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Assessing the economic profitability of fodder legume production for Green Biorefineries — A cost-benefit analysis to evaluate farmers profitability

Franka Papendiek [a, *], Valentina E. Tartiu [b], Piergiuseppe Morone [c, 1], Joachim Venus [d, 2], Anne Hönig [e, 3]

[a] Leibniz Centre for Agricultural Landscape Research, Eberswalder Straße 84, D-15374 Müncheberg, Germany
[b] Institute of Systems Sciences, Innovation and Sustainability Research, University of Graz, Austria
[c] Unitelma Sapienza—University of Rome, Department of Law and Economics, Viale Regina Elena, 295, 00161 Rome, Italy
[d] Leibniz Institute for Agricultural Engineering Potsdam Bornim, Max-Eyth-Allee 100, D-14469 Potsdam, Germany
[e] Technical University of Munich, Alte Akademie 14, D-85350 Freising, Germany

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ABSTRACT

Fodder legumes play a major role in developing sustainable agricultural production systems and contain a range of compounds, which can be utilized to produce a wide spectrum of materials currently manufactured from petroleum-based sources. Hence, if associated with Green Biorefinery technology, the use of fodder legumes brings about significant advantages in terms of overall environmental sustainability. Since fodder legume production in Europe is currently very low, the objective of this study is to assess if a new value chain generated by Green Biorefineries can make fodder legume production profitable for farmers, and therewith increase cultivation numbers. We conducted a financial cost-benefit analysis of producing biomass from agricultural land in the federal state of Brandenburg (Germany) in three different production scenarios at two farm size levels. Costs, benefits, expected profits and risks between the scenarios were quantified. Fodder legume production for traditional fodder production was already able to increase the internal rate of return, while the production of feedstocks for Green Biorefineries, depending on prices paid for the legume juice showed an even higher profit potential. Therefore, in future agricultural production systems, fodder legumes should be part of crop rotations again.

1. Introduction

A growing demand for agricultural sustainability and, more broadly, environmental sustainability, has brought to the attention of researchers and policy makers the need to reconsider farming production systems. In this regard, legumes and specifically fodder legumes play a major role in contributing to the development of sustainable agricultural production systems by i.e. accumulating nitrogen in the soil. Moreover, if associated with Green Biorefineries,[4] the use of fodder legumes brings about other significant advantages in terms of overall environmental sustainability as Green Biorefineries, like any biorefinery create a wide range of substitutes for fossil-based products, generating marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat) from biomass (de Jong et al., 2009).

In spite of all these desirable features, fodder legume production in Europe is currently very low, being the outcome of a secular decline (Stoddard, 2013). The reasons for the sharp decrease in its production over the last 100 years are to be partly found in the low cost of mineral nitrogen fertilizers and in the substitution of

* Corresponding author. Tel.: +49 (0)33432 82 441; fax: +49 (0)33432 82 223.
E-mail addresses: papendiek@zalf.de (F. Papendiek), valentina.tartiu@uni-graz.at (V.E. Tartiu), piergiuseppe.morone@unitelma.it (P. Morone), jvenus@atb-potsdam.de (J. Venus), anne.hoenig@tum.de (A. Hönig).
[1] Tel.: +39 0649910392.
[2] Tel.: +49 (0)331 5699 112.
[3] Tel.: +49 (0)8161 71 3410; fax: +49 (0)8161 71 4426.

[4] In Green Biorefineries, wet, ‘green biomass’, such as fodder legumes or grass, is used as feedstock. The biomass is processed into press cakes and juice, which can be then utilized for a wide range of applications (de Jong et al., 2009; Kamm et al., 2010).

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domestic protein feed with imported protein soy (Stoddard, 2013). Even though prices for mineral fertilizers are increasing (Jenkinson, 2001), making fodder legume production a viable economic option, these remain under-represented in the farmers' choices. This phenomenon calls for further understanding, having the objective of assessing if a new value chain generated by Green Biorefineries can make fodder legume production more profitable for farmers, and therewith increase sustainability in agricultural systems.

The aim of this paper is twofold, namely: (i) to quantify how profitable fodder legume production is, compared to more common market crop systems in a sustainable agricultural production system; and (ii) to assess the impact of Green Biorefineries on this profitability. To this aim, we shall present and compare the following three scenarios, which involve crop rotations with: (a) only market crop production, (b) legumes for fodder production and (c) legumes as Green Biorefinery feedstock.

The remainder of the paper is structured as follows: in Section 2 a brief overview on fodder legumes and Green Biorefineries is provided, while the experiment design and a detailed description of the three proposed scenarios are depicted in Section 3 as well as the method used in the cost benefit analysis. Results of the CBA are illustrated in Section 4 and Section 5 gives some conclusions on these results. In Section 6 the results are discusses in order to support farmers in the decision making process.

2. Motivation: fodder legumes and Green Biorefineries as means for economic profits and environmental sustainability

The focus of our study is on fodder legumes; we shall now briefly describe the impact this feedstock has on environmental sustainability, and how such impact could be magnified when associated with Green Biorefineries.

First and foremost, fodder legumes have a potential to mitigate the adverse effects of agricultural production on the environment through:

(i) their positive impact on soil structure and composition, i.e. improving water storage capacity and increasing organic matter content (Kahnt, 2008; Kautz et al., 2010);
(ii) their unique ability to fix atmospheric N_2 and therefore to have no requirement for N-fertilizers (National Research Council, 2002);
(iii) their diversifying effect in cereal-rich cropping systems reducing the requirement for pesticides (LEGATO, 2014);

Indeed, agricultural systems using nitrogen from legumes are potentially more sustainable than others when ecological integrity, food security and fossil energy input are compared (Crews and Peoples, 2004; Pimentel et al., 2005). Moreover, a growing number of authors argue that legume production could increase farmers' profits by increasing income stability and reducing production costs because of lower pesticide demand (for instance (Malézieux et al., 2009; Peeters et al., 2006).

Along with these benefits, grain crop yields and grain quality are improved by the preceding legume crop (Gooding et al., 2007; Grzebisz et al., 2001; Hejcman et al., 2012) with yield benefits of 10%–20% for the succeeding crop (Freyer, 2003; Kirkegaard et al., 2008).

Combining fodder legumes production with Green Biorefineries might yield additional benefits. The arising press cake can be used to produce, for example, solid fuels (Thomsen et al., 2004), fibrous composite materials (Biowert Industrie GmbH, 2013) or feed (Bryant et al., 1983; Lu et al., 1979). The press juice, on the other hand, is a valuable fermentation medium for the biochemicals industry (Andersen and Kiel, 2000; Kamm et al., 2010). Fermentation experiments showed that press juices from fodder legumes are a very good substitute for synthetic compounds in existing processes like the polyhydroxyalkanoates production (Davis et al., 2013; Koller et al., 2005).

More in general, the Green Biorefinery technology matches future developments in non-food industries that will undoubtedly lead to an increase in the amount of renewable raw materials required as feedstock. The reasons for this expected development are that fossil resources are limited and that there is a shift in consumer demand towards eco-friendlier, more sustainably-produced products (European Technology Platform for Sustainable Chemistry (SusChem), 2005). As a viable example of such trend we can refer to lactic acid (2-hydroxypropionic acid), a promising platform chemical that can be produced from a carbon source (i.e. cereals) by using press juices as fermentation medium. Food, cosmetic, pharmaceutical and biochemical industries use lactic acid in many applications (Castillo Martinez et al., 2013). Furthermore, lactic acid is applied in the production of poly (lactic acid) (PLA), which is a bioplastic that has the potential to substitute ample amounts of petroleum-based plastics in the future (Jim Jem et al., 2010; Madhavan Nampoothiri et al., 2010). There are moves afoot within the European Union to drastically reduce plastic bag utilization (Council of the European Union, 2014) and bioplastic is an alternative especially for lightweight plastic carrier bags that are endangering the environment. Already today, bioplastics play an important role in the field of packaging, agriculture, gastronomy and automotive (European Bioplastics, 2012). In 2013, the demand for lactic acid was estimated at 714,000 t and it is expected to further increase at an annual rate of 15.5% between 2014 and 2020, mainly as a result of the growing demand for bioplastics (Abdel-Rahman et al., 2013; SpecialChem, 2014).

Pooling these together, fodder legumes do not bring about only improvements in terms of environmental sustainability, but might rather generate significant profit increase in the farm sector. In what follows, the hypothesis of profit increase will be tested through a cost-benefit-analysis (CBA) mainly based on field data collected in the Federal State of Brandenburg (Germany). As a matter of fact, in 2013, fodder legumes represented only 2.9% of the arable land in the Federal State of Brandenburg (State Statistical Institute Berlin–Brandenburg, 2014), a figure highly comparable with that of Germany which is now equal to 2.3% (DESTATIS Statistisches Bundesamt, 2014), marking a sharp drop from the 1955 level of 9.7% (Bauer et al., 1956). Many countries in Europe are facing a similar strong decline in cultivation numbers (e.g. Poland and Denmark), even though the positive effects on agricultural production systems are known (Stoddard, 2013).

3. Methods

3.1. Case study and scenario definition

In order to enhance understanding of the contribution of fodder legumes to the development of sustainable farming production systems, we based our cost-benefit analysis on data gathered from experimental sites situated in Germany.

Field trials were conducted in two different sites in north Brandenburg (Germany) (Papendiek and Venus, 2014). We cultivated alfalfa (*Medicago sativa*) on one hectare of arable land at Leibniz Centre for Agricultural Landscape Research (ZALF) Muencheberg field station (coordinates: 52.516045, 14.124929) and at Paulinenaue field station (coordinates 52.683381, 12.685897). The sites are typical for glacial shaped landscapes and have continental-influenced humid climate. They are characterized by respectively low precipitation, cold winter and warm summer periods. The field experiment was established in summer 2011. The biomass was

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