentioned before. The catch cropping would be applied to the croplands in the system every 2-5 production years, and then combined with the production of grassland which will not change.

3.6 Comparing different inflow and outflow methods

Alternative Farming Scheme with different SOC input

As mentioned before, the hand book of soil and fertilization (Handboek Bodem Bemesting, 2019) had a crop rotation scheme which provides an original 5590 kg of effective organic matter input over four years, or 1400 kg effective organic matter per year on average. This value could be increased to 8120 kg EOM per hectare over four years or 2030 kg per hectare per year when the scheme and the residue utilization are optimized and extra input was added (Handboek Bodem Bemesting, 2019). The original EOM, and the extra input EOM will be used as EOC input, by using the following equation:

$$EOC\ input = EOM\ input \times EOC\!: EOM \qquad \textbf{\textit{Eq 10.}}$$

Where the ratio of EOC:EOM is 0.5 (Conijn and Lesschen, 2015). And this input will then be integrated into a carbon stock model mentioned in figure 5, with a stock size of 94 ton/ha (Conijn and Lesschen, 2015). The result will be compared with the cropland scenario and the Dutch system scenario.

Janssen (1984) 's method of SOC outflow calculation

In the work of Janssen (1984), the soil organic matter as a percentage (y,%) of the soil can be calculated as:

$$y = 100\% \times Y/(Y+1) \qquad \textbf{\textit{Eq 11.}}$$

Where Y is the ratio of organic matter and the mineral soil (Janssen , 1984; Wadman and De Haan, 1997). Y can then be calculated using the following equation:

$$\mathrm{Y(t)} = Y(0) \times \exp(4.7 \times \left(\frac{1}{(a+t)^{0.6}} - \frac{1}{a^{0.6}}\right)) \qquad \textbf{\textit{Eq 12.}}$$

Y decreases as a function of time (t in years), and *a* is the value of a concept which is called 'apparent initial age', which is different between different soil types. The number of 'apparent initial age' is always greater than 0 and could vary from 0.99 of green matter to 13.62 of a certain kind of peat (Jassen, 1984).

After this process, the relative decomposition rate (RDR) of the soil organic matter can be calculated at a year *t* by using the following equation (Janssen , 1984; Wadman and De Haan, 1997):

$$\mathrm{RDR} = \log\left(\frac{y(t)}{y(t+1)}\right) \qquad \textbf{\textit{Eq 13.}}$$

A attempt of calculating this value will be made and then plotted against the RDR value of Wadman and De Haan (1997) 's work and see if the calculation can be reproduced. Table 14 is the RDR calculated by Wadman and De Haan (1997):

Table 14. Relative decomposition rate (RDR) as a function of time (t, year) (Wadman and De Haan, 1997)

Organic matter content at t = 0 (100% × g g^{-1})	RDR (yr^{-1})				
	t = 0	t = 4	t = 9	t = 19	t = 49
2	0.0365	0.0187	0.0087	0.0024	0.0002
4	0.0291	0.0160	0.0082	0.0031	0.0010
6	0.0248	0.0144	0.0080	0.0035	0.0015
10	0.0194	0.0125	0.0077	0.0040	0.0021
15	0.0151	0.0109	0.0075	0.0044	0.0026
20	0.0120	0.0098	0.0073	0.0046	0.0029

4. Results

4.1 Agricultural Product yield output

Table 15 shows the annual yield of all the products from both cropland and grasslands. The table shows the highest yield is potato with around 81.23 ton per hectare.

Table 15. The results of gross yield of crops taking as an average from year 2009 to 2018, as well as the average density of cattle dry grass production in the Netherlands.

Total wheat	Total potatoes	Total Sugarbeet	Total Grass	Cattle Density
	Gross Yield, ton/ha		Gross Yield, ton/ha (dry)	Cattle/ha
8.75	43.64	81.23	15.75	4.30

4.2 Residue Inventory (Dry)

Table 13 shows the amounts of crop residues. In this table the total dry residue for wheat is the sum of both residue and additional residue. Because of the large yield of sugar beets, although with a relatively high moisture level, it produces the most dried residue per hectare. Potato produces the least residue due to the highest moisture content. The grass residue is also higher than the residues produced on cropland. The residue for cropland is calculated using HI whereas for grassland the simple subtraction was used. The slurry, although with a rather high annual production per hectare, because of the effective content and the moisture level, the final dry residue is rather low as table 16 showed.

Table 16. The total dry residue for cropland (wheat, potato and sugar beet) and grassland (grass and slurry) with only wheat having additional underground residues from the roots and other residues don't have any additional residue.

Product	Residue (Normal)	Residue (underground)	Dry Residue Total
	ton/ha	ton/ha	ton/ha
Wheat	4.09	0.61	4.70
Potato	2.37	0.00	2.37
Sugar beet	5.29	0.00	5.29
Grass	7.73	0.00	7.73
Slurry	28.03	0.00	28.03

4.3 Effective Organic Carbon from Different Products

Total Effective Organic Carbon (EOC) for each crop, grass and slurry is calculated by applying Humification Coefficient (HC) to the dry residue. Each type of residue has different HC. In the end wheat produces the most EOC and potato produce the least EOC per hectare per year. The results are shown in table 17. Because of the relatively low carbon content of slurry, it have low total EOC in the end despite having relatively high residue. Potato has the lowest EOC because of the lowest reissue as well as the relatively low HC. Wheat has the highest EOC amongst crops.

Table 17. The final Effective Organic Carbon (EOC) input on an annual basis from different residue types.

	Total Residue	**Total EOC**
	ton/ha	**ton/ha**
Wheat	4.70	0.77
Potato	2.37	0.24
Sugar beets	5.29	0.53
Grass	7.73	0.89
Slurry	28	1.00

4.4 Results for Different Scales

Bottom Scale

It is clear that after 20 years, none of the crops or grassland would have same amount of organic carbon. In fact, the stock size of organic carbon of all the crops and grassland has decreased by a certain portion. The most drastic is potato as it has the least EOC inflow on a yearly basis. Only 75% of the carbon remains after 20 years. Wheat on the other hand, has 94% of carbon left, because of it has the highest EOC inflow every year. The results can be seen in figure 11 and 12. The declines shown in figure 8 are actually not straight lines, but are curving downwards indicating that the rate of the outflow is slowing down as the year passes. This is because the as the stock size is getting smaller, the outflow rate, as a function of the size of the stock, is getting smaller accordingly. None of the crops and products can reach a carbon balance because of the trend.

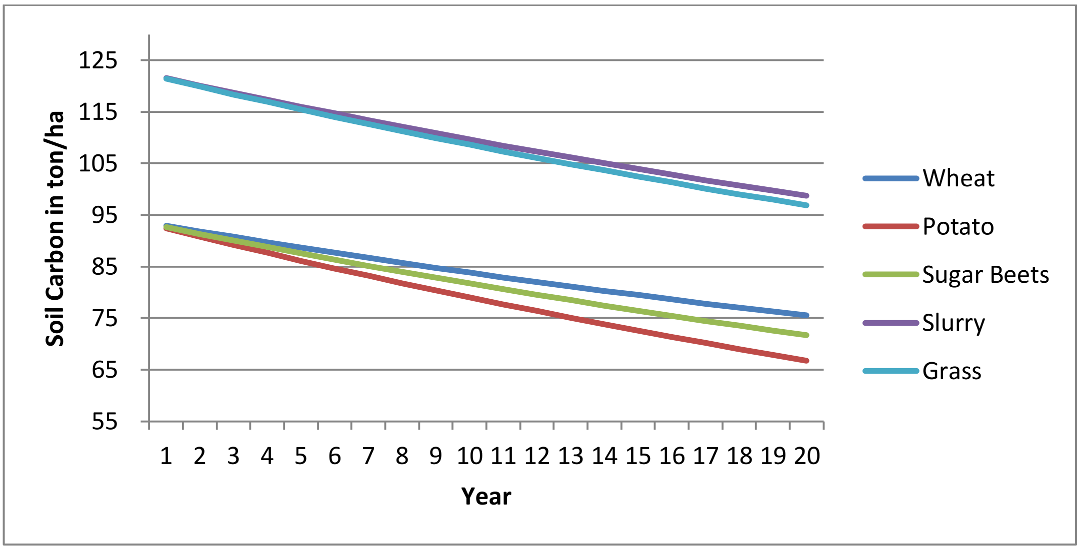

Figure 11. The change of carbon stock of the top 30cm of the soil for wheat, potato, sugar beets, grass and slurry over 20 years when all the residues are put back to the soil In the Netherlands (No rotation system with no additional input other than residues)

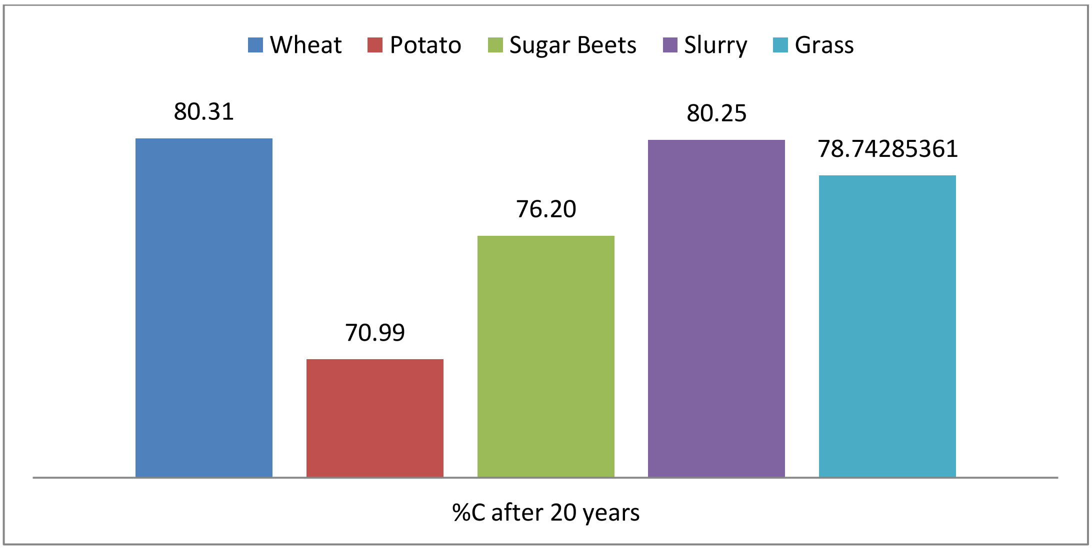

Figure 12. The percentage of carbon of the top 30cm of the soil which still remains after 20 years, compare to the initial stock size.

Middle Scale

In the middle scale, when the crop rotation is applied and the average of three crops were taken as the annual input, it is still not enough to make up for the annual loss of the carbon. Therefore in figure 13, a constant decline can be observed. In the end, 75% of the carbon still remains in the land compare to the initial carbon stock size as figure 13 shows when the lost rate is 2%. As for the grassland, it is almost enough for the grassland to maintain the carbon level, as figure 10 shows an almost flat line at 2% lost rate. As for sensitivity analysis, if the outflow rate is 1.8%, cropland will still lose SOC; same for grassland, after 20 years there will be 95% of the carbon left in the soil, which means there will be more carbon in the soil compared with cropland. If the outflow rate is 3.2%, both grassland and cropland SOC will decrease drastically. Again, in figure 13, the line is curved because of the outflow is getting smaller as time pass by.

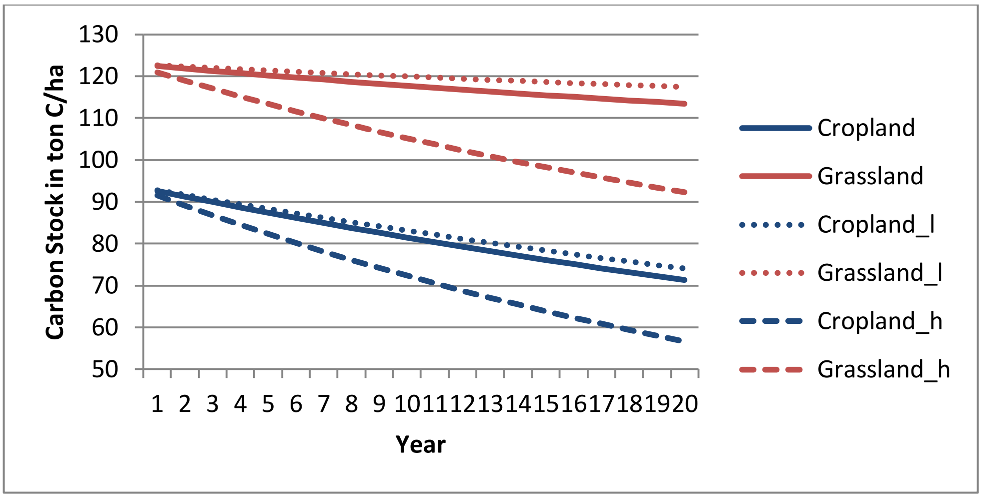

Figure 13. The change of carbon stock size for cropland and grassland after 20 years, with outflow rate set at 2.0%, sensitivity analysis of 1.8%(Cropland_l and Grassland_l), and 3.2%(Cropland_h and Grassland_h)

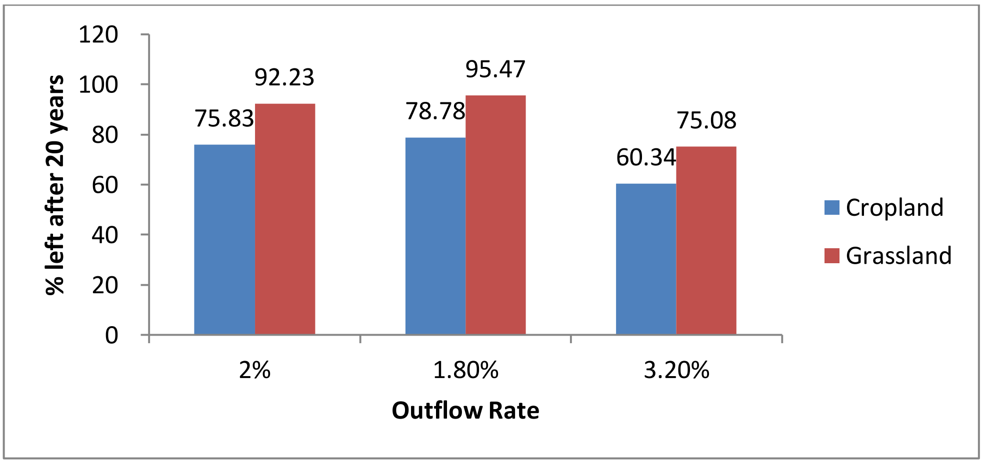

Figure 14. The percentage of carbon that still remains after 20 years for cropland and grassland, compare to the initial stock size, with outflow rate set at 2.0%, with outflow rate set at 2.0%, sensitivity analysis of 1.8%(Cropland_l and Grassland_l), and 3.2%(Cropland_h and Grassland_h).

Top Scale

At the national level the two land types are combined to be a representation of the Netherlands. The initial stock size is different using a Dutch national average, but the result is pretty much the same. Because none of the residue can have enough carbon to make up for the loss, therefore as shown in figure 15, the carbon stock size is still on decline. This is true for any outflow rate. As presented in figure 16, in the end of 20 year, the most idea situation would lose around 10.3% of the carbon. This is because in all outflow rates the cropland would lose carbon because of the low input, and the only exceeding carbon from grassland when outflow rate is set at 1.8% wouldn't be enough to compensate that lose.

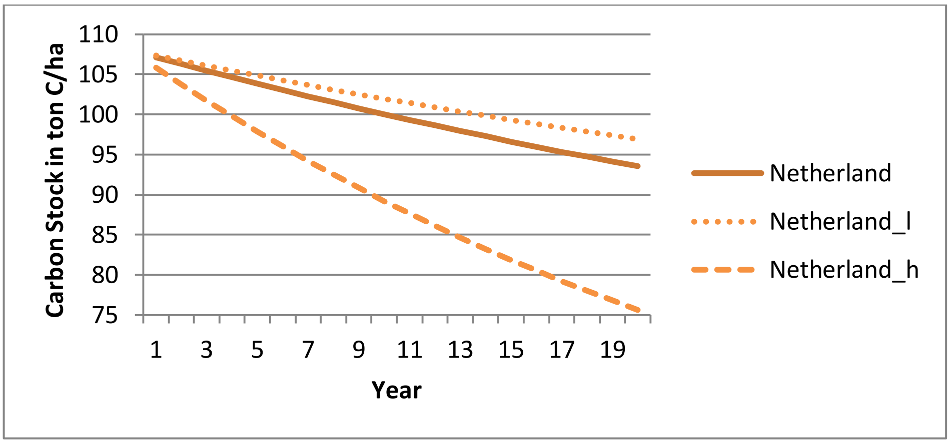

Figure 15. The change of carbon stock size over 20 years when a simple crop rotation of three crops as well as the grassland slurry residue has been applied on the field, with outflow rate set at 2.0%, with outflow rate set at 2.0%, sensitivity analysis of 1.8%(Netherland_l), and 3.2%(Netherland_h)

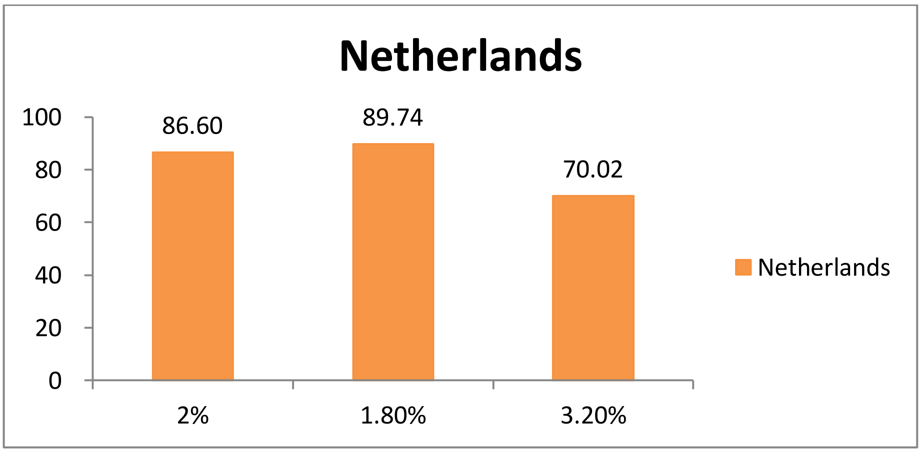

Figure 16. The percentage of carbon that still remains after 20 years when crop rotation and slurry is applied, compare to the initial stock size.

4.5 No-meat Scenarios

Gap year

As it shows on figure 17, introducing a gap year do have an effect on the carbon stock of the top 30 cm of the soil. However, because of the relatively high outflow rate compared with the relative low inflow rate of the crops themselves every year, it seems that introducing a gap year every 3 production years would have small effects on the carbon stock in a short term. In a long term, the stock will be stable after roughly 150 years at 54 ton C/ha which is not a best soil quality. As for a gap year every 2 years, the stock size will also be stable after 130 years at a size of 62 ton C/ha, which is better compared with every 3 years. A gap year every 1 production year provides the best output so far, which would have a carbon stock of around 76 ton C/ha, and the stock size will remain stable for the following years.

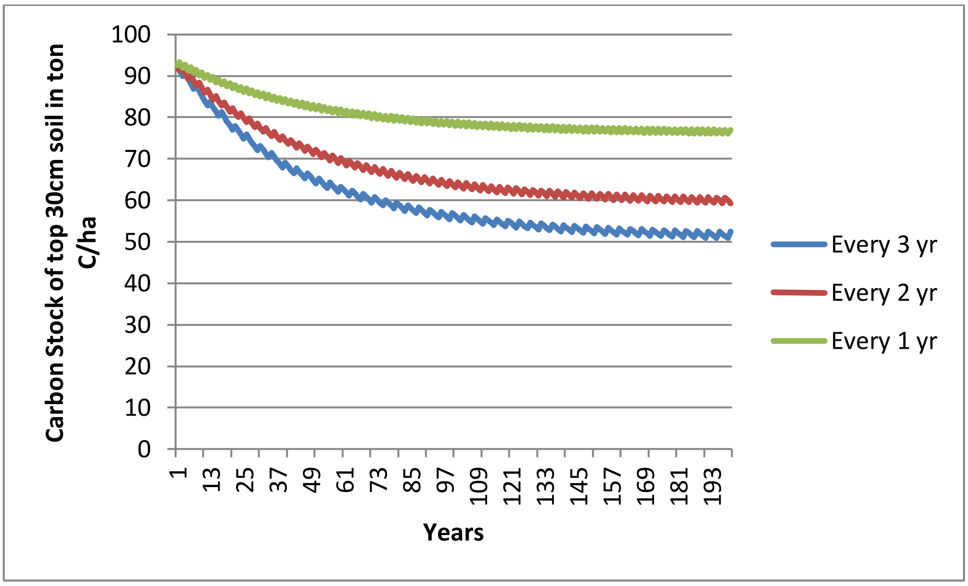

Figure 17. Applying a gap year in between every 1- 3 production years and the corresponding change of the carbon stock in top 30cm of the soil with an initial stock size of 94 C/ha.

Catch Crop

Catch crop will increase the carbon inflow of the land significantly, as it has shown in figure 18. Normal cropping system without any catch crop would results in a huge loss of the carbon content in the soil on a yearly basis, after 100 years the carbon content in the land will be extremely low. or the systems with a catch crop, because oat has the highest biomass output, therefore for the system using oat as a catch crop, after 90 years the carbon stock of the soil will be relatively stable at around 85 ton c/ha in the top 30cm of the soil, which is the highest compared with other catch crops. Triticale and barley have lower biomass output therefore these two systems will be at equilibrium around 75 ton C/ha and 65 ton C/ha. A mixed system will have similar carbon balance compared to barley, with a carbon stock at around 65 ton C/ha.

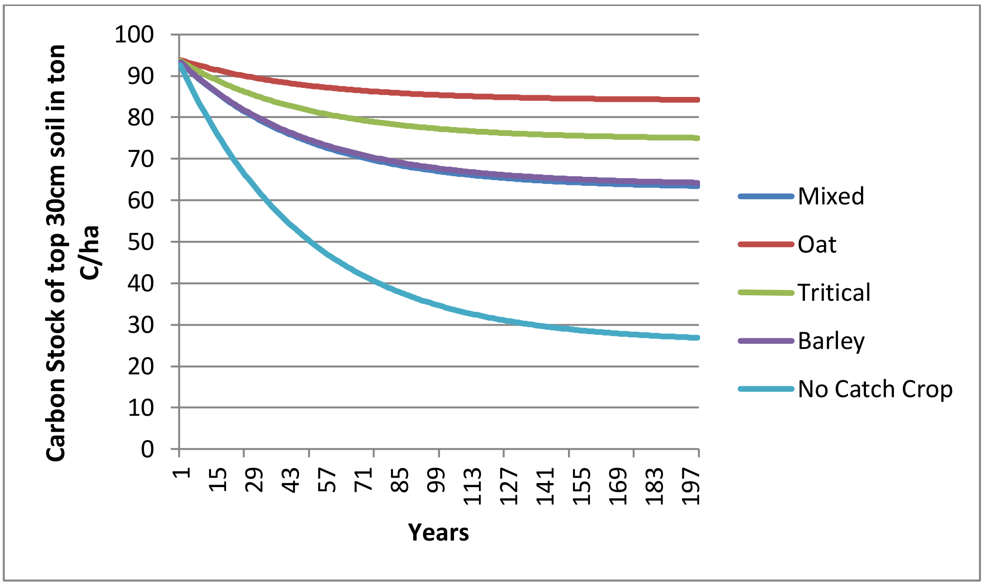

Figure 18. The annual change of carbon stock with different catch crops (oat, triticale and barley), as well as a mixed catch cropping system with three crops included, comparing with a normal cropping system with no catch crop.

Lower Carbon Initial Carbon Stock

Although the stock size of the 'Kalkhoudende zandgrond' (calcareous sandy soil) and 'Kalkloze zandgrond' (Lime-free sandy soil) is different at the beginning, and the outflow rate is also different at the beginning, because of the relative low input of a normal cropping system which is used in this research, both soil type will reach a balance at around 26 ton C/ha after roughly 160 years. The soil type itself at the start is poor enough, and at the balance the soil quality will be extremely poor and hence not at all productive.

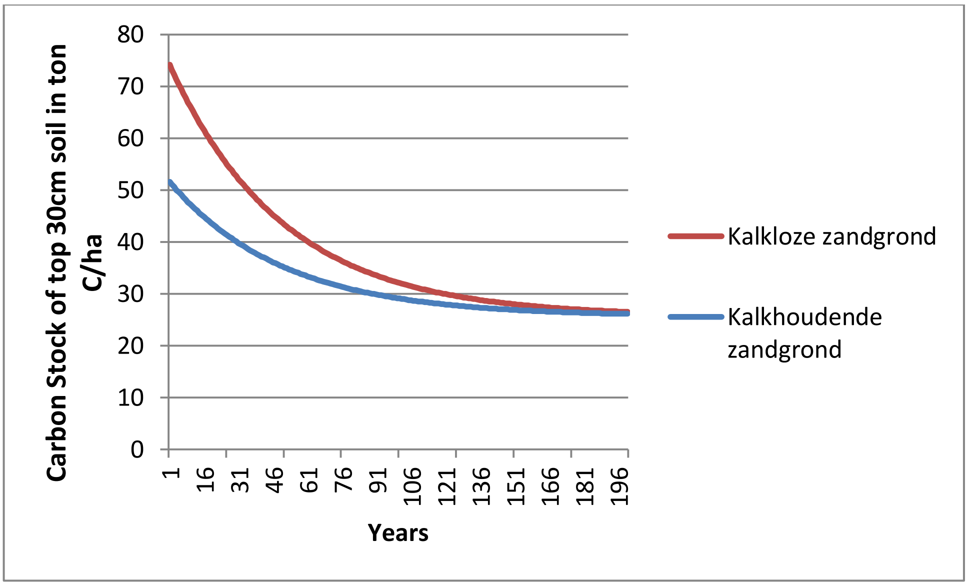

Figure 19. The change of carbon stock of 'Kalkhoudende zandgrond' (calcareous sandy soil) with a carbon stock of 52 ton/ha in the top 30cm layer of the soil and 'Kalkloze zandgrond' (Lime-free sandy soil) with a carbon stock of 75 52 ton/ha in the top 30cm layer of the soil, when a normal cropping system is applied.

Mixed Cropping System

Overall a mixed cropping system might be the best solution of keeping the carbon balance at a relative reasonable level. In this system, the catch cropping is already included, at a gap year would be included for every 2-5 years. As figure 20 shows, one gap year every 2 years provides a best soil carbon balance of an equilibrium at around 82 ton C/ha almost only a decade into the cycle. One gap year in 5 years would have equilibrium at around 72 ton C/ha after around 70 years and one gap year in 3 years would have equilibrium at around a reasonable 79 ton C/ha.

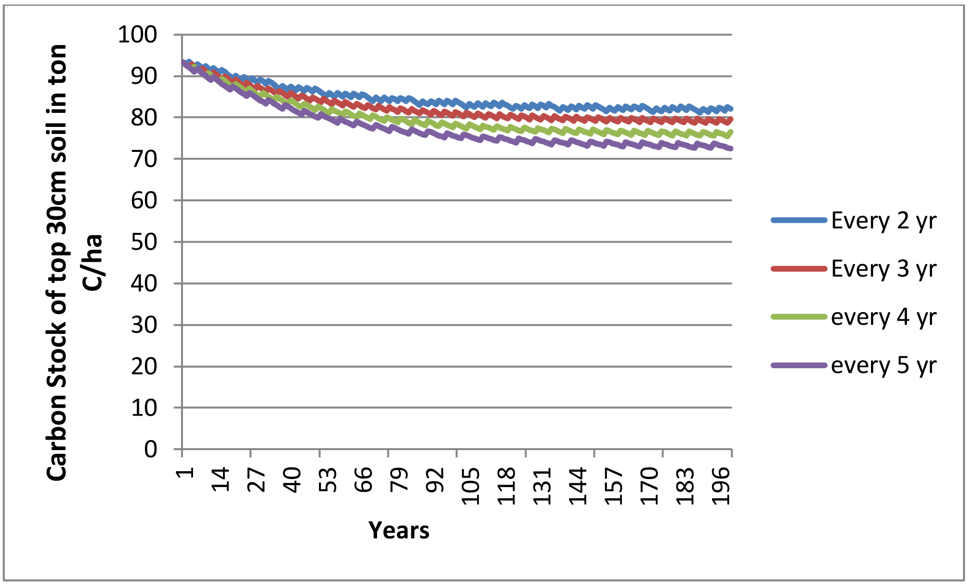

Figure 20. The change of the carbon stock annually on the cropland with an initial stock size of 94 ton C/ha, with a normal Dutch crop rotation of potato, wheat and sugar beets, including a mixed catch cropping (oat, triticale and barley), combined with a gap year every 2 to 5 years, during which grass growth is assumed.

4.6 Dutch System with Catch Cropping and Gap Years

In figure 21 the results suggests that overall the soil quality will be ideal when the catch cropping and gap years are introduced into the Dutch System. For a gap year between 2 production years, the carbon stock will eventually be around 89 ton C/ha which is smaller compared with the original stock size. A gap year between 4 production years would results a balanced stock size at around 86 ton C/ha, and one gap year every 5 years would have a balance at around 85 ton C/ha which is a minor reduction on the original carbon stock. Therefore there are no major differences between different lengths of gap years.

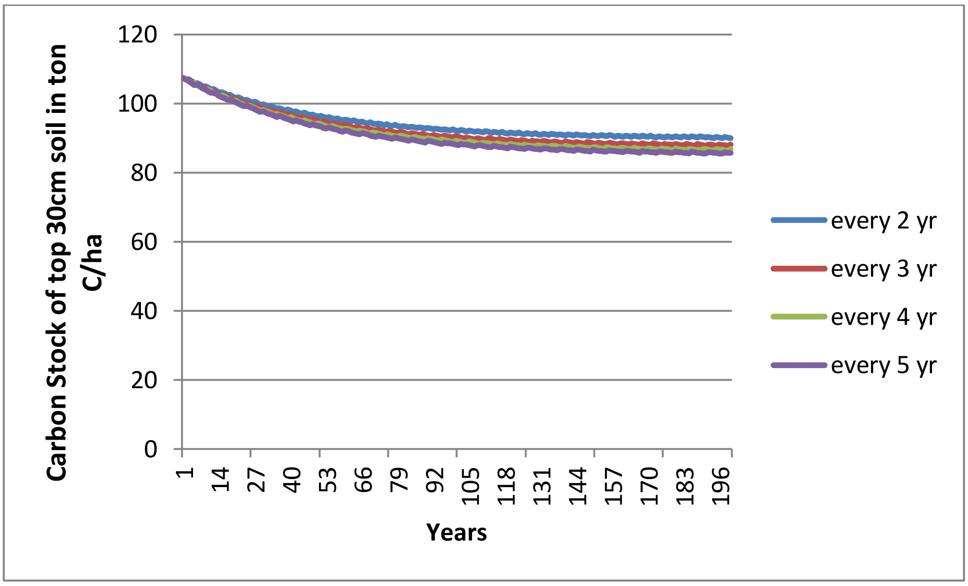

Figure 21. The change of carbon stock of the Netherlands with an initial stock size of 108 ton C/ha, with a mixed catch cropping system (oat, triticale and barley), as well as a gap year for every 2-5 production years for the cropland assuming a normal crop rotation of potato, wheat and sugar beets, and cattle slurry + grass production for the grassland.

4.7 Results of different inflow and outflow methods

Alternative Farming Scheme with different SOC input

It is clear from figure 22, the original SOC input that was suggested by the Handboek Bodem Bemesting (2019) was not enough to sustain the SOC level, although with extra pig manure input, it perform better than pure cropland with no animal manure. With extra input of straw and cow slurry, the SOC is better than the original input, but still not as good as Netherland system mentioned before which had more slurry input.

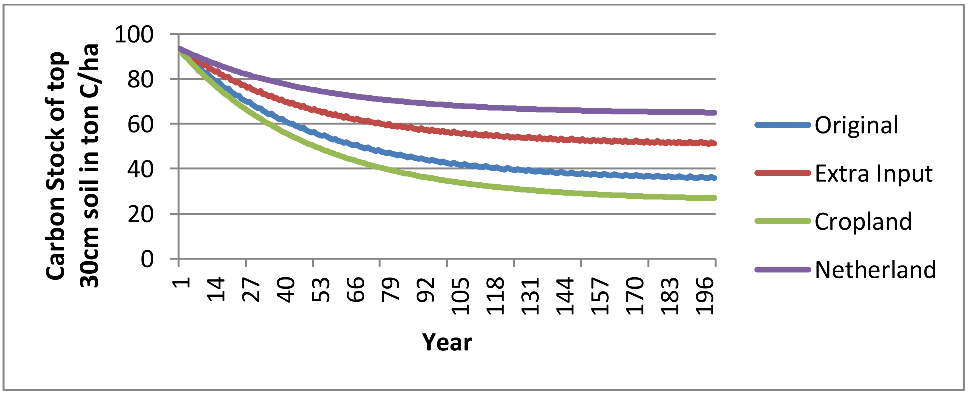

Figure 22. The change of carbon stock of the Netherlands with an initial stock size of 108 ton C/ha, with original and extra input from the suggestion of Handboek Bodem Bemesting (2019), in comparison with pure cropping only in cropland with no animal manure and grass residue input, and a Dutch scenario with cow slurry and grass residue.

Janssen (1984) 's method of SOC outflow calculation

In figure 23, although the calculation of the relative decomposition rate of 2% soil organic matter percentage conducted by this research matches the first slop with the research done by Wadman and De Haan (1997), from year 0 to year 4, the following slops at year 9, 19 and 49 was off. Although the difference seems to be minor but when the RDR is going to be put in action this difference would create drastically different results.

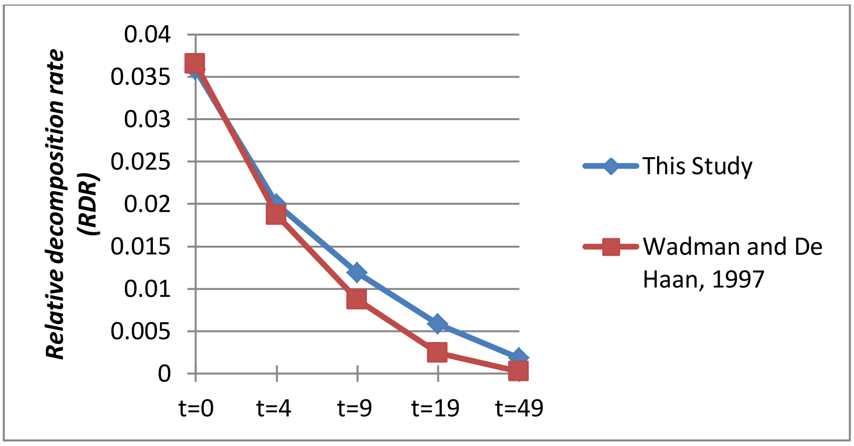

Figure 23. Relative decomposition rate of soil organic matter (SOM) calculated by Yuan and Wadman and De Haan (1997), at year 0, 4, 9, 19 and 49, *when the initial SOM is at 2%.*

5. Discussion

5.1 Product yield output

The product yield is relatively representative because of the fact that they are an average of the production during the past decades. However, the calculation for the density of the cattle in the farm might differ from the reality. Other researches and reports suggest that on average there are 108.7 cows on a 62.4 ha of farm land (Fokkert, 2014) which is around 1.7 cattle per ha for dairy farms in the Netherlands. Whereas in the results, the conclusion is that there are 4.3 cows per hectare of grassland. The results from Forkkert (2014) only conclude the situation in the dairy farms with producing adult cows, the young ones which are not yet producing are not taken into account. Also, in this research, all the cattle population were accounted for, including the ones for other purposes other than dairy.

5.2 Residue Inventory and residue carbon content

During the calculation of dry residues, the carbon content of the residue is calculated using a rather general number from only one source. Although it was stated I that C content of biomass is almost always at around between 45 and 50% (by oven-dry mass) (Dyer et al., 2004), specific carbon ratio can be found for specific residues of different crops to make to make this calculation more accurately. In this study, only three crops representative for the Netherlands are used, however there are other crops farmed in rather large scale in the country. From the result of this study, it is clear that wheat plant yield more residues and these residues contain more carbon when compared with residues from other crops. This might lead to an over estimation of the SOC that can be obtained from crop residues other than wheat. Therefore more studies on the residue yield and their effective carbon input when returned to the land is needed. In future studies a dataset about the residues and their carbon content can be developed in order to be more inclusive, which can then be applied to

For the manure production and its carbon content, data from one specific farm was used. This is because of the complexity of finding a generalized and consistent moisture content and carbon content of the slurry. Although it would be hard in practice, the calculation will be more accurate when a data for the Dutch slurry content and quality is used, because this is a case study on the Netherlands. Therefore the results in the end could be more accurate to the local condition of the Netherlands. The calculation would be more accurate when it is scaled down to a specific farm, of which the moisture and carbon content of the slurry can be measured on site and then used in the model.

5.3 Effective organic carbon input

The Humification Coefficient is essential to calculate the carbon inputs of any residue. However there is a huge variation in the values of the HC from different sources. This is because different sources would have different conditions set for the residues to be applied in the soil, and the soil conditions are also different. The HC depends on environmental conditions and also the crop. Therefore, the HC should be used for the place where the study is taken place. Also, although the Dutch researches and scientific world has a strong focus on this topic, sources from other countries could differ from the Dutch ones. These reasons caused the difference in the value of HC, which will lead to a different result in the EOC input (Conijn and Lesschen, 2015). A thorough literature review accounting all the factors could be conducted to look into the specifics of this topic, and then a rather generalised and standardised conclusion could potentially be applied to this research to have a stronger conclusion. For future studies focusing on the same topic, spending more time on HC is recommended.

5.4 Different Scales

In this study the farms are assumingly specific to cropping and cattle farming purposes only and there are no exchanges between them and the outsider, greater agricultural systems. This limits the scope of this research. At the bottom and middle scale where the carbon stock changes are specific to a certain residue only, the results are rather a theoretical one and have uncertainties, but it provides an important foundation to the system. At higher scale, the carbon is exchanged between different farming practices within the model. Crop rotation and land sparing are common practices in the Netherlands, as well as applying manure to the croplands (Conijn and Lesschen, 2015). The system built in this study is a closed system; in reality the agricultural system and the carbon flow of this system will be more complex.

At the top level, there will be exchanges between the grassland and cropland systems in this study, however this is merely a simplification of how the system actually works. In the study, the carbon stock at this level is taken as a uniformed one, using the Dutch average carbon content as the stock size. This is to provide an overview of the country in whole. To be more precise, the grassland and the cropland carbon stocks, with interactions between each other should be calculated and reported separately. Then the question arises where the carbon input flows between the different farms should be defined, for example how much slurry are used in the cropland.

In this study, although the major input sources of carbon in farms are considered, there are still some minor inputs which are missing. For example, kitchen compost and other kinds of compost are one of the carbon sources of croplands in the Netherlands (Conijn and Lesschen, 2015). Although in provinces like Groningen and Drenthe, the amount of composts been put in the croplands are negligible, but in provinces like Noord Holland and Friesland the composts counts up to 10% of the total inputs. This is only neglected in this study because it is not really residue from agriculture and the source of the compost is rather hard to allocate (Conijn and Lesschen, 2015). Also, similarly for grassland, it is reported that grazing manure in also one of the major source of carbon for the grasslands, because they are really hard to allocate and quantify (Conijn and Lesschen, 2015)., therefore they are not counted in this study. Future studies should try and include the grazing manure into the cycle.

Figure 24 is a direct comparison of the measurements and calculations done by Conijn and Lesschen (2015) on soil organic matter of the Netherlands and this study. In this study, the calculation is done by applying the effective organic carbon whereas Conijn and Lesschen (2015) used effective organic matter. To make two studies comparable, the ratio of carbon in organic matter of 0.5 from Conijn and Lesschen (2015) is applied to the results of this study. In figure 23, it is clear that the grass residue input from this study is a bit samller than Conijn and Lesschen (2015), this might be because of all the residues are assumed to be returned to the land in this study, and the grass that was lost during collection and process were already deducted from the grass yield (Cornelissen et al., 2015). Whereas in the study of Conijn and Lesschen (2015), the carbon input is an actual measurement and calculation. In reality not 100% of the grass residue will be returned to the land. Some of the residues could be used for other purposes such as for the housing of the animals, as building material, as material that will be added in slurry or added to compost (Millner and Sikora, 1998). This is also true for slurry. The amount of slurry applied back into the land in this study is a bit larger compared with Conijn and Lesschen (2015), this is because in practice some of the slurry will be used for biogas, and other purposes (Insam et al.,2015). As for crop residue, the results of this study is slightly smaller compared with Conijn and Lesschen (2015), this might because of in this study only three crops are included, are in the study of Conijn and Lesschen (2015), all the crops are included.

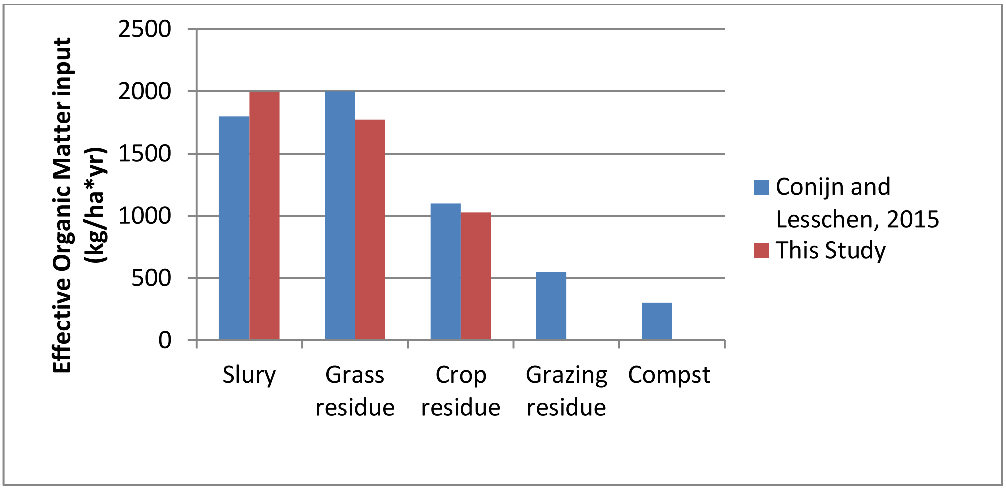

Figure 24. Comparing the amount of effective organic matter input from different sources between two studies(Conijn and Lesschen, 2015; This study).

The result at the Netherlands level of in the study suggest that the soil organic carbon level of the Netherlands is more or less slightly not sustainable, which is different to the conclusion of Conijn and Lesschen (2015), where they state that only certain regions are in risk. This is because the reason stated that some of the sources of carbon inputs are not included in this study. Overall it is easy to conclude from both papers that croplands are less stable compared with grassland. This is because the major product that contains carbon, which is the food are removed from the land for consuming purpose.

It is also important to mention that in the modeling of the scales, the carbon outflow rate is set at a constant 2%, with the only exception of using 1.8% and 3.2% in the sensitivity analysis. Although 2% outflow rate is a valid conclusion made by Conijn and Lesschen (2015), this is the simple approach to the problem, and other method should be considered in future studies. For example, Wadman and de Haan (1997) modeled the outflow for 36 different types of soil using measurements over 30 years, and this model can be applied to SOC stock with no inputs. A model like RothC Soil Carbon Turnover Model (Coleman and Jenkinson, 2014) does consider SOC inputs but has five different SOC stocks and requires nine different data entries, which is more accurate but meanwhile more complicated.

5.5 No-meat Scenarios

Looking at the results from this section it is conclude that in theory, methods like have a gap year every production year could maintain the soil carbon stock at a relatively stable level, but this is highly theoretical and not practical to apply in large scale. Therefore the optimal way to maintain a reasonable soil carbon stock is to combine catch cropping and gap years. The reason why The SOC stock size would eventually balance itself is because eventually the SOC outflow would equal to SOC inflow and reaches a balance when the SOC stock size is low enough, given that SOC outflow is dependent on SOC stock size. There is a mathematical reason behind the model as stated, because of the limitation of the modeling process. In reality because of the complexity of the SOC stocks and its relationship with the outflow rate, it is unlikely to achieve same equilibrium as the model did in this research.

In the calculation of the gap year, it is assumed grass will grow, and the data from the grassland grass production was used directly. In reality, because of the lack of maintaining (i.e. applying fertilizer and pesticides) during this gap year, comparing with the maintained grass production of the grassland, the amount and rate of biomass growth on croplands during this period could be smaller than the amount in maintained grassland.

As for the catch crops, this study used the ones from the French CIVE project for the aim of this project is to maximize the biomass production (Marsac et al, 2018; Laboubee, 2018). However this project is designed for France, and in the Netherlands there are other species of catch crops used, and for different purposes like providing nitrogen leach (Van Dam, 2006). Therefore a Dutch catch cropping system can be developed for this study to have a more accurate result.

Also, the relative lower soil carbon stock on different type of soil, in general, means that the productivity of the soil would be lower than the normal ones, because of poor soil structure caused by poor SOM content (Conijn and Lesschen, 2015). Therefore the production of residues will be lower than normal. This fact was not taken into consideration because of the simplicity of the study, but should be taken into consideration in future studies. The reason why two different types of soil would end up having same stable SOC stock size is because the annual SOC input is assumed to be the same in the model. Eventually the SOC outflow would equal to SOC inflow and reaches a balance when the SOC stock size is small enough, and because the SOC inflow for both soils are the same, leading to same SOC outflow and, which would results in same stable SOC stock size.

Although the results suggest crops-only can be optimized, this results was calculated under the assumption that the soil quality and productivity of the Dutch soil will remain the same. Now the Dutch soil have a surplus of nitrogen because of the amount of cattle manure that's been added into the system (Korevaar, 1992), but in reality if the meat industry is to be removed from this system, the nitrogen level will be dropping, and at some stage, nitrogen catch crop needs to be added in the system to provide extra nitrogen (Thorup-Kristensen, 1994), and this would compromise the biomass and carbon production of the catch crops.

5.6 Netherland System with Catch Cropping and Gap Years

This system has the best carbon balance, with relatively reasonable compromises. Even with one gap years for every 5 production year, the carbon stock will be balance at around 85 ton C/ha which is still optimal for agricultural production. Under this system, despite of regional variations, it might be possible to spare some of the residues for bioenergy purpose.

5.7 Different Inflow and Outflow Methods

Alternative Crop Rotation Scheme with different SOC input

The crop rotation scheme suggested by Handboek Bodem Bemesting (2019) does provide more SOC input when compared with the cropland only scenario from this study, but when compared with the Dutch scenario the SOC is actually smaller. This is because the crop rotation scheme only adds in cow slurry once every two years, and in the Dutch scenario the cow slurry is applied every year. In then end the crop rotation scheme suggested by Handboek Bodem Bemesting (2019) seem to be not sufficient in terms of SOC input every year, however this is under the assumption that the soil quality/SOC level is on a national average, which could be actually larger than majority of the farming land in the Netherlands because this average is enlarged by the abundant amount of peat land in the country. If the farming land is to have smaller SOC value the scheme could be sustainable in term of SOC cycle.

Janssen (1984) 's method of SOC outflow calculation

Although effects were made to recreate the calculation done in the Janssen (1984) and Wadman and De Haan (1997) paper, to calculate a relative reliable RDR value which is dynamic to the stock size of SOC, instead of using the simplified 2% relative lost rate deducted by Conijn and Lesschen (2015), but the effect was failed because in the paper it was not stated anywhere what *a* value (apparent initial age) was used, the papers were more or less like a black box for a none soil scientist. Further study can be made on realizing a better SOC outflow model than the static one used in this research.

6. Conclusion

It is logical to conclude from the results of this study, that almost all the residues need to be returned back to the land in order to keep the soil organic carbon in balance. Despite the uncertainty of the results based on the simplified version of the model, this study provides a point of reference of the system and addresses the idea that agricultural residues are an unlimited source for bioenergy.

When all the carbon inputs are accounted for and a catch cropping and gap year systems are in use, with a good soil quality and productivity, it might be possible that some of the residue will be available for other purposes. As the soil condition changed, this availability could potentially change accordingly. Therefore it is not smart to plan large scale regional bioenergy (biofuel) productions which only use and dependent on agricultural residues, when it is concluded that this source is not stable and could be scarce in some situations. The production of food should be prioritized considering the need for food security

There is a need of more comprehensive understanding regarding the soil quality and the agricultural residue availability before the promotion of second generation biofuels can be included in decision making agendas. Although the amount of agricultural residues can be calculated according to the size of the agricultural practice, from an agricultural perspective, the residues have a lot of potentials uses such as animal feed and animal housing, and not all of them are available at all time. When estimations or calculations are made to explore the potential or the availability of source for second-generation biofuel in certain country or region, the agricultural use of such residues should be taken into consideration from the beginning.

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