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Assessing the case for sequential cropping to produce low ILUC risk biomethane

Final report

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1 Introduction

1.1 Reducing agricultural carbon emissions while feeding more people

In recent years and especially since the COP-21 climate agreement reached in Paris last year, efforts to mitigate climate change accelerate. All sectors need to contribute in order to achieve the well below 2 degree climate target. The agricultural sector is relevant for climate change in various ways. Agriculture is the first sector in which the consequences of global warming are being felt already. This impacts productivity in arid regions. While starting to suffer climate change consequences, the sector is also co-responsible for creating global warming, with 12% of global greenhouse gas emissions coming from agriculture. It will be a major challenge to reconcile the need to mitigate agricultural carbon emissions with the need to feed more than 9 billion increasingly wealthy people by 2050. Awareness about this challenge is growing, also among farmers. The challenge becomes even greater if agricultural land is used to decarbonise the transport sector by cultivating crops used to produce biofuels. From the perspective of the large challenges to make agriculture more sustainable it may make sense to stop using crops for biofuels.

1.2 Sustainable biofuels needed to decarbonise transport

Like the agricultural sector, the transport sector is also responsible for significant greenhouse gas emissions. About 14% of global emissions are caused by transport. Biofuels are needed in much greater quantities than today to decarbonise the transport sector in order to achieve the well below 2 degree climate change target. Renewable transport fuels is necessary in all fuel types, including both liquid biofuels as well as biomethane for CNG-vehicles.

In recent years, the willingness by policy makers to support a further deployment of biofuels in the EU has dwindled as a result of discussions on biofuel sustainability, most notably related to indirect land use change and 'food versus fuel'. Indeed, it is important not to increase emissions in the agricultural and land using sectors or to put pressure on food markets in an attempt to decarbonise transport. Should this be a reason to phase out crop-based biofuels and focus solely on non-land-based biofuels from waste and residue materials?

Advanced biofuels and biogas produced from wastes and residues can play an increasingly important role in the transport mix. At the same time, available quantities may be insufficient to decarbonise transport. Therefore, it makes sense to also identify under which pre-conditions land-based feedstocks can be produced without negative indirect impacts and can be equally 'advanced' in terms of sustainability performance as cellulosic or waste biomass.

1.3 Italian farmers produce additional crops for biomethane

In Italy, 600 Italian farmers are organised in the Italian Biogas Council (Consorzio Italiano Biogas e Gassificazione, CIB). CIB members currently produce around 5 billion cubic metres of biogas per year. The sector has the ambition to upgrade part of this biogas to biomethane that can be injected into the gas grid and used for transport. A new Italian government Decree is expected to provide an incentive for biogas upgrading to biomethane to be injected into the gas grid for the purpose of its use in the transport sector. About 5% of the Italian passenger car fleet consist of CNG-vehicles that can run on biomethane.

Traditionally, biogas production was based on a combination of manure and silage maize, with the silage maize being produced as a monocrop. This conventional biogas system has the associated risk to cause Indirect Land Use Change. The 2015 GLOBIOM ILUC quantification study by Ecofys, IIASA and E4tech[1] found that silage maize used for biogas can lead to 21 grams of $CO2_{eq}$/MJ of indirect emissions. This is not as high as some other feedstocks[2] but it still poses a risk for the overall sustainability performance of biogas.

Some years ago, CIB members developed a concept that they coined Biogasdoneright[3]. In collaboration with various research institutes they seeked for a way to combine biogas feedstock production with crop production for food and feed as a way to generate additional income in a sustainable manner. The core of the Biogasdoneright concept is that farmers apply sequential cropping by growing a winter cover crop on land that was previously fallow during winter time, while maintaining the main crop production during summer time as previously. The additional biomass produced as cover crops, e.g. silage maize or triticale, are being used to produce biogas. The farmers aim to avoid nutrient depletion of the soil by feeding back the biogas digestate to the field, partly by mixing the liquid part of the digestate with water which is applied to the field in a targeted manner by a drip-feed irrigation system. This also reduces the dependency on fossil-based fertilisers because it includes nutrients from manure used for biogas. The farmers aim to further ensure soil quality by leaving crop stubbles on the field after harvesting and by applying strip tillage, which helps to keep soil carbon underground. In addition to the climate, soil and renewable energy benefits of the Biogasdoneright concept, it also enables farmers to enhance the profitability of their operations by creating biogas as an additional product next to their business as usual agricultural output. In developing and improving the Biogasdoneright concept, CIB is assisted by the Italian research centre for animal production (Centro ricerche produzioni animali, CRPA) and by the universities of Milan, Catania and Verona amongst others.

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[1] https://ec.europa.eu/energy/sites/ener/files/documents/Final%20Report_GLOBIOM_publication.pdf

[2] And still allow significant overall greenhouse gas savings if direct emissions are taken into account.

[3] Named after an article by Prof. Bruce Dale (Michigan State University) et al., ' Biofuels done right' Land Efficient Animal Feeds Enable Large Environmental and Energy Benefits', *Environ. Sci. Technol.*, 2010, *44* (22), pp 8385–8389

The combination of growing additional biofuel feedstock while maintaining food production in a way that doesn't harm the environment, sounds like a truly advanced feedstock cultivation system; almost too good to be true. CIB has asked Ecofys to perform an assessment of their claims. Figure 1 below illustrates the Biogasdoneright concept with a central role for sequential cropping and returning biogas digestate back to the field.

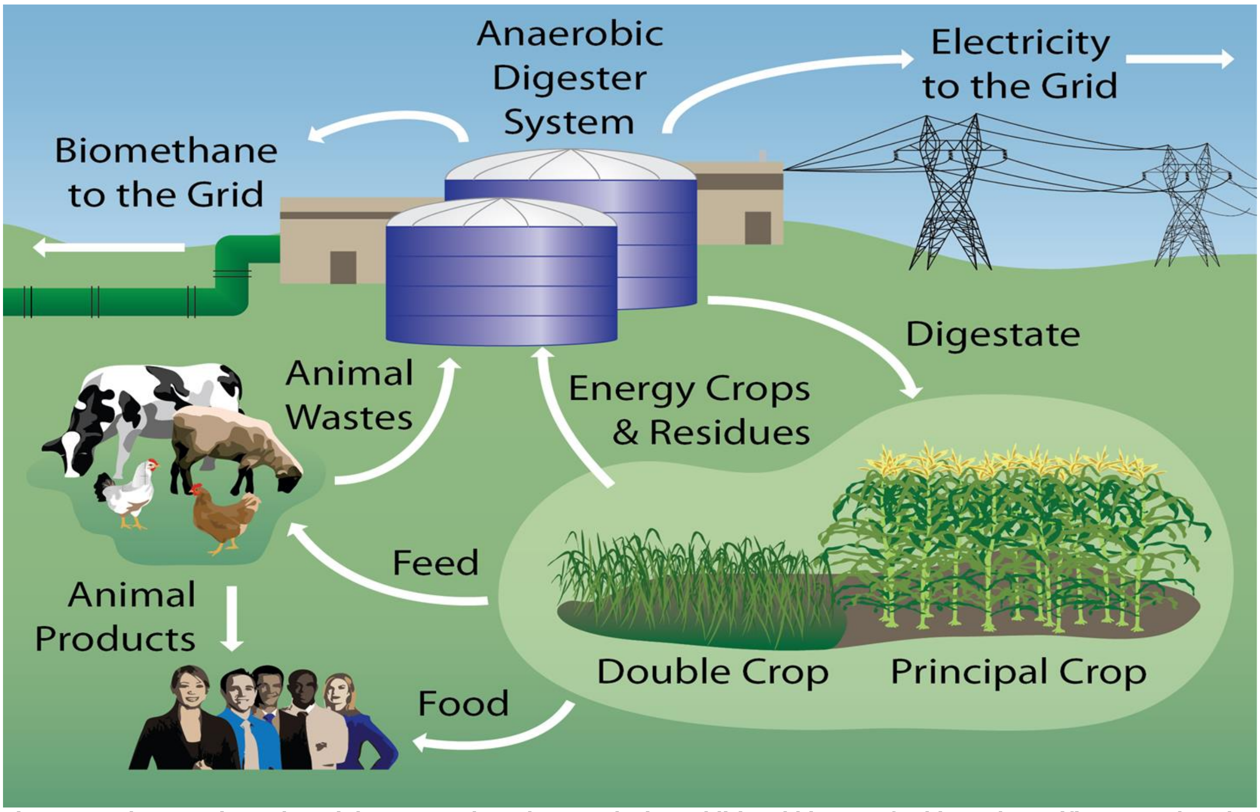

Figure 1 – The CIB Biogasdoneright concept based on producing additional biomass for biomethane (figure produced by Michigan State University)

1.4 Aim of this study: assess claims related to 'Biogasdoneright'

Multiple claims can be made about Biogasdoneright, for example related to the large potential role for biogas in our future energy system. We focus here on the most relevant claims related to the use of biomethane in transport, with a focus on sustainability aspects. The following claims are assessed:

1. Sequential cropping to produce additional, low ILUC risk biogas feedstocks can be introduced in a truly sustainable manner, meaning low ILUC risk, because *additional*, while maintaining and enhancing soil quality, low impact on water availability and no negative impact on on-farm biodiversity.
2. Silage maize/triticale cultivated as cover crop for biogas **contribute positively to mitigate climate change and the decarbonisation of transport emissions**.

3. A **positive business case** exists for farmers to introduce sequential cropping for biofuel
4. Sequential cropping for sustainable biofuels is **scalable**

We base our assessment on data provided by CIB and research institute CRPA. These data have not been verified by us and our work is not a certification exercise. An Ecofys consultant did visit Palazzetto farm as well as several other farms in northern Italy that apply sequential cropping to produce biogas feedstock, and we met with researchers from CRPA.

2 Assessing Palazzetto farm

2.1 Palazzetto farm in Cremona province in Northern Italy

An increasing number of Italian biogas-producing farmers have introduced sequential cropping with the aim to use cover crops to feed their biogas installation. One of them is Ernesto Folli, owner of Palazzetto farm in Cremona province in northern-Italy. Palazzetto farm is a large farm with 255 hectares of land, a stable of 650 cows, 300 of which producing milk and a biogas installation with a production capacity of 1 MW electricity. Mr. Folli invested in a biogas installation in the year 2009, and initially fed the installation with a mixture of manure and agricultural crops produced as main crop. In 2012 Palazzetto farm embraced the Biogasdoneright concept and first introduced sequential cropping, which changed farming practices in many ways. After an initial testing, sequential cropping has been consistently applied since 2014. In this report we will use his farm to study the effects of the Biogasdoneright concept. Figure 2 below shows Palazzetto farm with its various fields. The three fields with their names in boxes are the fields which we focus our assessment on.

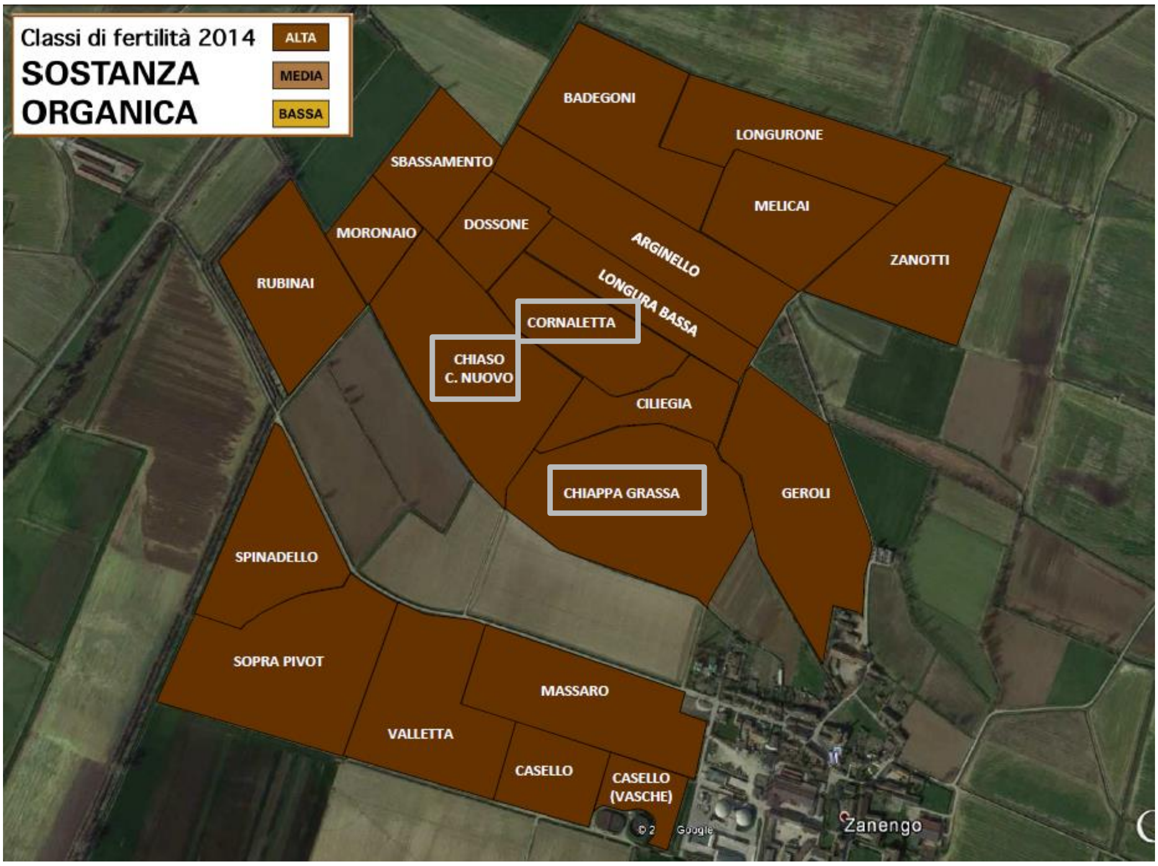

Figure 2 - Map of Palazzetto farm with pilot fields highlighted

Why focus on one farm?
We chose to focus on one farm because it allows us to study the effects of sequential cropping in quite some detail, supported by an extensive data collection effort. A downside of this approach is of course that we have a sample size of one farm, which is not statistically relevant. We involved experts from the Wageningen University Crop Systems Analysis institute who were able to put situation at Palazzetto farm into a wider perspective, without being conclusive on this. While we are convinced that our findings can and are replicated with similar results by other Italian farmers that practice Biogasdoneright, strictly our conclusions only relate to the performance of Palazzetto farm.

2.2 Cropping scheme on Palazzetto farm

Palazzetto farm cultivates a variety of crops, mostly to produce animal feed and since 2009 also biogas. The farm rotates crops on several fields but does not use a fixed rotation scheme. The choice of crops can vary from year to year based on market prices for agricultural commodities. Up to 2012-13 the farm only produced summer crops and after the harvest the land was left fallow until the next cropping season. In 2012 and 2013, sequential cropping was introduced, which means that crops are now cultivated also during the previous fallow period, resulting in a crop production system with two crops being produced each year in a field. Figure 4 below shows the historical cropping situation from 2010 onwards as well as the new sequential cropping situation per individual field. Before 2010, various other crops were produced on the fields, including barley, maize grain and occasionally wheat grain, almost all for animal feed. All prior crops since 2005 are taken into account in our low ILUC risk assessment. Throughout this report the impact of the introduction of sequential cropping on three pilot fields of Palazzetto farm is compared to the previous cropping situation.

Figure 3 - sequential cropping, maize silage grows with triticale straw still left on the land after harvest

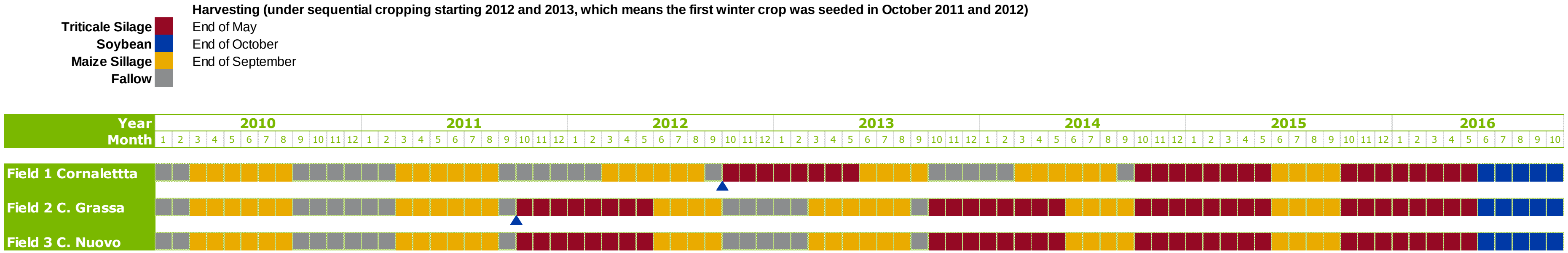

Figure 4 – Summer crop only cultivation and sequential cropping situation at Palazzetto farm

3 Low ILUC risk assessment

3.1 How we assess the output of low ILUC risk biomass on Palazzetto farm

In general, the use of agricultural crops for biofuels can lead to indirect land use change effects due to the risk that existing food and feed production is displaced by bioenergy production. Especially conventional biodiesel crops can lead to very high indirect greenhouse gas emissions. But ILUC is not a given, it only occurs when agricultural land is used to produce biofuels. ILUC effects do not take place either if no agricultural land is used to produce biofuel feedstock or if agricultural land is used while maintaining existing food or feed production on the land. This means that ILUC risks for agricultural crops can be avoided if it can be demonstrated that biomass is produced *additional* to existing production for food and feed.

Crop-based biofuel feedstock has a low ILUC risk if it is produced additional to existing agricultural production. Additionality is triggered by investments in agricultural productivity or by sustainable expansion into natural land with low biodiversity levels and carbon stocks. Investments to generate additional biomass can be targeted to individual specific crops or to multiple crops produced on a farm at the same time. An example of the first is the use of an improved genotype of the crop, while an example of the latter is the investment in GPS-tracked fertilisation of all crops cultivated on a farm. It is also possible to add a new, more productive crop to a crop rotation scheme. One example of an investment in increased productivity is a switch from a single (summer) crop cultivation scheme to a sequential cropping scheme, a cultivation system in which a new winter crop is cultivated after the existing summer on the same plot of land in the same year.

How we assess additionality is by first capturing the previous and current agricultural production on a defined plot of land in what we call a 'reference scenario'. Then, following a yield increase measure, we assess the extent to which crop yields are higher in the new situation compared to the reference yields. The difference in yields has a low ILUC risk.

How to set the reference scenario?

It is possible to calculate a crop-specific reference based on historical annual yields of a specific crop or of various crops cultivated on a farm. This enables to precisely calculate additional yields for that specific crop. Such an approach is possible and credible and will work in many instances. It works in a relatively static monocrop or crop rotation situation in which the same crop(s) are cultivated after the investment in increased productivity as before. It also works if a sequential cropping system is introduced with a new crop as winter crop, as long as the summer crop or rotating summer crops remain(s) the same as cultivated before the introduction of the sequential cropping system. However, a crop(s)-specific does not work is a situation in which a new (set of) crops is introduced.[4] Such a situation requires a different reference calculation approach. The approach should be relevant for the end market of the crop. Crops used for food or biofuels are mainly valued for their sugar, starch, oil plus protein. Crops used for feed are valued for protein but also a set of other components. For example, silage as feed crop uses many valuable components of the crop. Therefore we propose that in addition to a crop(s) specific reference, a crop-component reference and a forage unit reference could be used. Both are explained in the box below.

Box 1 – alternative methods to calculate the yield reference and above-reference biomass

Calculating the historical yield reference and additionality based on crop components
Each crop consists of various components such as cellulose, lignin, protein, fats and sugar or starch. Of these, sugar, starch and fats are used to produce liquid biofuel. For biogas production the entire crop is used. And animal feed is mainly valued for protein and digestible energy. It is possible to calculate the reduced availability of one or more relevant crop components as a result of reduced summer crop yields. This quantity of each component is then deduced from the available quantity of additional winter crop biomass. The remaining quantity of 'entire crop' winter crop counts as additional. For liquid biofuels, Ecofys proposes to only include protein and the 'biofuel feedstock component', i.e. starch, sugar or vegetable oil, in this compensation exercise. This because these are the components that mainly determine the market value of crops for the purpose of liquid biofuels and animal feed. It is important to note that within liquid biofuel production there is always protein and the respective biofuel feedstock component being produced.

Calculating the historical yield reference and additionality based on forage units
For crops used for animal feed and biogas the crop component based approach does not seem immediately appropriate because the entire crop is useful feedstock for biogas or feed, not just a single component. Silage crops are not just valued as feed for their protein value but also for their other components (e.g. fibre, starch, etc). In order to reflect the full market value, we use forage units for crops that are cultivated for feed production. A forage unit is 1,700 kcal and thereby provides a standardised value to compare different feed crops.

How to credibly calculate the additionality that results from a shift from a 'summer crop only' situation (monocrop or crop rotation) to a sequential cropping scheme?

Ecofys recommends that if crops are cultivated for the purpose of animal feed, the result of a yield increase measure can be calculated by using a forage units. This allows us to compare the feed value of different crops with each other. This is useful if we observe that the introduction of sequential cropping from one feed and biogas crop to two feed and biogas crops per year leads to a drop in one

[4] We note in this respect that changing from one crop to another, more productive crop, does not constitute a credible ILUC mitigation measure.

crop and additional yields of the newly introduced crops. Based on forage units we can 'compensate' a summer crop yield loss by deducting a corresponding quantity from the yield of the winter crop. This means that the total additionality might be less than the full winter crop yield, but possibly still substantial. We stress that the introduction of sequential cropping does not necessarily lead to a loss in summer crop yields.

In summer 2012, Palazzetto farm introduced a sequential cropping scheme on C. Grassa and C. Nuovo fields with maize silage a summer crop and triticale silage as winter crop. In the following year, sequential cropping was also introduced on Cornaletta field. It is expected that the sequential cropping will result in additional biomass compared to the previous situation where only maize silage was cultivated. In the remainder of this chapter we first calculate the reference for each of the three fields based on forage unit yields and subsequently assess to what extent the introduction of triticale silage led to additional biomass while maintaining the total quantity of forage production on the farm.

3.2 Calculating the reference scenario and above-reference biomass

The reference scenario is a counterfactual scenario against which the yield increase is measured. The reference scenario is built upon historical yields. Crop yields typically fluctuate quite significantly from year to year. However, a constant average yield increase can be seen, both in the EU as well as globally. In a simplified manner this historical yield increase can be expressed in linear trendline. The reference scenario is the calculated point on the trendline in the last year before the ILUC mitigation action was implemented. Based on the assumption of linear business as usual yield development, the reference scenarios for the three pilot areas in Palazzetto farm are established as follows:

1. The historical yields 2005-2011 of forage unit are used to determine the linear trendline for C. Grassa and C. Nuovo fields. For Cornalatta field the historical yield 2005-2012 of forage units are used for the trendline, as the sequential cropping was introduced one year later. Our methodology ideally uses the data of the last 10 years or at least historical yields of the past 5 years.
2. The linear trendline is calculated by using the statistical method of least squares. This method basically identifies the least distance for all input values to the trendline. The outcome is a linear function that best fits a data set. Due to this approach all yields within the last 10 years are equally represented in the trendline;
3. This trendline is used to calculate the reference point.

Equation 1: Linear trendline

$$Y_{ref,\, t=x} = \text{Statistical starting point} + \text{slope} * \text{year}$$

Whereas:

Statistical starting point is the beginning of the linear trendline in year 1, which is 10 years before the application for low ILUC risk.

Slope is the annual yield growth of the last 10 years.

Year is the year for which the point on the linear trendline is to be calculated. Year 1 is 10 years ago, whereas the previous year before the application is year 10.

Reference Point is the statistical point on the trendline yields in the year before sequential cropping was introduced.

For C. Grassa and C. Nuovo fields the reference starts 7 years before the introduction of sequential cropping in 2012. For Cornaletta field, the reference starts 8 years before the introduction of sequential cropping in 2013.

Table 1 – Forage unit yields – reference C. Grassa field

Year	2005	2006	2007	2008	2009	2010	2011	Reference Point
Forage unit yield	17,259	17,876	18,800	6,581	19,725	20,033	21,574	**19,354**

Table 2 – Forage unit yields – reference C Nuovo field

Year	2005	2006	2007	2008	2009	2010	2011	Reference Point
Forage unit yield	12,320	12,320	5,460	18,492	19,108	18,492	20,958	**20,869**

Table 3 – Forage unit yields – reference Cornaletta field

Year	2005	2006	2007	2008	2009	2010	2011	2012	Reference Point
Forage unit yield	12,880	12,880	13,440.	19,108.	6,075.0	18,800	19,724	18,492	**18,273**

3.3 Quantity of above-reference biomass

The sequential cropping of maize silage as summer crop and triticale silage as winter crop is compared to the reference situation, in which several crops for feed production were cultivated. The respective reference point in forage units is deducted from the summed up forage unit yields of maize silage and triticale silage in the sequential cropping scheme. This results in an additional amount of forage units for each of the three pilot fields which can be converted into t/ha of triticale silage. On C. Grassa field sequential cropping resulted in additional forage units of 8,989 in 2012, which equals 35.18 t/ha of triticale silage. On C. Nuovo field, additional 7,271 FU was achieved, or 28.46 t/ha of triticale silage. On Cornaletta field, the introduction of sequential cropping in 2013 resulted in an additional 9,5558 FU, or 37.41 t/ha of additional triticale silage.

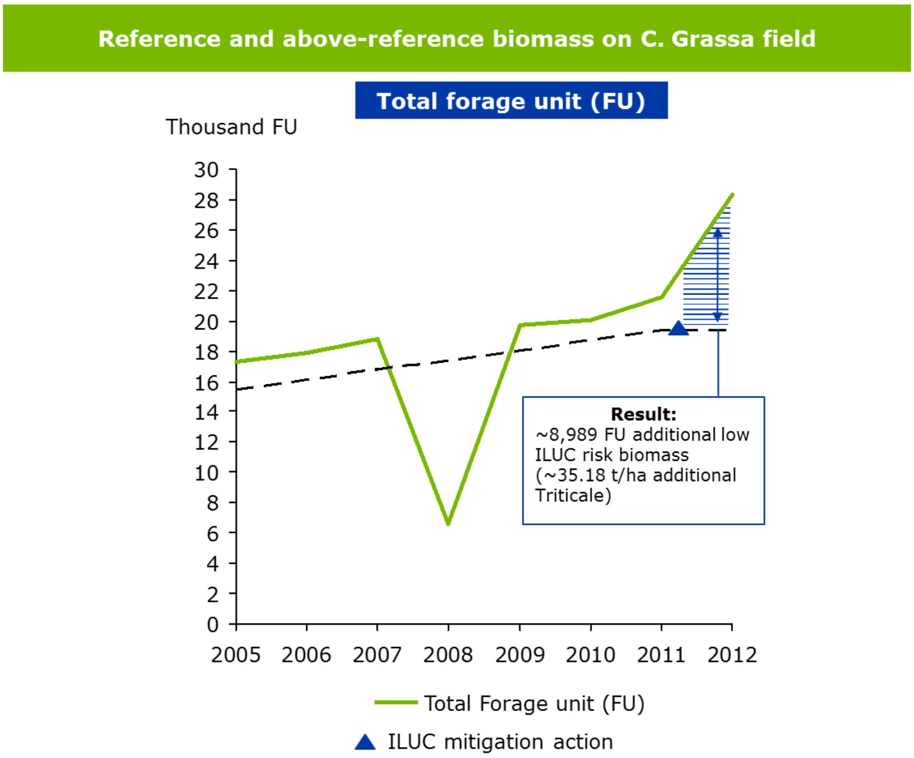

Figure 5: Quantity of additional biomass compared to the yield reference on C. Grassa field

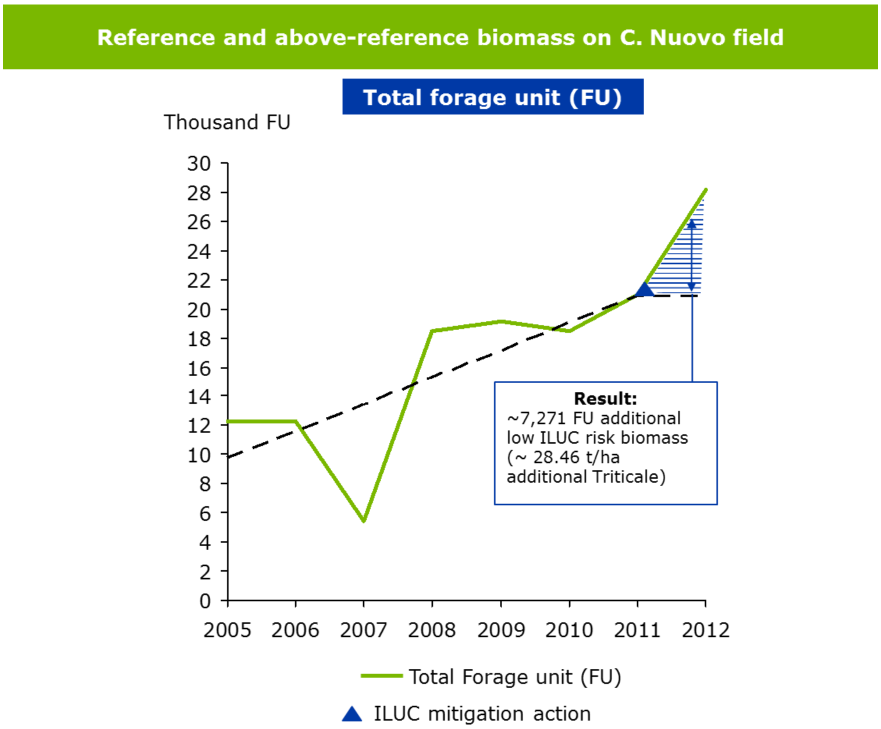

Figure 6: Quantity of additional biomass compared to the yield reference on C. Nuovo field

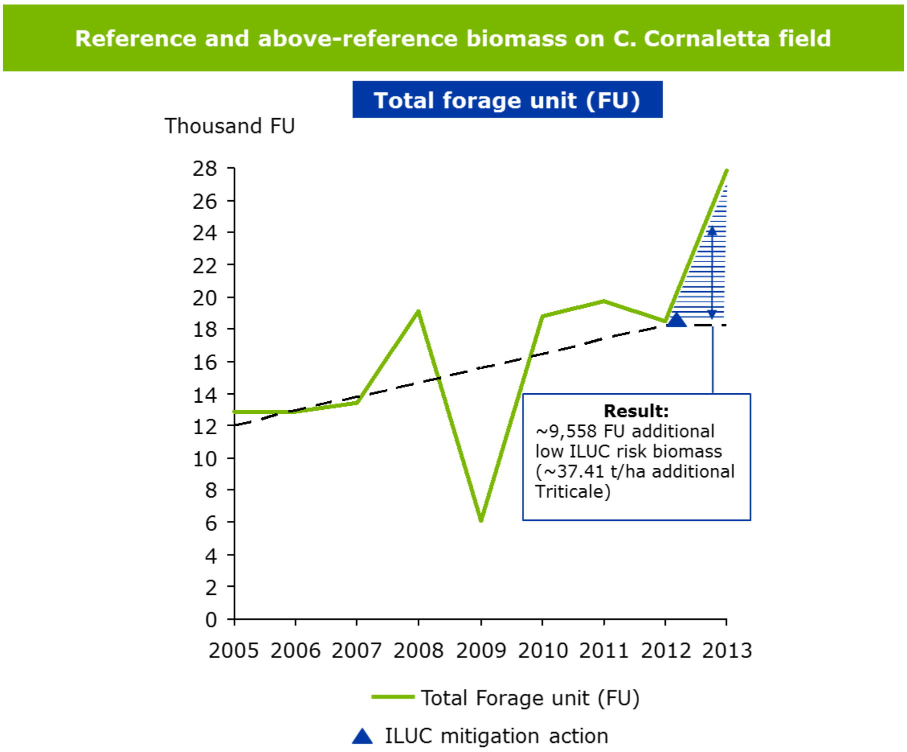

Figure 7: Quantity of additional biomass compared to the yield reference on Cornaletta field

On Cornaletta field, the introduction of sequential cropping in 2013 resulted in an additional 9,5558 FU which equals 37.41 t/ha of additional triticale silage.

3.4 Conclusions

Biofuels are low ILUC risk or ILUC-free if it can be demonstrated that no displacement of existing food and feed production takes place. This is the case if biofuel feedstock is produced additional to food and feed production. We assessed whether sequential cropping can be a good model to increase crop yields and lead to substantial production of additional biomass. Palazzetto farm produces maize silage and triticale silage in a sequential cropping scheme. Both crops can be used for animal feed or biogasl production. We want to ensure that sequential cropping does not lead to a lowering of animal feed production. This is why we calculated the overall crop yields of the previous 'summer crop only' situation translated into 'forage units', a measurement used to quantify the feed value of different feed crops. We observe that at Palazzetto farm the quantity of forage units increases after the introduction of sequential cropping. Calculated from forage units to tonnes per hectare, 35.18 t/ha of additional triticale silage as winter crop was produced on C. Grassa field, in 2012 and 28.46 t/ha on C Nuovo field in the same year. On Cornaletta field, sequential cropping was introduced in 2013 with additional, above reference yield of triticale silage as winter crop of 37.41 t/ha. These results show that **sequential cropping results in a substantial production of additional biomass** that does not lead to negative indirect land use change and does not negatively impact food production.

4 Sequential cropping and soil quality

4.1 Palazzeto farm surrounding landscape and soil texture

Palazzetto farm is located in Cremona province in the Po-valley in Northern-Italy. The Po-valley is a region characterized by a flat morphology formed by floodplains current and recent formed by small escarpments sloping down to the river system. In this central portion of the Province of Cremona, the morphology is defined by contour lines distributed between 57 and 46 meters above sea level.

Two soil texture types are present on Palazzetto farm and on the specific pilot fields: loam and sandy loam. The Chiappa Grassa field has a loamy soil texture with 44% sand, 40% silt and 16% clay. The Cornaletta field had a sandy loam texture with 55% sand, 34% silt and 11% clay. Chiaso c Nuovo field also has a sandy-loam texture. with 58% sand, 33% silt and 9% clay. In general, both soil types are considered to be relatively fertile.

4.2 Soil quality indicators

The aspects of soil quality that are most likely changed by changes in agricultural practice are: (1) soil carbon levels, (2) soil nutrient levels (specifically nitrogen, phosphorus and potassium) and (3) soil erosion vulnerability (4) soil biota like macro fauna, nematodes and pathogens.

4.3 Soil quality before and after the introduction of sequential cropping

Development of soil organic carbon

Based on data provided by CIB we note that a very substantial increase in soil organic carbon occurred between 2009 and 2016, from 2.5% to 3% on two out of three pilot fields. Only for Chiappa Grassa field soil carbon levels increase only slightly from 2.9% to 3%. The substantial increase in soil organic carbon is very good for the overall soil quality. Probably it results from the introduction of sequential cropping, which leads to an increased quantity of agricultural residues such as triticale straw which is left on the field to decompose. The fact that strip tillage is applied helps to keep carbon below ground. Strip tillage means that only narrow strips where plants are seeded are ploughed. The rest of the field is left untouched which helps to keep soil carbon below ground.

Figure 8 - Strip tillage helps to keep soil carbon below ground

Development of soil nutrient levels

CIB provided soil sample testing results by DuPont Pioneer, an international seed company that performs soil testing. The test results show a remarkable increase in nutrients between 2009 and 2016, especially of potassium, which nearly tripled and phosphorous. Nitrogen levels increase only slightly. The N/P ratio decreased from between 33 and 14.5 to between 23 and 12.3. The N/K ratio decreased from between 24 and 13 to between 6.5 and 4.5. In sum, the soil nutrient levels have increased in recent years. We don't however observe a step-change in 2014 when sequential cropping was introduced. This can indicate that the increase in nutrients is at least partly the result from applying biogas digestate manure (about 40% of biogas feedstock consists of manure).

Accumulation of nutrients is beneficial up to a point. Too much accumulation could eventually lead to nutrient losses to the environment (either greenhouse gas emissions or leaching losses) that might well have environmental impacts. We did not assess this in detail. A quantitative analysis of nutrient flows at the level of the field and the farm is needed to obtain an understanding of the possibility of a long term accumulation of nutrients in the fields used for the sequential cropping, a 'nutrient budget'.

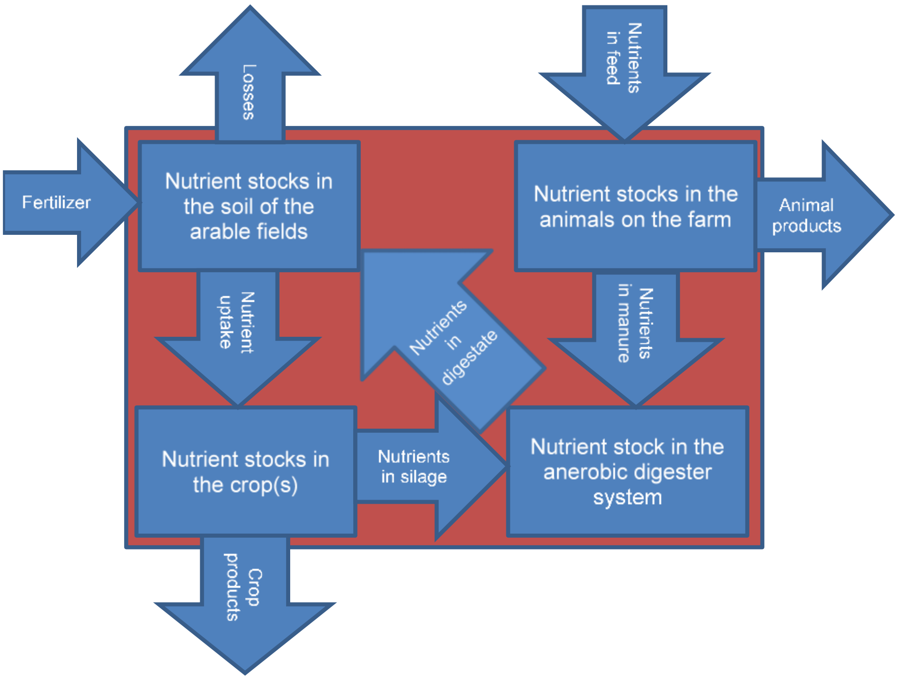

Figure 9 - Elementary nutrient budget for a mixed farm with an anerobic digester system fed with animal manure and crop residues

The figure above illlustrates the concept of an elementary nutrient budget. The large red box represents the whole farm. Four major compartments are distinguished in the farm: the soil, the crops, the animals and the anerobic digester system (including its storage). Each system compartment has a stock of chemical elements. For a nutrient budget, the elements Nitrogen (N), Phosphorus (P) and Potassium (K) are of major importance. These elements enter the farm via two pathways: (1) fertilizer, and (2) animal feed. Elements in the fertilizer are immediately available to the crops, while elements in feed become in part, and after some time, also available to the crops because animal manure is digested and the digestate is used to fertilize the soil. Whether or not there will be accumulation of nutrients in the soil depends on the uptake of nutrients by the crops, and the proportion of those nutrients leaving the farm as crop product. The nutrient balance of the whole farm is determined by the net balance of inflows (mainly fertilizer + feed) and outflows (mainly crop and animal products). If the balance shows a surplus, nutrient stocks on the farm will increase over time, and losses will tend to increase. Nutrient budgets need to be balanced to ensure the system is sustainable in the long term (over many years). Continual monitoring of soil nutrient stocks, crop yields, and other metrics in the years to come will help tailor farm inputs to the levels that ensure sustainability. Existing regulations on nutrient budgets help ensure this sustainability.

Data of CIB indicate increases in stocks of C, N, P and K in the soil. While such increases have (very) positive effects in the short term, e.g. an increase in soil fertility and a reduced need for fertilizer, there could be a long term risk of losses of nutrients if levels of soil nutrients continue to increase substantially in the future. A budgeting at farm level could contribute to gauging whether the Biogasdoneright concept is sustainable from the perspective of a sustainable nutrient balance.

Assessing nutrient budgets and soil nutrient levels should also take into account the buffering capacity of organic matter in the soil, and the (slow) release of nutrients from organic matter decomposition and the possibility of uptake during two consecutive crops in one season. Previous studies highlight the potential beneficial effect of an extended cropping season resulting from sequential cropping on the recovery of nutrients from decomposition (Sorensen, 2004)[5]. Two recommendations may be given: (1) develop nutrient budgets to ascertain that there will be no accumulation of nutrients beyond critical levels, (2) monitor nutrients levels in soil and surface water.

Assessment of soil erosion vulnerability

Soil erosion vulnerability depends on the extent to which soil is covered and on soil compaction, if soil is too compacted rainwater cannot be absorbed and runs-off. The introduction of sequential cropping leads to a situation in which the soil is covered year-round which has a positive effect on prevention erosion. The main driver for soil compaction is traffic on the field. Sequential cropping leads to increased traffic on the field which increases compaction. Palazzetto farm tries to reduce compaction by using feeding the digestate fertiliser not by using a big tank behind a tractor but by either a drip-feed system or an 'umbilical cord', a long tube connected to a tractor to inject the digestate into the soil. In addition, the soil texture of sandy-loam is generally not prone to compaction. The extra input of organic material resulting from the introduction of sequential cropping, leaving more agricultural residues on the field, increases soil organic matter which can increase resistance to compaction. Sequential cropping increases soil coverage which helps to avoid erosion. Growing a second crop leads to an increase in field traffic, such traffic is in general associated with soil compaction. Palazzetto farm minimises compaction by minimising the weight of the equipment when managing the field, e.g. by using an 'umbilical cord' (Figure 10) when applying digestate.

[5] http://dx.doi.org/10.1007/s11104-005-0121-6

Figure 10 - Digestate is injected into the soil using an 'umbilical cord' to avoid soil compaction

Assessment of soil biological characteristics

The introduction of sequential cropping probably increases soil life. This is enforced by the notion that the additional winter crop cultivation does not lead to increased pesticide usage. Introducing additional plant life and more diversity will increase the biota levels. See Section 7.2 for further thoughts on this aspect.

4.4 Conclusions

We assessed potential impacts on soil carbon and nutrient levels, soil erosion vulnerability and soil biota. Based on soil sample testing by DuPont Pioneer, an international seed company, we conclude that soil carbon levels increased greatly after the introduction of sequential cropping. The same is true for soil nutrients potassium and phosphorous, although nitrogen levels remained relatively constant. The remarkable increase in potassium would need further clarification, can be (partly) attributable to the application of biogas digestate which is partly based on manure. A risk of longer term over-accumulation of nutrients exist, which we recommend is further looked into. Sequential cropping increases soil coverage which helps to avoid soil erosion. It also increases field traffic which in general can lead to soil compaction. Palazzetto farm has taken a number of measures to minimise compaction. The introduction of sequential cropping probably increases soil life, although we do not have data that demonstrate this.

5 Greenhouse gas performance of biomethane from manure and cover crops

This chapter provides an estimation of greenhouse gas emission savings of biogas produced on Palazzetto farm from a mix of manure and winter crops cultivated in a sequential cropping scheme, with the biogas being upgraded to biomethane with the aim for it to be used in transport. The Renewable Energy Directive (2009/28/EC) specifies that transport biofuels must achieve at least 50% greenhouse gas emission reduction compared to the fossil fuel reference from 1 January 2018 and 60% reduction for new installations operational since October 2015. Therefore, the emission savings for biomethane should be at least 50%.

5.1 Introduction of sequential cropping leads to higher emission savings

The emission saving of biomethane compared to the fossil fuel reference is estimated for two different agricultural practices:

1) Anaerobic digestion (biogas production) from a combination of maize silage from **mono-cropping** and manure (43%, by weight)
2) Anaerobic digestion from a combination of maize silage and triticale silage from **sequential cropping** as well as manure (40%, by weight)

Figure 11 below shows the emission savings for both practices. The results show that both agricultural practices result in very high emission savings compared to fossil fuel (fossil fuel, 83.8 gCO_2 eq/MJ as included in the EU RED). In the monocrop and manure case a saving of 79.1% and in case of sequential cropping and manure even higher with 86.5%. Since the amount of manure added to the anaerobic digester (AD) is almost the same in both cases, the effect of manure on the emission saving will be the same. These high savings shows that producing biogas from crops cultivated in a sequential cropping scheme can have a positive effect on the greenhouse gas balance of biogas and biomethane. The introduction of sequential cropping therefore not only results in additional biomass that has a low ILUC risk, the practice also improves the direct greenhouse gas balance of biomethane compared to a monocrop or crop rotation 'summer crop only' situation. We note that the total carbon savings can be even higher if the effect of soil carbon accumulation, storing carbon below ground and keeping it below ground by reduced tillage, would be taken into account. We believe that soil carbon accumulation takes place and recommend that this is taken into account in an update of this report.

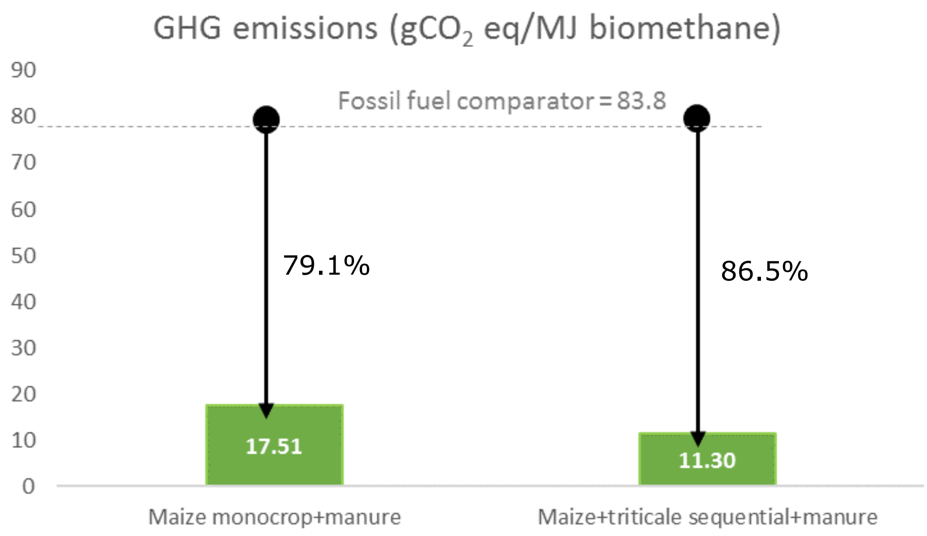

Figure 11: greenhouse gas emissions for biomethane production from co-digestion of manure and monocrop maize silage and saving compared to fossil fuel (left) and for biomethane from manure and maize silage and triticale silage in a sequential cropping scheme (right).

5.2 How biomethane emission savings are calculated

The GHG emissions from co-digestion of different substrates are calculated according to the method described in the Joint Research Centre (JRC, 2014) report [6]. As described there, a possible way to estimate GHG emission of biogas production via co-digestion of multiple substrate is to treat the co-digestion as a simple weighted average of the results obtained for single-substrate pathway, based on the share of biogas produces by each single substrate. The equations used are shown in Box 2 below. Emission savings is then calculated comparing to the fossil fuel reference of 83.8 grams gCO2 eq/MJ.

Emissions from each single-substrate pathway are calculated according to the methodology outlined in Annex V of RED. Figure 11 shows the emissions for different steps of the life cycle of biomethane production from each single agricultural commodity substrate.

[6] Solid and gaseous bioenergy pathways: input values and GHG emissions, JRC, 2014, Report EUR 26696 EN

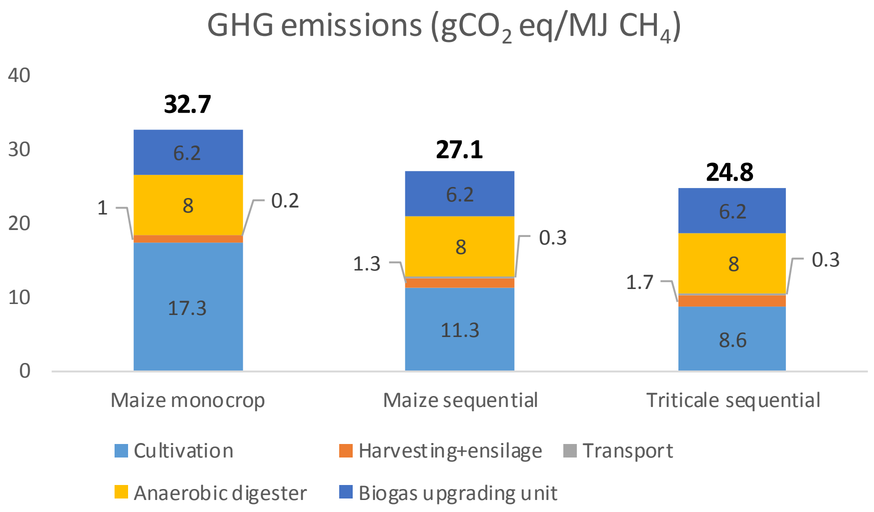

Figure 12: emissions per steps of biomethane production cycle from different crops

The main difference in emissions from maize mono-crop and sequential crops (maize and triticale) stems from the cultivation stage; in case of sequential cropping agricultural machinery and pesticides are used to lesser extent and no synthetic fertilizer is used, compared to the mono-cropping practice. It is noteworthy to also mention that sequential cropping will result in soil carbon accumulation in several years from the beginning of the practice due to the following claims: i) the land is covered during the whole year and strip tillage is used which adds carbon to the soil which is maintained ii) the winter crops are harvested but residues are left in the field to decompose, adding organic matter to the soil and iii) the non-degradable carbons of the crops, which remain at the bottom of biogas installation, the digestate, will be injected or drip-fed into the soil. For emissions of biogas production from anaerobic digestion of manure, a credit value of -111.9 gCO_2 eq/MJ was used from the JRC report. This results in a negative emission of – 75.9 gCO_2 eq/MJ for biomethane production from manure in a closed digestion system with no-off gas burning.

As can be seen from Figure 11 and Figure 12, co-digestion of manure with crops has significant influence in reduction of emissions from biomethane production. Use of manure to produce biogas not only results in renewable energy but also avoids significant methane and nitrogen dioxide emissions from agriculture. Therefore, biogas produced from anaerobic digestion of manure generates an emission credit.

Box 2: method for calculating emissions of biogas production from co-digestion of multiple substrates

The following formulas describe the calculations needed for estimation of GHG emissions of biogas produced *via* co-digestion of multiple substrates:

P_n= biogas yield $_n$ [m^3 $_{biogas}$/ kg $_{volatile\ Solids}$] × volatile solids $_n$ [kg $_{volatile\ solids}$/kg $_{wet\ feedstock}$] × LHV biogas [MJ $_{biogas}$/m^3 $_{biogas}$]

Where:

P_n is the productivity of biogas for each substrate n.

LHV biogas produced from each substrate is calculated based on purity of CH_4 in biogas.

The final share of each substrate n to be used for the weighted average is then given for each feedstock n (maize silage, manure, triticale silage) as:

$S_n = [P_n \times W_n]/\Sigma[P_n \times W_n]_n$

Where the W_n is considered to be the weighting factor of substrate n defined as:

$W_n = (I_n/\Sigma\ I_n) \times (\ 1 - Am_n/1 - SM_n)$

Where:

I_n = Annual input to digester of substrate n [tonne of fresh matter]

AM_n = Average annual moisture of substrate n [kg water / kg fresh matter]

SMn = Standard moisture for substrate n.

The final typical or default GHG emissions for a co-digestion case, starting from single-feedstock values, would then be given by the following formula:

Emissions (co digestion) [gCO_2 eq/MJ $_{biogas}$]= $\Sigma S_n \times En_n$

Where E_n represents the GHG emissions calculated for each single feedstock pathways (maize silage, manure, triticale silage).

6 Impact of sequential scheme on water supplies

As shown in Chapter 3, a more intense agricultural use of land through the introduction of sequential cropping leads to higher crop yields. But has this been achieved without unduly pressure on local water resources and water quality? This chapter explores the water impact of the introduction of the sequential cropping scheme on Palazzetto farm.

Our evaluation will focus on the following indicators:

1. *What is the climate and rainfall during the winter months on the farm?*
2. *Did the introduction of sequential cropping lead to a shift in the irrigation system?*
3. *Can any change in water quality in surrounding water bodies be expected?*

We developed a three-stage approach based on the indicators outlined above to assess what impact the introduction of sequential cropping will have on water availability. The methodology used to assess the impacts of sequential cropping on water availability is based on a qualitative approach. We use available information received from stakeholders, data collected during an on-site visit by Ecofys as well as data from the public sources. The following sections will assess the indicators outlined above.

6.1 Assessment of climate and rainfall in northern-Italy

The climate can be considered typical of the Po valley, relatively uniform region in terms of climate, characterized by cold winters, hot summers, high humidity, especially in areas with richer hydrography, with frequent mists in winter. The average amount of rainfall in the Lombardy region was 827 mm from 2000 to 2009[7]. Wind is low and thunderstorms are frequent during the summer. Figure 13 shows the average amount of rainfall and the temperature at Cremona from 2015 to 2016.

[7] Retrieved on October 21, 2016 from http://www.asr-lombardia.it/ASR/lombardia-e-province/ambiente-e-territorio/clima-e-inquinamento/tavole/100157/

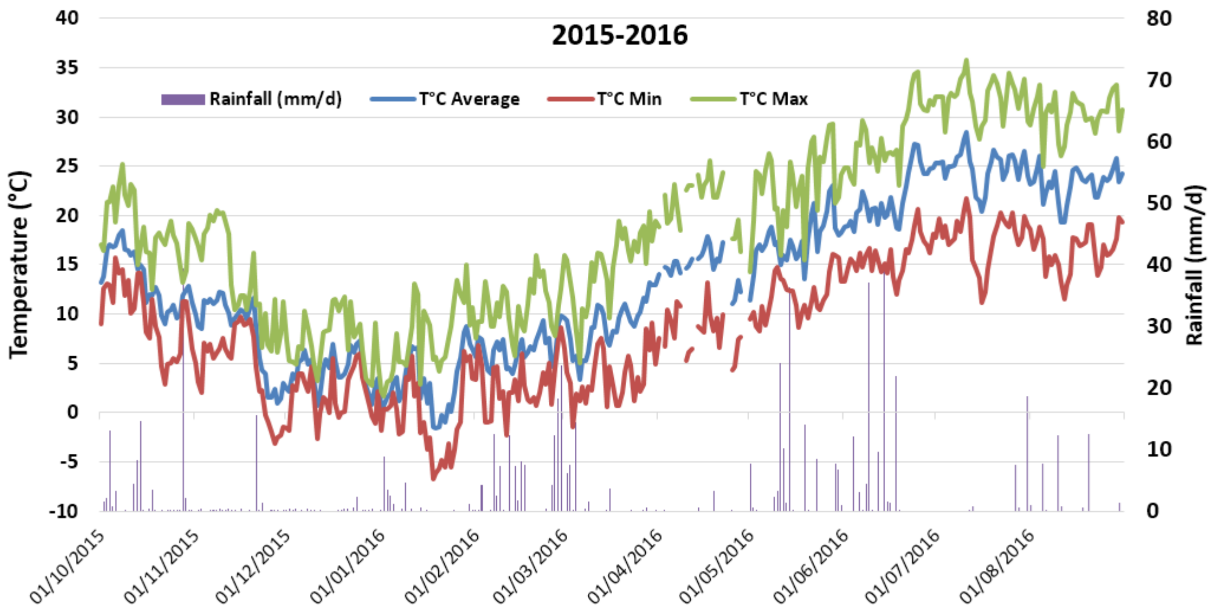

Figure 13 Overview of rainfall and temperature at the Palazzetto Farm - Grumello Cremonese (Cremona) 2015-2016. Data retrieved from Regional Environmental Protection Agency (ARPA) Lombardia Region

6.2 Water availability - irrigation previously and today

Like other farms in northern-Italy, Palazzetto farm uses irrigation to provide sufficient water to cultivated crops. Because the region has relatively high rainfall, with a relatively moist air irrigation is not required year-round. Usually, farmers stop irrigation by end of July. This means that summer crops are irrigated but winter crops are not. A shift from fallow (bare) land to the cultivation of a winter cover crop does not change this situation.

To coordinate the management of local water channels in the Po river basin a system of water rights has been established to ensure that the fields are not flooded at the same time by different farmers. Since 1990 the Po river basin Authority[8] has been responsible for protecting water resources, to mitigation hydrogeological risks, such as floods and landslides as well as to enhance the sustainable use of water resources. It is ensured that the water table of the total river system is sufficiently high for all functions of the water. Water rights are determined based on the surplus compared to the minimum required water table.

Since the introduction of biogas production, Palazzetto farm invested in an efficient drip-irrigation system. The new drip-irrigation and pivot system with sprinklers replaced a *scorrimento* system. The

[8] For more information about the Po river basin Authority please see: http://accbat.eu/the-team/po-basin-authority/

latter refers to an ancient irrigation system which uses dams to raise the water level until the water floods the fields. The fields are left flooded for a few hours for 5-7mm until the fields are drained with water being channelled back into the irrigation channel. The *scorrimento* irrigation system is water intensive and a system which uses local water channels. The pivot system also uses rainwater from local channels as well as groundwater from farm wells. The drip-irrigation system on the other hand uses only groundwater from wells because water from the channels would risk to clog the dripholes.

The change from the *scorrimento* to a drip-irrigation and a pivot system was introduced on the farmland because the drip-irrigation system allows for more precise and efficient irrigation. The farmland irrigation system consumed a substantiate amount of water for the cultivation of maize as a main crop per year with around 240 to 280 mm based on the low efficiency irrigation system *scorrimento* system. Considering the fact that around 500 to 600 mm of water are generally needed to grow a crop, the *scorrimento* system is highly water intensive providing around half of the water needed for the crop cultivation. With the introduction of the drip-irrigation system the water consumption was reduced to around one third of the overall water needed for the crop cultivation with 100 to 150 mm of water. Overall, although the farm switched to a system which mainly uses groundwater - which might have potentially impacts on the aquifer in the long-run - the investment into an effective irrigation system is positive and led to a significant reduction of overall water consumption on the farmland.

The winter crop in the sequential cropping system does not need any additional irrigation and only uses rainfall (even without rain in the winter period since the area is highly moist). It would be useful to make a further analysis of water use at the rotation level as water not used in one year may be stored in the soil profile and used by crops in the next year. Thus, the water budgets of subsequent crops over years are linked.

It would be useful to develop water budgets for the sequential cropping system to make a prospective analysis of the water needs of this system over time (e.g. van Oort et al., 2016)[9]. Water budgets usually contain the following components (FAO, 1998)[10] as illustrated in Figure 14: precipitation, irrigation, evaporation, transpiration, drainage, percolation and capillary rise.

Precipitation is the yearly rainfall, which does not change with sequential cropping. Irrigation was already changed with the introduction of double cropping, using fertigation (drip-feed irrigation and fertilisation), rather than a central pivot irrigation. The total amount was reduced compared to previously, and the efficiency of administering the water to the soil is better with fertigation than with overhead irrigation from a central pivot. **Evaporation** is water loss directly from the soil. **Transpiration** is water lost by the plants when they have their stomata open to fix carbon from the

[9] http://dx.doi.org/10.1016/j.agwat.2015.11.005
10 Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements. FAO Irrig. Drain. Pap. 56, FAO, Rome, 300 p.

air using solar energy (photosynthesis). **Drainage** represents sideways water loss from the field, e.g. through drainage pipes or through canels in the ancient scorrimento system. **Percolation** is water loss to deeper soil layers, out of reach of the roots. **Capillary rise** is water going upwards in the soil against the force of gravity of a result of suction forces due to a wetness gradient in the soil profile.

Sequential cropping reduces evaporation by covering the soil with vegetation, but at the same time it increases transpiration (e.g. van Oort, 2016). Usually, the increase in transpiration is larger than the reduction in evaporation because the vascular system of plants is in general more efficient in transporting water from the soil to the atmosphere than the soil itself. The increased use of water resulting from the introduction of double cropping may (but does not have to) increase water use over time. In the Biogasdoneright system as implemented by the CIB, a water saving system for irrigation was introduced, which may very well offset or more than offset the greater use of water in double cropping for transpiration as compared to monocropping. While this claim is plausible, it would benefit from a further demonstration by the construction of a quantitative water budget.

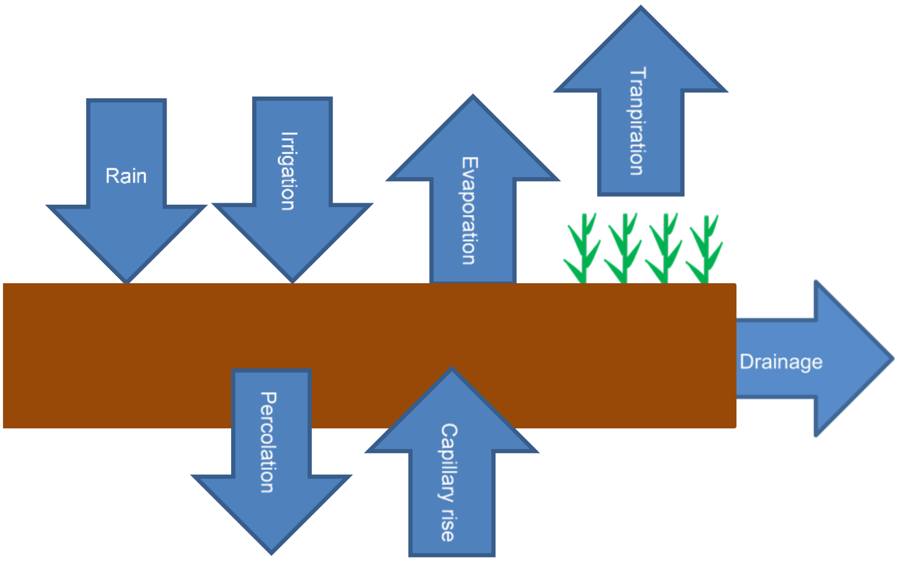

Figure 14 - Elementary water budget for a field. The blue arrows represent yearly flows (m3/ha/year) while the brown box represents the amount of water stored in the rooted zone of the soil (i.e. accessible to plant roots; m3/ha).

6.3 Water quality

The level of nutrients of water that leaves the soil compartment of the crop fields as runoff, percolation or drainage depends on the nutrient levels in the soil and the buffering capacity of organic matter in soil. Thus, the water quality is closely linked to the nutrient and organic matter levels in the soil. Therefore, ensuring a sustainable nutrient budget is a key tool to managing the water quality.

The increased levels of nutrients (P, K) and organic matter in soil at Palazetto farm indicate that the system is dynamically changing under the new system, and changes in soil nutrient levels will need to be managed sustainably in order to safeguard the quality of the water leaving the field. Practices at Palazetto farm are targeted at minimizing water losses, e.g. through keeping the soil covered (which reduces runoff), which will tend to result in minimisation of nutrient emissions.

6.4 Conclusion

Cultivating a second crop as part of the sequential cropping system did not require irrigation during the winter period on the farm because the climate in the Po valley is highly humid and the region does not experience water stress during the winter period. However, growing a winter crop requires more water and increases water consumption. In the case of Palazzetto rainwater is used. It would be useful to make a further analysis of water use at the rotation level as water not used in one year may be stored in the soil profile and used by crops in the next year. A situation has to be avoided that growing a second crop leads to an increase of water needed for growing the main crop. Therefore, we strongly recommend the approach the Palazzetto farm has taken, namely to invest into a highly efficient irrigation system if irrigation is necessary for sequential cropping. Generally, limiting the irrigation needs is strongly recommended. Based on this assessment, further research would be beneficial on the impact of cultivating a second crop during the winter months on the water budget as compared to the previous ‘summer crop only’ situation.

7 On-farm biodiversity impacts

Changes in agricultural management practice from mono-cropping systems to sequential cropping can have an impact on biodiversity. The most dramatic biodiversity losses that can occur result from land-use change, the conversion of natural land such as forest or natural grassland into agricultural land or infrastructure. In this report we assess the shift from a single-crop cultivation practice to a sequential cropping system on existing farmland. This does not lead to direct land use change. Therefore, this chapter focuses on the impact which the shift to sequential cropping can have on on-farm biodiversity.

7.1 How we asses on-farm biodiversity impacts

The methodology used to assess the impacts of introducing sequential cropping on biodiversity levels is based on the following approach:

1) Compilation of available information received from CIB and data collected during an on-site visit by Ecofys as well as from academic journals;
2) A reasoned argumentation of potential impacts based on the information and expertise in the team;
3) A compilation of answers to questions related to field observations by farmers (mainly related to questions 5 and 6 above) contained during an on-site visit by Ecofys.

The results of our evaluation are summarised in the table below.

Table 4 - Overview of biodiversity assessment when introducing sequential cropping

Assessment approach	Indicator	Sequential cropping reference compared to monocrop reference
Management changes	Changes in the management practices occur that have a negative effect on biodiversity?	No
	Changes in cover crop density, providing a change in shelter for small animals and insects?	Yes
	Changes in the risks of floods and related impact on natural habitat?	Yes, the likelihood of erosion is decreased
	The possible effects on belowground biodiversity level, e.g. worms, insects and bacteria in the soil due to differences in root systems?	Yes
Observed changes	Occurrence of animals on the fields	Slightly
	Occurrence of birds on the land in the spring	Slightly

7.2 Assessment of various biodiversity indicators

In the following paragraphs more details and background for each of the indicators assessed is provided.

Management changes: Changes in the management practice
Comparing to the reference situation of bare land during the winter period to the introduction of sequential cropping we observed a change in management practices. The Palazzetto farm used the pesticide FORCE Syngenta which contains Tefluthrin, a pyrethroid insecticide. Farmers reported that before the introduction of sequential cropping 13 kg/ha of FORCE Syngenta was used for maize as a main crop. Following the introduction of sequential cropping the use of FORCE Syngenta for maize grown as a main crop stayed the same with 13 kg/ha. Pesticides were not applied to the winter crop in the sequential cropping system. In terms of changes on the amount of insecticides used when monocropping was replaced by sequential cropping, we did not find an increase in pesticides used and we conclude that the impact on biodiversity did not change.

Management changes: Density of the cover crop
With this indicator, we are analysing changes in the size and the density of the cover crop and whether it increases or reduces the shelter for small animals or insects or whether they remain the same. Figure 4 – Summer crop only cultivation and sequential cropping situation at Palazzetto farmshows that until 2014 the farm only produced summer crops. In 2014 sequential cropping was introduced. As fertilizers and pesticides are not used for the second crop grown during the winter months, we do not expect any harmful effects on habitat for small animals and insects. In contrast, due to the introduction of plants on the field that has been previously unused during the winter months, we expect an increase of insects and small animal densities, particularly through associated weedy plants and the resources they provide to vertebrate and invertebrate fauna, and especially if the winter crop is extensively managed (e.g. Clough et al. 2007[11]).

Management changes: Flood risks
Changes in the likelihood of floods are relevant because of possible effects on natural habitats. The increased coverage of the soil in the double cropping system can contribute to mitigating erosion. This effect is particular to be expected if a small cereal such as triticale is used as a winter crop. The biogasdoneright method does not use tillage for the cultivation of the winter crop, which could counteract the positive effects of covering the soil. On this basis a decrease in flood risks is expected.

We expect that water quality would impact biodiversity less at the farm level but downstream along the Po river. The long-term impacts of sequential cropping on water quality especially on the potential risks associated with the digestate is outlined in chapter 6.

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[11] Clough, Y., Kruess, A., & Tscharntke, T. (2007). Local and landscape factors in differently managed arable fields affect the insect herbivore community of a non-crop plant species. Journal of Applied Ecology, 44(1), 22-28.

Management changes: Belowground biodiversity

Our understanding of biodiversity and ecosystems functioning often comes from observational investigations that usually focus on aboveground productivity in terms of species richness. However, above-and belowground communities shape ecosystem functioning and should be investigated in combination[12]. Crop rotation with a diversity of crop species has a significant positive impact on belowground microbial biodiversity (Venter et al., 2016[13]). However, the consequences of this microbial diversity for the provision of ecosystem services are a topic of ongoing scientific study (Eisenhauer, 2016[14]). Tieman et al. (2015[15]) found that increased crop species diversity through crop rotation in an agro-ecosystem increased both microbial diversity and ecosystem services such as soil carbon content, soil nitrogen content, and soil aggregation.

We expect that the introduction of sequential cropping and the Biogasdoneright method will have a positive impact on the belowground biomass compared to the reference situation with bare farmland during the winter months as a result of greater input of plant litter into the soil (Cong et al., 2015[16]). We expect that cultivating crops during the winter months may also increase the crop diversity in the rotation and thereby may not only increase the level of belowground biomass but also diversify the belowground communities as different crops support different species (e.g. Castro et al., 2016[17]). Such diversification tends to support valued soil ecosystem services (Tiemann et al., 2015[15]). Since detailed belowground biodiversity assessment data were not available at the time, further research could be done on the positive impacts sequential cropping can have on belowground biodiversity and ecosystems. Furthermore, it should be determined whether positive diversity effects identified in rotations with one crop per year (e.g. Tiemann et al., 201515 above[15]) also extend to rotations with two crops per year. Verzeaux et al. (2016[18]) report on positive effects on soil properties of including cover crops as a second crop in a season. Results for cover crops cannot be directly translated to second crops which are harvested, such in sequential cropping, because in the case of cover crops the whole biomass is usually incorporated in the soil, while in the Biogasdoneright cropping systems, only belowground biomass and agricultural residues (straw etc.) remain, while only part of the aboveground biomass will be returned to the land as digestate. Nevertheless, it is expected that the direction of effect for cover crops and second crops will be the same.

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[12] Jing, X., Sanders, N. J., Shi, Y., Chu, H., Classen, A. T., Zhao, et al. (2015). The links between ecosystem multifunctionality and above- and belowground biodiversity are mediated by climate. *Nature communications, 6*.

[13] Venter, Z. S., Jacobs, K., & Hawkins, H. J. (2016). The impact of crop rotation on soil microbial diversity: A meta-analysis. Pedobiologia.

[14] Eisenhauer, N. (2016). Plant diversity effects on soil microorganisms: Spatial and temporal heterogeneity of plant inputs increase soil biodiversity. Pedobiologia.

[15] Tiemann, L. K., Grandy, A. S., Atkinson, E. E., Marin-Spiotta, E., & McDaniel, M. D. (2015). Crop rotational diversity enhances belowground communities and functions in an agroecosystem. Ecology letters, 18(8), 761-771.

[16] Cong, W. F., Hoffland, E., Li, L., Six, J., Sun, J. H., Bao, X. G., ... & Van Der Werf, W. (2015). Intercropping enhances soil carbon and nitrogen. Global change biology, 21(4), 1715-1726.

[17] Castro, H., Barrico, L., Rodríguez-Echeverría, S., & Freitas, H. (2016). Trends in plant and soil microbial diversity associated with Mediterranean extensive cereal–fallow rotation agro-ecosystems. Agriculture, Ecosystems & Environment, 217, 33-40.

[18] Verzeaux, J., Alahmad, A., Habbib, H., Nivelle, E., Roger, D., Lacoux, J., ... & Dubois, F. (2016). Cover crops prevent the deleterious effect of nitrogen fertilisation on bacterial diversity by maintaining the carbon content of ploughed soil. Geoderma, 281, 49-57.

Observed changes: Occurrence of new animal species
We investigated the natural vegetation levels before and after the introduction of sequential cropping and whether species richness increased, decreased or whether it remained the same. CIB indicated that farmers did not observe any changes in species richness and diversity on the farmland. Positive benefits in terms of species richness depend on the amount of fertilizers and pesticides used. There are no changes in fertilizer and pesticide use in the main crop after the introduction of double cropping, hence the effect is neutral in the main crop. The winter crop, grown for biogas, is additional and is grown using less intensive methods (e.g. no pesticides). This would tend to conserve biodiversity and might provide some limited resources for small animals and insects, e.g. through providing cover and food resources such as nectar, pollen and seeds from weedy plants in the winter crop. If there are effects of small animals and insects, these are likely to be increases in abundance and diversity rather than decreases. We expect that there will be slight improvements in terms of biodiversity because crop rotation during the winter period provides for a greater variety of food sources (weeds and grains) at different times of the year.

Observed changes: Occurrence of birds
The winter crop in double cropping can in principle provide some resources to farmland birds in the form of shelter and food resources from weedy plants in the crop (e.g. nectar from flower, and seeds). However, the data we received indicates that there was no change in the observation of farmland birds. We have not managed to talk to bird watchers. Nesting within the field is not considered relevant. Thus, while there is a limited potential for improvements in bird life, current data suggest no change occurred as a consequence of the introduction of sequential cropping.
However, we expect slight positive effects on common farmland birds that will depend on the crops cultivated and whether weeds stay on the fields. Triticale for example is expected to have a positive impact on birds since it is often used in wild bird seed mixes (mainly because triticale sheds seeds later compared to other cereals). Brassica could potentially provide additional shelter because of the pests on plants. In addition, we expect positive effects if the winter crop flowers (e.g. phacelia and buchwheat as well as some legumes) that can provide nectar and pollen (see also: Storkey et al. 2013[19]; Holland et al. 2012[20]; Holland et al. 2015[21]).

7.3 Conclusion

Small positive on-farm biodiversity impacts are expected after replacing monocropping with sequential cropping combined with nutrient recovery via biogas digestate. This is especially the case

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[19] Storkey, J., Brooks, D., Haughton, A., Hawes, C., Smith, B. M., & Holland, J. M. (2013). Using functional traits to quantify the value of plant communities to invertebrate ecosystem service providers in arable landscapes. Journal of Ecology, 101(1), 38-46.
[20] Holland, J. M., Smith, B. M., Birkett, T. C., & Southway, S. (2012). Farmland bird invertebrate food provision in arable crops. Annals of Applied Biology, 160(1), 66-75.
[21] Holland, J. M., Storkey, J., Lutman, P. J. W., Birkett, T. C., Simper, J., & Aebischer, N. J. (2014). Utilisation of agri-environment scheme habitats to enhance invertebrate ecosystem service providers. Agriculture, Ecosystems & Environment, 183, 103-109.

if crop species diversity in the rotation is increased through the inclusion of winter crops that are not included in the previously existing rotation of the main crop (i.e. soybean). We found small positive impacts of the sequential cropping in terms of crop density and additional shelter for species, prevention of soil erosion, observation of new animal species and below-ground biodiversity levels. The benefits of sequential cropping on biodiversity depends on the overall approaches taken, e.g. the species chosen and the management, e.g. soil tillage and input of fertilizer and pesticides. Farmers may consider using cover crops for biogas that offer a broader range of services in addition to pure biomass, for instance legumes for biological N fixation, crops producing seeds that are attractive to birds, and flowering crops that support bees. From these findings, further research would be beneficial particular on the impact of sequential cropping on belowground biodiversity and ecosystem services at the farm level.

We recommend that further research is conducted on down-stream biodiversity impacts where negative effects on biodiversity could potentially take place in the long-term. This would depend on the effect of sequential cropping on water quality, see Chapter 6.

8 Economic feasibility and scalability

8.1 Business case for sequential cropping

Even if may be possible to introduce sequential cropping to create additional biomass in a truly sustainable manner, the question arises whether farmers would be willing to change their way of farming. Is there a solid business case to support such change? We estimate the business for the sequential cropping of maize silage and triticale silage in comparison to mono-cropping of maize silage based on data provided by CIB. This is in line with the target crop approach used for the low ILUC assessment in chapter 3. The respective costs are listed in the table below.

Table 5: Business case – Sequential cropping of maize and triticale silage

Costs / revenue	Unit	Maize silage – Monocrop	Triticale silage in sequential cropping	Maize silage in sequential cropping	Maize silage & Triticale silage – Sequential cropping
COSTS					
Yields - Fresh matter	t/ha	**58**	46.2	53.1	**99.3**
Yields - Dry matter	t/ha	**20.3**	14.8	18.6	**33.4**
Forage Unit	FU	**17,864**	11,804	16,355	**28,159**
Land opportunity cost	€/ha	**750**	300	450	**750**
Labour and seeding cost	€/ha	**340**	300	380	**680**
Fertilizers*	€/ha	**480**	0	0	**0**
Digestate application	€/ha		100	90	**190**
Pesticides	€/ha	**125**		125	**125**
Irrigation	€/ha	**400**		450	**450**
Insurance	€/ha	**40**	30	40	**70**
Third parties harvesting transport and silaging	€/ton FM	**348**	277	318	**596**
TOTAL COST	**€/ha**	**2,483**	1,007	1,853	**2,861**
Costs per tonne of Fresh matter	€/tonne	43	22	35	
Biogas feedstock cost	€/MWt	38	22		
Feed costs per FU	€/FU	0.14		0.11	

* No mineral fertilisation applied for the winter crop in the sequential cropping scheme on Palazzetto farm.

Compared to the conventional cultivation of maize silage the sequential cropping of maize silage and triticale silage leads to a reduction of both biogas feedstock costs and animal feed costs. We note a 21% decrease in feed costs and a 42% decrease in biogas feedstock costs. This will be the most important reason for farmers to invest in sequential cropping as a yield increase measure.

8.2 Scope to introduce sequential cropping throughout the EU

Sequential cropping works on Palazzetto farm. Can it also work elsewhere? We did not assess this question in detail. Still, we would like to give a rough potential estimate based on some basic assumptions.

Our estimation focuses only on how the specific sequential cropping scheme as applied on Palazzetto farm, maize silage with triticale silage, can be scaled-up. It is clear that other types of sequential cropping as possible as well. Italian farmers that are members of CIB implement a variety of crop combinations in sequential cropping, which we did not assess in this study report. Also, our estimation focuses on Italy and France only. As Palazzetto is based in the northern part of Italy, with colder temperatures in winter than in the south, we assume that the sequential cropping scheme could be introduce in whole of Italy. Furthermore, we assume that the sequential cropping scheme can quite easily be introduced in the southern and central parts of France. Although we have indications that sequential cropping is tested also in northern Europe (Sweden, Netherlands), we did not assess this in our current study and therefore no not include it in our estimate here.

According to Eurostat, maize silage (referred to as green maize)[22] was cultivated on 0.342 million hectares in Italy in 2015. As Palazzetto is based in the northern part of Italy, with colder temperatures in winter than in the south, we assume that the sequential cropping scheme could be introduce in whole Italy. Furthermore, we assume that the sequential cropping scheme can partly be introduced in France, where maize silage was cultivated on 1.475 million hectares in 2015. For a conservative potential we assume that the sequential cropping scheme can be introduced on 50% of the land in France, i.e. 0.737 million hectares. In a conservative estimate, we assume that **at least 1 million of hectares can be used to introduce maize and triticale sequential cropping without displacing other crops in Italy and France alone.** A **much larger potential** is expected if other crop combinations suitable for sequential cropping are taken into account and if the potential in other countries is taken into account. We recommend a more detailed study into the potential of sequential cropping in the EU and elsewhere.

[22] http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=tag00101&language=en

9 Conclusions

Study aim and methodology

In this report Ecofys assesses for the Italian Biogas Council whether the introduction of a sequential cropping scheme for maize silage, triticale silage and soybean cultivation leads to additional, low ILUC risk biomass compared to the previous 'summer crop only' situation, in which the land was fallow during winter time. Sequential cropping is a cultivation system in which a summer crop and a different winter cover crop are being produced on the same plot of land in the same year. We also assess whether the more intense use of farmland is possible without negative impacts on soil, water and on-farm biodiversity and whether biomethane produced from the sequential cropping system meets the minimum required GHG threshold for transport biofuels. We focus our assessment on Palazzetto farm in the Po-valley in northern Italy, which introduced sequential cropping in 2012/13. Both before and after the change to sequential cropping, the farm produces animal feed and biogas from a mix of crops and manure, feeding the digestate, a nutrients-rich residue, back to the fields.

Low ILUC risk – additional biomass without displacement of existing feed production

Biofuels are low ILUC risk or ILUC-free if it can be demonstrated that no displacement of existing food and feed production takes place. This is the case if biofuel feedstock is produced additional to food and feed production. We assessed whether sequential cropping can be a good model to increase crop yields and lead to substantial production of additional biomass. Palazzetto farm produces maize silage and triticale silage in a sequential cropping scheme. Both crops can be used for animal feed or biogasl production. We want to ensure that sequential cropping does not lead to a lowering of animal feed production. This is why we calculated the overall crop yields of the previous 'summer crop only' situation translated into 'forage units', a measurement used to quantify the feed value of different feed crops. We observe that at Palazzetto farm the quantity of forage units increases after the introduction of sequential cropping. Calculated from forage units to tonnes per hectare, 35.18 t/ha of additional triticale silage as winter crop was produced on C. Grassa field, in 2012 and 28.46 t/ha on C Nuovo field in the same year. On Cornaletta field, sequential cropping was introduced in 2013 with additional, above reference yield of triticale silage as winter crop of 37.41 t/ha. These results show that **sequential cropping results in a substantial production of additional biomass** that does not lead to negative indirect land use change and does not negatively impact food production.

Soil quality

We assessed potential impacts on soil carbon and nutrient levels, soil erosion vulnerability and soil biota. Based on soil sample testing by Pioneer, an international seed company, we conclude that soil carbon levels increased greatly after the introduction of sequential cropping. The same is true for soil nutrients potassium and phosphorous, although nitrogen levels remained relatively constant. The remarkable increase in potassium would need further clarification, can be (partly) attributable to the application of biogas digestate which is partly based on manure. A risk of longer term over-accumulation of nutrients exist, which we recommend is further looked into. Sequential cropping increases soil coverage which helps to avoid soil erosion. It also increases field traffic which in general can lead to soil compaction. Palazzetto farm has taken a number of measures to minimise compaction. The introduction of sequential cropping probably increases soil life, although we do not have data that demonstrate this.

Greenhouse gas savings

We assessed greenhouse gas savings for biomethane of single-crop maize silage and manure as well as for sequential cropping and manure. Both result in very high emission savings compared to fossil fuel reference. In the monocrop and manure case a saving of 79.1% and in case of sequential cropping and manure even higher with 86.5%. Since the amount of manure added to the biogas installation is almost the same in both cases, the effect of manure on the emission saving will be the same. These high savings shows that producing biogas from crops cultivated in a sequential cropping scheme can have a positive effect on the greenhouse gas balance of biogas and biomethane. The introduction of sequential cropping therefore not only results in additional biomass that has a low ILUC risk, the practice also improves the direct greenhouse gas balance of biomethane compared to a monocrop or crop rotation 'summer crop only' situation. We note that the total carbon savings can be even higher if the effect of soil carbon accumulation, storing carbon below ground and keeping it below ground by reduced tillage, would be taken into account. We believe that soil carbon accumulation takes place and recommend that this is taken into account in an update of this report.

Water

Cultivating a second crop as part of the sequential cropping system did not require irrigation during the winter period on the farm because the climate in the Po valley is highly humid and the region does not experience water stress during the winter period. However, growing a winter crop requires more water and increases water consumption. In the case of Palazzetto rainwater is used. It would be useful to make a further analysis of water use at the rotation level as water not used in one year may be stored in the soil profile and used by crops in the next year. A situation has to be avoided that growing a second crop leads to an increase of water needed for growing the main crop. Therefore, we strongly recommend the approach the Palazzeto farm has taken, namely to invest into a highly efficient irrigation system if irrigation is necessary for sequential cropping. Generally, limiting the irrigation needs is strongly recommended. Based on this assessment, further research would be beneficial on the impact of cultivating a second crop during the winter months on the water budget as compared to the previous 'summer crop only' situation.

On-farm biodiversity

Small positive on-farm biodiversity impacts are expected after replacing monocropping with sequential cropping combined with nutrient recovery via biogas digestate. This is especially the case if crop species diversity in the rotation is increased through the inclusion of second crops that are not included in the previously existing rotation of the main crop (i.e. soybean). We found small positive impacts of the sequential cropping in terms of crop density and additional shelter for species, prevention of soil erosion, observation of new animal species and below-ground biodiversity levels. The benefits of sequential cropping on biodiversity depends on the overall approaches taken, e.g. the species chosen and the management, e.g. soil tillage and input of fertilizer and pesticides. Farmers may consider using cover crops for biogas that offer a broader range of services in addition to pure biomass, for instance legumes for biological nitrogen fixation, crops producing seeds that are attractive to birds, and flowering crops that support bees. From these findings, further research would be beneficial particular on the impact of sequential cropping on belowground biodiversity and ecosystem services at the farm level.

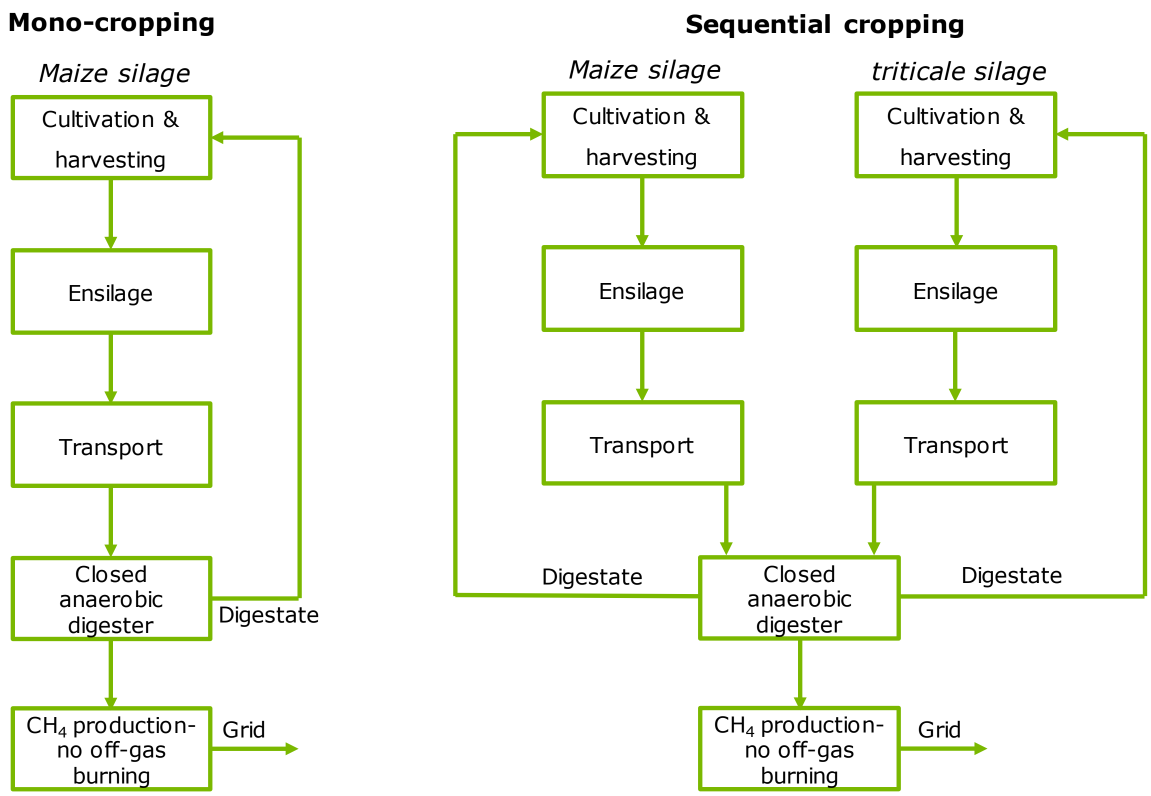
Business case and scalability

Even if may be possible to introduce sequential cropping to create additional biomass in a truly sustainable manner, the question arises whether farmers would be willing to change their way of farming. Compared to the conventional cultivation of maize silage the sequential cropping of maize silage and triticale silage leads to a reduction of both biogas feedstock costs and animal feed costs. Based on data provided by CIB, we note a 21% decrease in feed costs and a 42% decrease in biogas feedstock costs. This will be the most important reason for farmers to invest in sequential cropping as a yield increase measure.

Sequential cropping works on Palazzetto farm. Can it also work elsewhere? We did not assess this question in detail. Still, we would like to give a rough potential estimate based on some basic assumptions, focusing on Italy and France only. In a conservative estimate, we assume that **at least 1 million of hectares can be used to introduce maize and triticale sequential cropping without displacing other crops in Italy and France alone.** A **much larger potential** is expected if other crop combinations suitable for sequential cropping are taken into account. We recommend a more detailed study into the potential of sequential cropping in the EU and elsewhere.

Annex I – GHG saving calculation method

For the calculation of GHG emission from each of the two biomethane pathways, different steps of the life cycle as outlined in the graph below are taken into account.



The table below summarises the input data for the GHG emission calculation provided by CIB.

Parameters	unit	Maize silage mono-crop	Maize silage sequential crop	triticale silage sequential crop
Fresh product yield	t/ha	62.00	53.00	46.00
Water content	%	65	67	70
Fertilizers				
Urea - 46%N	kgN/ha	80	0	0
P2O5	kgP2O5/ha	-	-	-
K2O	kgK2O/ha	-	-	-
Digestate applied	t/ha	52.5	65.3	58.6
Agrochemicals				
Pesticides	kg/ha	12.00	0.00	0.00
Herbicide	kg/ha	3.4	3.40	
Insecticide	kg/ha	1	0	
Total farming operations				
Diesel	l/ha	211.8	146.3	96.3

The data provided are based on the following claims for sequential crops:

- No synthetic fertilizers are used due to well manure management and use of digestate as natural fertilizers on the field.
- Reduced amount of pesticides is used due to the claim that the soil is covered through the whole year which reduces the amount of fungus, and other unwanted vegetation hence reduces the amount of pesticides.
- Less amount of agricultural machinery activities is used due to improved agricultural management, e.g., less tillage, no passive harrowing, no machinery for the application of fertilizer.

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