Designing and assessing bioeconomy oriented cropping systems

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Abstract

France, and particularly Northern France, want to place bioeconomy at the heart of their economy. Agricultural sector is a strong link of bioeconomy, as bioeconomy is the photosynthesis economy, based on sustainable production, increased mobilization, and optimized use of biomass, in particular of agricultural biomass.
Biomass production has to provide various raw materials, to input a diversity of bioeconomy sectors: food, feed, biogas production, bio-sourced materials, oil and sugar chemical industry.
To allow this food/non-food complementarity and to develop biomass supply chains on rural areas, innovation in production systems is required to produce sustainable and efficient bioresources to supply locally bioeconomy sectors within a territory, while preserving agro-ecosystem performances and meeting stakeholder's expectations (farm, industrial and territory players).
Meeting the multiple objectives of bioeconomy seems to be a daunting challenge for agricultural systems, that need to be redesigned by developing in synergy agro ecological approaches and cropping system diversification.
One of the purposes of the "Demonstrating Sites Network" project is to demonstrate whether it is feasible, in the agricultural sector, to produce various sustainable and efficient bioresources in the current cropping systems of Northern France, in order to supply various bioeconomy sectors (food, feed, biogas production, bio-sourced materials, oil and sugar chemical industry).
To achieve its objectives, our approach aims at designing oriented bioeconomy cropping systems with a large range of bio resources production (green or dry lignocellulose, fiber, oilseeds) and by using innovative techniques. Prototype of new cropping systems were co-designed with Scientifics and Experts by focusing on the most currently cultivated cropping systems in Northern France (potato-, sugar beet- cereal/oilseed-and forage- oriented systems), from which bioeconomy oriented systems have been designed.
Each proposed system has to satisfying simultaneous goals: maximizing and diversifying biomass production, meeting farmers and industrial sectors issues, providing additional ecosystem services (organic matter, weed control, soil structure, soil fertility), given the major constraints and agro-ecological targets.
Several bioeconomy scenarios with increasing gradient of biomass production were designed for each current cropping system according to these guidelines. Many levers were used to devise prototypes: exportation of some straws, diversification of crops, intercropping including legume crops, introduction of dedicated non-food crops (hemp, camelina), cultivation of 3 biomass crops in 2 years, harvesting of catch crop…
Three types of cropping systems, with increasing biomass production gradient, were designed: 1) First scenario is "the control scenario", corresponding to the current systems. 2) Second scenario is the "light bioeconomy scenario": modifying the current system to increase the biomass production, while keeping food crops (species and number). 3) Third scenario is the "high bioeconomy scenario": innovative system, with major breakthrough: substitute food crops by non-food, elongation of crop succession, etc.
All the cropping systems are tested in long-term field experiments (2015-2020): 18 cropping systems are tested, divided on five experimental platforms located in different regions of Northern France. Regular measurements are realized in order to evaluate agro-ecosystem performances by calculating agronomic (yield and quality production, soil structure, pests and diseases control) environmental (organic content, N, P and K balance, nitrate leaching, water consumption, potential risks of pesticide transfers, GHG emissions, energy consumption, arthropod biodiversity) and socio-economic (gross margin, semi-net margin, peak work load, work time) performance indicators. The performances of the bioeconomy systems are then compared to the control scenario, and used to assist continuous improvement of the bioeconomy systems to ensure the technical feasibility and to meet the multiple objectives of the bioeconomy.
The expected output of these experiments is to provide references about performances, impacts and ecosystem services of bioeconomy oriented cropping systems, feedbacks, tools and methods to optimize biomass production and mobilization.

Applicable Topic: 1 Biomass Resources
Sub-topic number: 1.6 Integrated biomass production for energy purposes

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Introduction

Bioeconomy is the photosynthesis economy, based on sustainable production, increased mobilization, and optimized using of biomass, in particular of agricultural biomass (MAAF, 2017). It encompasses all biomass productions and processing activities: production of food, feed, bio-based materials, u, and energy. For a few years, the sustainable development of the bioeconomy is supported by French policies. Bioeconomy strategy in France have been recently clarified by the government and described into the "Bioeconomy strategy for France" (MAAF, 2016).
Northern France has major assets to exercise in bioeconomy sectors:

- existing or developing outlets, which are supported by the Industries and Agro-Resources biorefining cluster
- presence of transport infrastructures and industrial facilities hosting or able of hosting bioeconomy projects.
- high potential of biomass production

The agricultural sector is a huge carbon source that could contribute to supply locally bioeconomy sectors in Northern France. However, as competition between food and no food is complex to handle in bioeconomy, maximizing biomass production and optimizing its uses are expected. To allow this complementarity between food and non-food uses, innovation in production systems is required to produce sustainable and efficient bioresources to supply bioeconomy sectors, while preserving agro-ecosystem performances (biodiversity, landscape, soil fertility, environmental impacts…) and meeting stakeholder's expectations (farmers, industrials and territory stakeholders).
Meeting the multiple objectives of bioeconomy thus represents a huge challenge for agricultural systems, that need to be redesigned by developing in synergy agro ecological approaches and cropping system diversification (Messéan, et al., 2017).
In this background, one of the purposes of the "Demonstrating Sites Network" project is to design sustainable and efficient innovative cropping systems to supply, with various raw materials, a diversity of bioeconomy sectors (food, feed, biogas production, bio-sourced materials, oil and sugar chemical industry) adapted to Northern France.
To achieve these objectives, this project is based on multicriterial evaluation of long-term field experiments of bioeconomy oriented cropping system. The expected outputs of these experiments are to provide references about performances, impacts and ecosystem services of bioeconomy-oriented cropping systems, feedbacks, tools and methods to optimize biomass production and mobilization. These references will be integrated in a global approach developed by the "Demonstrating Sites Network" project[1], which aims at building assistant procedure to guide the future actors to develop a new sustainable bioeconomy project, from an industrial carrying a project to farmers producing the resources.
This paper presents the methodology which is going to be implemented to design and assess bioeconomy-oriented cropping systems.

Purpose of the work and approach

The aim of the "Demonstrating Sites Network" project is to demonstrate the feasibility, for agricultural sector, to produce various sustainable and efficient bioresources in current regional cropping systems in order to provide simultaneously various food and non-food outlets.
More precisely, the project should enable to:

- design innovative cropping systems adapted to Northern France, to supply diversified existing or emerging bioeconomy sectors, which reconcile high biomass productivity while ensuring environmental and farmer's revenue protection.
- provide farmers and their advisers with more agronomical keys to enhance the implementing of "bioeconomy-oriented" cropping systems
- evaluate benefits and externalities of producing food and non-food bioresources in cropping systems.

To meet our objectives, we used the prototyping method to design several innovative cropping systems, which are going to be tested, evaluated and improved in long-term field experiments in different soil and climatic conditions.

In this study, new cropping systems were co-designed on the basis of scientific and expert knowledge by focusing:
1) on the most currently cultivated cropping systems in Northern France (potato-, sugar beet- cereal/oilseed-and forage- oriented systems), from which bioeconomy-oriented cropping systems have been designed.
2) and on food, feed, biogas production, bio-sourced materials, oil and sugar chemical industry bioeconomy sectors; thus, designed cropping systems should produce resources to supply these sectors, such as green or dry lignocellulose, fiber, or oilseeds.

[1] Projet « Réseau de sites démonstrateurs IAR" in French

Each proposed cropping system needs to satisfy simultaneous goals: maximizing and diversifying biomass production, meeting farmers and industrial sectors issues, providing additional ecosystem services (organic matter, weed control, soil structure, soil fertility, etc.), given the major constraints and agro-ecological targets.
Several bioeconomy scenarios with increasing gradient of biomass production were designed for each current cropping system according to these guidelines. Many levers were used to devise prototype:

- the exportation of straw from oilseed and cereals crops
- the diversification of crops
- the intercropping including legume crops
- the introduction of dedicated non-food crops (hemp, camelina)
- the cultivation of 3 biomass crops in 2 years
- the harvesting of catch crop

Three types of cropping systems, with increasing biomass production gradient, were designed:
1) The first scenario is "the control scenario", corresponding to the potato-, sugar beet- or cereal/oilseed-oriented current systems. It is the conventional system used as reference to compare the performances of bioeconomy scenarios.
2) The second scenario is the "light bioeconomy scenario": modifying the current system to increase the biomass production, while keeping food crops (species and number), and satisfying all the aforementioned goals.
3) The third scenario is the "high bioeconomy scenario": a disruptive innovative cropping system, with major breakthrough as the substitute food crops by non-food crops, elongation of crop succession, etc.

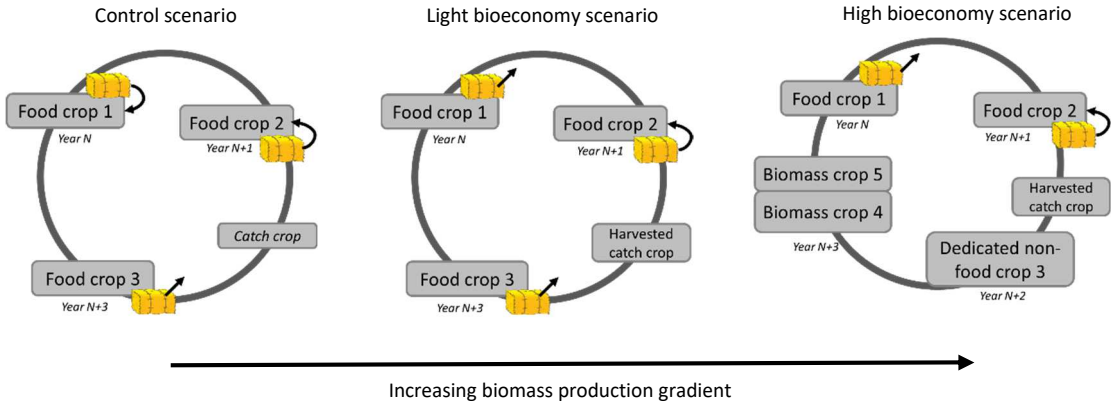

Figure 1: Principles of bioeconomy-oriented cropping systems designed from the control cropping system, with increasing biomass gradient. The small arrows symbolize the exportation or restitution of straw).

These cropping system prototypes were assessed with SIMEOS-AMG model[2] (ex_ante assessment) to make sure that soil organic matter is held, which is a major challenge and adjust the cropping system prototypes if required.
Once this criterion was satisfied, the designed cropping systems were implemented in several long-term field experiments, to evaluate the feasibility and the performances of each proposed scenario (ex post assessment), and enable their improvement. In total, eighteen cropping systems are carried out in five different pedoclimatic contexts, which is currently underway, under agricultural conditions (agricultural equipment's and inputs).

Result and conclusions

The study is based on five experimental platforms, located in different areas of Northern France. Each platform deals with one type of oriented current system and with 2 or 3 cropping bioeconomy systems. For each current cropping system, 3-4 specifics agro-ecological targets were identified. The bioeconomy cropping systems designed have to achieve these targets in addition to sustainable and efficient bio resource production.
For example, on the "Aizecourt-le-Haut" experimental platforms, the control scenario is a sugar beet-oriented system. The light and high bioeconomy scenarios have been designed to maximize biomass production, to preserve soil organic matter, to protect soil structure, and to improve nitrogen fertilizer independence. The tested scenarios are presented below (Figure 2).

[2] SIMEOS-AMG model: developed from the AMG model to modelling soil carbon dynamics under cultural practices effects over the long term

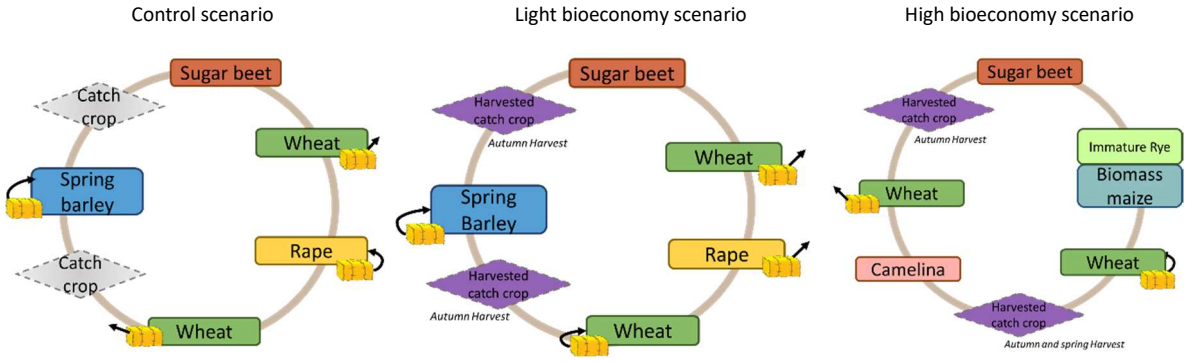

Figure 2: Example of tested scenarios in one of the 5 experimental platforms

On the experimental platforms, to free itself from inter-annual effects and to highlight the cropping system effects in a range of climatic conditions, each crop of the crop rotations is cultivated each year, on a plot of 0.25 hectares. For example, in the previous example (figure 2), the experimental plan consists of fifteen plots. Each plot will get the entire crop rotation. In total, 74 plots are monitored in this study until 2020.

In 2015, before the experiment beginning, several agronomic and pedological measurements have been implemented to characterize the plots (carbon, nitrogen, phosphorus and potassium content, granulometry, bulk density, soil depth, soil structure, etc.).

During the cropping season, crop walk is weekly conducted to observe growth stage, to monitor pests, diseases, lodging, and vegetation state (vigor, homogeneity, % of soil cover). Moreover, several measurements are carried out in order to evaluate agro-ecosystem performances: plant emergence rate, plant height, yield and quality of the crop from manual harvest and weight, dry matter C, N, P and K content analysis. All the climate and cultivation intervention data are recorded as well….

The collected experimental data are used either to parametrize some models : STICS (Brisson et al., 2003), AMG (Saffih-Hdadi & Mary, 2008) or to fill calculation methods: LCA (ISO, 2006), ARTHUR (Minette, 2009) or tools in order to value agronomic (yield and quality production, soil structure, pests and diseases control…) environmental (organic content, N, P and K balance, nitrate leaching, water consumption, potential risks of pesticide transfers, greenhouse gases emissions, energy consumption, arthropod biodiversity ...) and socio-economic (gross margin, semi-net margin, peak work load, work time…) performance indicators. The performances of the bioeconomy systems are then compared to the control scenario, and used to facilitate continuous improvement of the bioeconomy systems to ensure the technical feasibility and to meet the multiple objectives of the bioeconomy.

One part of the experiment (2 platforms, i.e. 23 plots) was initiated in 2015, the other part (3 platforms, i.e. 53 plots) in 2016. The results of these two cropping seasons, are currently being analyzed. Several technical problems have already been identified, particularly concerning the innovative techniques which did not succeed as expected: insufficient catch crops biomass to allow a harvest due to late sowing, failure of hemp establishment behind ryegrass, maturity of camelina not reached to be harvested due to late sowing, difficulty to position the harvest date and sowing date to maximize biomass and to guarantee establishment of the crops in the case of 3 crops in 2 years. Further researches on these innovative techniques are still required to precise the success factors

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