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

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A B S T R A C T

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

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[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 harvested, as it is typical in this region, three times per year. The biomass was chaffed at the study sites, and then transported to the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB), where a wet fractionation took place. This is a process where fresh plant material with a low dry matter content is mechanically forced, in this case pressed, to produce a juice fraction and a solid residue (Venus, 2006). The fresh biomass was pressed using a screw press Cv (VETTER Maschinenfabrik GmbH & Co.KG, Kassel/Germany). Samples of the fresh biomass, press cakes and press juice were analysed. Dry matter, raw protein as well as sugar content were determined. The press juice was processed as fermentation medium in a batch fermentation together with a glucose solution to produce lactic acid (see chapter 4.3) (Papendiek and Venus, 2014). The press cake was silaged and nutrition content as well as feed value were identified (Hönig, 2014). The performance of the different biomass batches in the pressing process was analysed to estimate the average juice and cake yields (Papendiek et al., 2015).

As outlined in the Introduction, we performed a CBA based on the gathered data comparing three scenarios, which where replicated for a typical small farm size in Brandenburg (set equal to 210 ha) and a medium farm size (set equal to 420 ha). 88% of agricultural area in the Federal State of Brandenburg is farmed at farm sizes from 200 ha to more than 1000 ha (Amt für Statistik Berlin-Brandenburg, 2014). This proportion is typical for states of former Eastern Germany (Statistisches Landesamt Sachsen-Anhalt, 2014). In other European Countries the field sizes set in our study are also typical, as in Denmark, France or Spain or count already to the big farm sizes, i.e. in Poland or Greece (Eurostat Statistics Explained, 2014). Since farm sizes of more than 600 ha are rare in Europe, we focussed in our model on small and medium sizes. The field size cycling the two developed crop rotations was set at 10 ha to keep the risk of erosion low. The farm-field-distance was constant and equal to 10 km for all three scenarios. Base investments for cultivation and processing, like rental fee and acquisition costs for machines, were not taken into account for all three scenarios, except for the additional investment for the presses in scenario (c). The presses were bought not hired because price variations for hiring in different regions are big. The purchase of presses can only cause an underestimation of economic profitability in scenario (c) and is therefore accepted in the context of our research question.

Sustainability of the agricultural production system was set as fixed condition in our model so that tight crop rotations and big erosion causing field sizes are not appearing. This is crucial because the approach of the study is to demonstrate if under environmental sound conditions legume production is economically profitable. We also determine that pressing of the green biomass in scenario (c) is always carried out on-farm so that farmers profit from the additional working step and more added value stays in the rural area.

a) State-of-the-art scenario without fodder production

This scenario describes a today's typical crop rotation on arable land. The farm produces market crops and there is no livestock. The rotation consists of 3 crops, namely: winter barley (WB), winter rape (WRA) and winter rye (WR). Both corn and straw of cereals are marketed. Rape straw stays on the field for carbon return, while 70% of rye and 80% of barley straw are taken out of the system (Table A1). Fertilizers and pesticides are applied according to the specific demand of each crop (Table A2).[5]

[5] Specific costs for the state of the art scenario without fodder production are given in Table A3.

b) State-of-the-art scenario with fodder production

The state-of-the-art scenario with fodder production describes a crop rotation with market crop and feed production. It is a 7-year rotation that consists of winter rye (WR), alfalfa (AL) cultivated for 3 years, winter barley (WB), winter rye (WR) and, finally, winter rape (WRA). As in the first scenario, cereals, cereal straw and rapeseed are marketed. Rape straw is left on the field, while 60%–75% of cereal straws are taken out of the system (Table A1).

Alfalfa as perennial fodder legume is cultivated as feed for cattle on the farm hence it is not marketed. Alfalfa is harvested three times a year with a dry matter content of about 30%. Directly after harvest the biomass is chaffed and compacted in a concrete silo for silage production. Pesticides are not used in alfalfa cultivation. Nitrogen fertilizers are only needed in small quantities in the initial phase of the perennial crop (Table A2). The effect of soil quality improvement caused by legumes is measured in the CBA having in mind the beneficial effect on the succeeding crop. The succeeding winter barley does not need any additional nitrogen input, but still achieves corn yields which are 13% higher. The positive impacts on the whole crop rotation (such as higher yields and lower pesticide demand) cannot be taken into account because of the lack of reliable data necessary to be included in the cost benefit analysis (CBA). Therefore, all crops except of the barley directly succeeding alfalfa are assessed in the CBA as they are in the first scenario.[6]

c) Green Biorefinery scenario

In the Green Biorefinery scenario the crop rotation is the same as in scenario (b). Cultivation and harvest of all crops are also identical. Cereals, cereal straw and rapeseed are marketed. However, in the Green Biorefinery scenario fodder legumes are processed differently. The biomass is not silaged directly after harvest but pressed in a screw press to divide it into press cake and juice. Juice yield is 40% of the fresh biomass yield. The juice is sold to lactic acid producing plants as fermentation medium.[7] The remaining press cake is silaged and finally used as feed for cattle, preferably dry cows.

Due to the scarcity of reliable information regarding the juice price, we consider this variable as 'uncertain' in our cost-benefit analysis model. More specifically, juice price is estimated under the assumption that the obtained press juice fully substitutes semisynthetic fermentation media used in biochemical industries (Papendiek and Venus, 2014). Green juice contains proteins, free amino acids and inorganic salts which are essential for microbial growth and can therefore be used as fermentation medium for lactic acid bacteria instead of the standard medium MRS (according to De Man, Rogosa and Sharpe) (De Man et al., 1960). The water content and natural variations in the biomass have no major influence on the quality of bacterial nutrients for lactic acid formation (Papendiek et al., 2015). The price of the MRS bouillon that is substituted is around 5000 € t^{-1} (AppliChem GmbH, 2014). The focus of this study is on the costs for a farm, taking into consideration the cultivation, harvest and first processing (pressing) of the biomass to produce a juice utilizable as MRS substitute. For the screw press, additional investment costs have to be taken into account. A screw press from VETTER Maschinenfabrik GmbH & Co.KG, with a throughput of 5 t/h, costs 200,000 €. Five of those presses are needed to press the biomass of a small/medium farm (pressing, on average, the biomass of a 10ha plot within a working day). Depreciation of screw presses was calculated using the straight-line

[6] Specific costs for the state-of-the-art scenario with fodder production are shown in Table A4.

[7] Specific costs for the Green Biorefinery scenario are shown in Table A5.

method[8] with an assumed useful life which covers the whole project lifetime (21 years) and no salvage value for the machinery at the end of the project lifespan.[9] Also the maintenance of the machines has to be considered, with an annual average cost per press of 12,500 € for new sieves and 25,000 € every third year for a new screw. The press is delivered with a hopper and a wheel loader to fill the hopper with the chaffed biomass material is available on the farm for silage production.

For an estimation of the costs in the succeeding engineering process, we refer to Thomsen (2005b) who was doing a cost estimation of the equipment needed for the provision of press juices. These calculations go far beyond the on-farm processing since they include costs like fermentation, stabilization, long-term storage and transportation. The value is used to estimate the costs for the engineering part of MRS substitute production. Thomsen states these costs to be 17 € t^{-1} for a green pellet factory to sell it to a processing plant (2005a). We have to assume higher costs for our scenario because in the harvest season the fresh press juices (40–70 m^3) must be picked up daily. We determine the processing plant and not the farmer bears these costs. Accordingly and since the price for the substitute should be much lower to be an attractive alternative, the maximum price is assessed to be not more than 50% of the MRS medium and therefore is set at 2500 € t^{-1}, the most likely price at 1000 € t^{-1} and the minimum price at 500 € t^{-1}.

3.2. Cost-benefit analysis

In order to conduct the cost-benefit analysis of biomass production for the three different scenarios described in Section 3, a cost-benefit decision model was built using Microsoft Office Excel 2013. The model includes a systematic categorization of the costs and benefits associated with different crop production systems on a typical soil type in Brandenburg. The project lifetime is 21 years – corresponding to seven rotation cycles for scenario (a) and 3 rotation cycles for scenarios (b) and (c).

More specifically, the following categories of costs have been considered: total land preparation costs (€/ha), total growing costs (€/ha), total harvest, transport & processing costs (€/ha), total production costs (€/ha). Benefits, on the other hand, have been calculated based on the prices paid after harvest.

As mentioned in Section 3, analyses were carried out for farm sizes of 210 ha and 420 ha; this allowed us to compare the three scenarios both for small and medium sized farms and to assess at what farm size investments for the Green Biorefinery scenario pay off. For all scenarios it was assumed that for each new crop within the rotation the working steps were: ploughing, rolling and ciscel ploughing. The constant working steps for all scenarios, their costs, timing and needed machinery are outlined in Table A6. We integrated in the CBA labour, machinery and diesel as costs associated with all working steps. The appropriate figures were obtained from a tool used in Germany by farmers to calculate their costs for the upcoming year (KTBL – Board of Trustees for Technique and Engineering in Agriculture, 2014). Fig. A1 shows how the KTBL database is set up. The selected machinery for the specific working steps is given in Tables A3–A5.[10] Diesel costs were calculated by multiplying diesel demand (given in the KTBL database) with the current diesel costs. Analogous the labour costs are the coefficient from labour demand and average wages of 9.50 € h^{-1}. In addition to labour, machinery and diesel costs, for every crop, seeds as well as fertilizers and pesticides costs were integrated in our cost-benefit model. Costs for these specific working steps of each scenario were cumulated for all crops over the study lifetime of 21 years (Tables A3–A5).

Benefits were calculated from prices paid for cereals and rape after harvest (Bauernzeitung for Brandenburg Mecklenburg-Western Pomerania and Saxony-Anhalt, 2014b). Due to their volatility over time, prices were kept constant – over the lifetime of the simulation – at their 2013 values. Cereal and rape yields were taken from the Landesbauernverband of Brandenburg, an association of farmers in the Federal State, for the current harvest year of 2013 (LBV Brandenburg e.V., 2014). For alfalfa, the yields were available from the field trials. However, prices were not directly accessible for legumes. They are in general used as feed on the producing farm and have therefore no market price. We assumed from literature that legume silage can partly substitute maize silage (Bulang et al., 2006). Prices for maize silage were available (Bauernzeitung for Brandenburg Mecklenburg-Western Pomerania and Saxony-Anhalt, 2014a) so the ratio between the NEL (net energy content for lactation) amount in maize (Engling et al., 2009) and alfalfa silage was calculated. Therewith a corrected price was available to determine the costs saved for maize silage purchase.

In the case of the third scenario, since there is no reliable market yet for press juice and cake from alfalfa, prices were estimated based on available data (see Sections 3.1 and 4.3). Moreover, in order to account for the significant fluctuations possible in the case of juice price, we associated a triangular distribution based on the minimum price, the most likely price and the maximum one (we shall come back to this in Section 4.3).

In order to evaluate the financial performance of the three considered scenarios, we took into account two indicators (Karellas et al., 2010), namely:

(i) net present value (NPV) – i.e., the difference between the present value of the future after-tax cash flows from an investment and the amount of the initial investment. Present value of the expected cash flows is computed by discounting them at the required rate of return.
(ii) the internal rate of return (IRR) – i.e., the average annual return earned through the life of an investment calculated as the discount rate that reduces to zero the after-tax net present value.

These two indicators provide different information on the overall profitability of the investment and might be traded off one against the other. For instance, an investor/farmer might prefer a project that has a low IRR and a high NPV over a project with a very high IRR and low NPV. At the same time, an investor might be concerned about a large project that has a high value of NPV but an IRR just above the cost of capital.

We took into consideration a discount rate of 5% and VAT equals to 10.7% (steuerberaten.de Steuerberatungsgesellschaft mbH,

[8] The annual cost of screw presses was calculated using the following equation for the straight-line depreciation method plus the opportunity cost of capital represented by the average value times the interest rate: $((\textit{Total Investment} - \textit{Salvage Value})/(\textit{Useful Life})) + ((\textit{Total Investment} + \textit{Salvage Value}) \times (\textit{Interest Rate}))/2$.

[9] No salvage value is a common assumption in this type of studies (e.g. Anderson et al., 2013), especially when the project life is above 15 years it is assumed that dismantling costs would cover the residual value of the machinery. Moreover, it corresponds to the 'worst scenario' in terms of costs. Hence, if the Green Biorefinery scenario will prove to be profitable under such assumption it will be even more so under less stringent costs assumptions.

[10] The used machinery was recommended by the KTBL tool for the specific working steps. For an economically sound CBA it was necessary to keep the number of different machines used in the scenarios to a minimum to ensure optimal use of machine capacity. However, due to fixed machinery combinations given in the KTBL tool, this was not always possible.

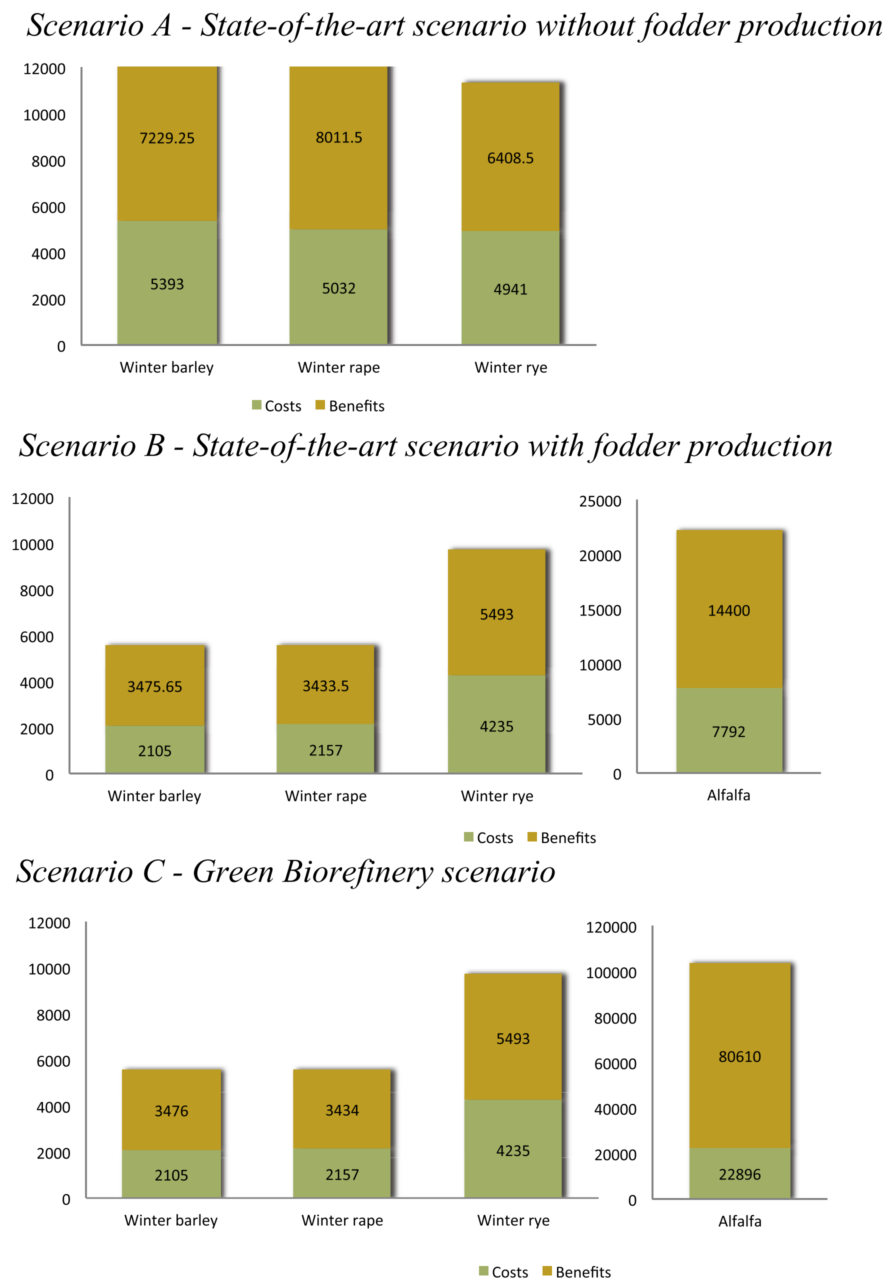

Fig. 1. Total costs and benefits over project lifetime of 21 years for the crops.

2014). Choosing the right discount rate is not a trivial task. In fact, the discount rate is effectively a desired return, or the return that an investor would expect to receive on some other typical investment projects of equal risk. The discount rate typically includes: (1) the *rate of time preference* (most people prefer consumption undertaken now rather than later; thus, a euro available now is more highly valued than one received later); (2) *uncertainty and risk* associated with the project (there is necessarily some degree of uncertainty and risk as to whether a future euro will actually be received; therefore its value is lessened in proportion to the expected size of this uncertainty/risk factor).

There is no single rate of return that is appropriate for every project. Many economists use discount rates in the range of 8%–12%. However, the higher the discount rate is, the lower is the value associated with the future (and future generations). Moreover, many national public institutions have recently lowered the interest rate associated with social cost-benefit analysis. This revision is mainly justified in light of the big changes in macroeconomic conditions, including the low interest rates, the deflation threatening the Eurozone, and the need of a more significant long-term planning in public projects appraisal (Cruz Rambaud and Munoz Torrecillas, 2006). In light of these changes, we decided to set the discount rate at 5%.

As for the VAT level, this corresponds to the rate applied under the farmer's flat rate scheme to suppliers of typical agricultural goods and services, as well as to specific suppliers by sawmills.

4. Results

This study aims at quantifying and comparing costs, benefits, expected profits and risks among the three scenarios depicted in Section 3. Thus, Tables A3–A5 show the costs in the different

Table 1
Cost-benefit analysis of the state-of-the-art scenario without fodder production.

	Farm size – 210 ha	Farm size – 420 ha
Costs (€)	1075634.81	2151269.63
Benefits (€)	1353294.62	2706589.24
Net benefits (€)	277659.81	555319.61
Net present value (€)	137183.42	274366.84
Cost-benefit ratio	0.79	0.79
Internal rate of return (%)	26%	26%

Assuming a 5% discount rate and 10.7% taxes.

Table 2
Cost-benefit analysis of the state-of-the-art scenario with fodder production.

	Farm size – 210 ha	Farm size – 420 ha
Costs (€)	488682.68	977365.36
Benefits (€)	718029.60	1436059.20
Net benefits (€)	229346.92	458693.84
Net present value (€)	124992.04	249984.09
Cost-benefit ratio	0.72	0.72
Internal rate of return (%)	41%	41%

Assuming a 5% discount rate and 10.7% taxes.

scenarios for the needed working steps. At first sight, we can notice that the crop rotation in the two scenarios with legume cultivation led to a reduction in the use of fertilizers (29%) and pesticides (45%) with respect to the market crop rotation in the first scenario. However, costs for harvest and conservation (i.e. silage production) in the two legume scenarios are more than twice that of the market crop scenario. We shall now look in more detail at the key results of the CBA for the three considered scenarios at different farm size levels.

4.1. State-of-the-art scenario without fodder production

The cost-benefit analysis shows that farm size influences neither the cost-benefit ratio nor the internal rate of return, with CBR equal to 0.79 and IRR being equal to 26% in both cases (Table 1). This finding suggests the absence of economies of scale and shows an overall profitability of the investment.

If we look at costs and benefits associated with individual crops, we can get a more fine-grain picture. In this market crop rotation, rape is the most profitable crop. Benefits are more than 25% higher than for rye even though only the seed and not the rape straw is marketed (Figs. 1 and 2 and Table A7). Straw recovery from cereals however is profitable with about 100 € profit per ha for the farmer. The highest fertilizer and pesticide costs in the crop rotation of rape are compensated by comparably low seed prices and a high market price for rapeseed. Rye shows a profit loss per ha of 18% compared to barley and 38% compared to rape. In Brandenburg, however, rye is a very important crop with stable yields even in years with low precipitation and production costs are the lowest of the whole crop rotation.

4.2. State-of-the-art scenario with fodder production

Findings for the second scenario show an overall increased profitability of the investment, which is displayed with an IRR of 41% compared to 26% in scenario (a) and a CBR dropping from 0.79 to 0.72 (see Tables 1 and 2).

The increased IRR is likely to be linked to the fact that farmers can save costs for maize silage purchase for cattle when legumes are cultivated. If the alfalfa silage was sold and not used on the farm, the benefits would be lower because transport costs need to be taken into account. Also in this case findings suggest the absence of economies of scale.

Again, we can get more insights by looking at costs and benefits associated with individual crops (Figs. 1 and 2 and Table A7). Rape and rye display costs and benefits which are identical to those observed in the first scenario. Barley after alfalfa becomes more profitable since fertilizer costs are saved and a yield increase of 13% is estimated due to the preceding crop effect of alfalfa. In this scenario farmers profits from barley exceed the profits from rape per hectare by 45% and are nearly 60% higher than in the first scenario. Alfalfa cultivated for 3 years has similar preparation and growth costs like the other crops in one year. However, harvest, transport and processing costs are much higher even for one year of alfalfa production because harvest takes place three times a year. The price for alfalfa deduced from the current maize silage price is 28% lower than the maize silage price. Still, annual profits for the farmer are higher than for the other crops in the rotation. This finding suggests that introducing the cultivation of legumes makes this second scenario more profitable when compared with a rotation scheme, which considers only market crop production.

4.3. Green Biorefinery scenario

In the Green Biorefinery scenario the crop rotation is the same as in the state-of-the-art scenario with fodder production. Therefore, costs and benefits for cereals and rape are the same as in the previous scenario (Table 2).

The additional investments in screw presses for the production of press juice as feedstock for biochemical industries make the farm size and potential prices for press juice and cake important parameters to determine the profitability of alfalfa cultivation. As discussed in Section 3, we associated a triangular distribution for

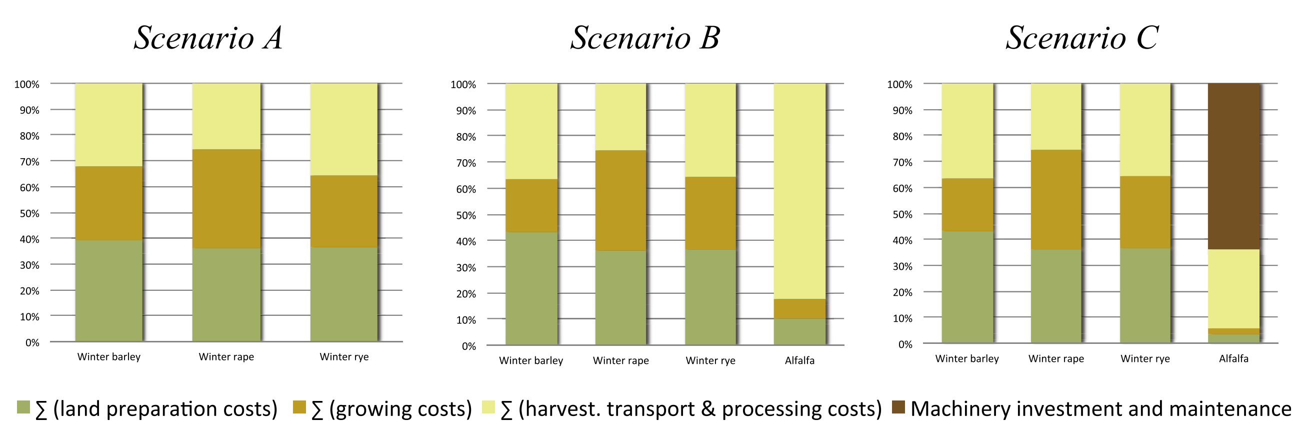

Fig. 2. Total costs breakdown.

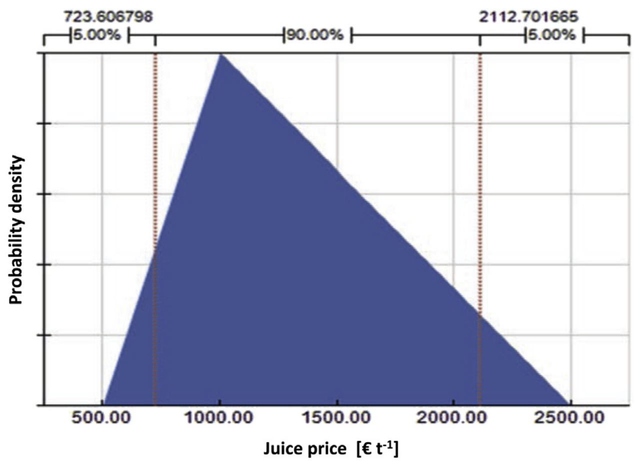

Fig. 3. Triangular distribution of juice price.

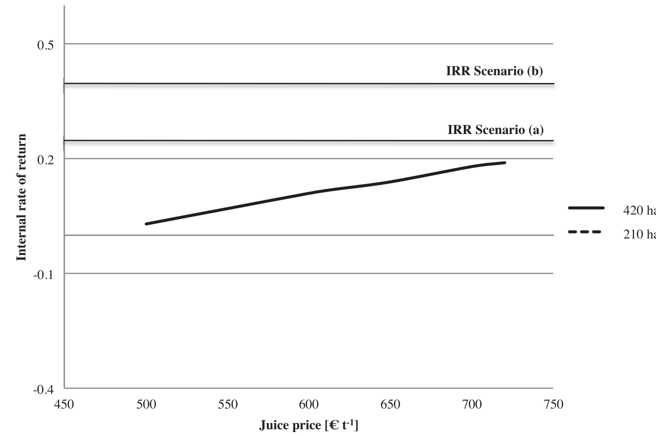

Fig. 4. IRR for various juice prices (minimum price interval).

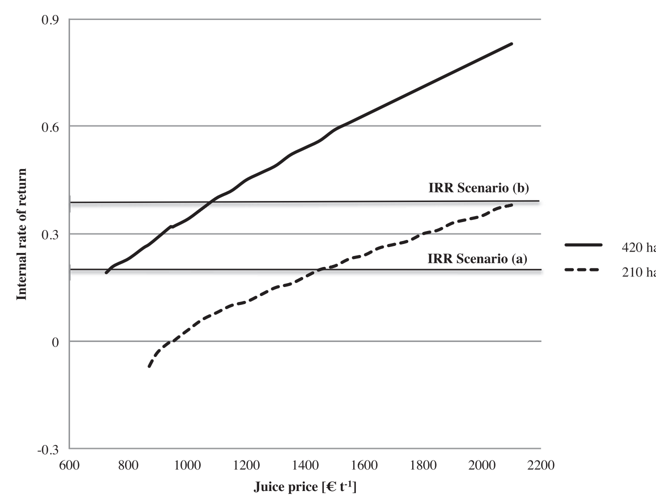

Fig. 5. IRR for various juice prices (most likely price interval).

the juice price with a minimum price of 500 € t^{-1}, the most likely price of 1000 € t^{-1} and a maximum price of 2500 € t^{-1} (Fig. 3).

Looking at these results, we notice that there is a probability of 5% for the juice price to belong to the interval [500.00; 723.60], a 90% probability for the juice price to be part of the interval [723.60; 2112.70], and a 5% probability to be included in the interval [2112.70; 2500.00].

Estimations of the price for press cakes are derived from analyses on the application of alfalfa press cake in ruminant feeding (Hönig, 2014). When estimating this price, we observed less fluctuations around an average price of 29 € t^{-1} (with the price ranging from 27 € t^{-1} to 32 € t^{-1}). Hence, due to the fact that press cake price span is lower, fluctuations are less of an issue than in juice price, and its influence on the overall profitability of the scenario is negligible (due to its relatively low *per-ton* price), we decided to perform the cost-benefit analysis keeping the press cake price constant at its average price of 29 € t^{-1}.

Obtained results are reported in Tables 3, A8, A9 and in Figs. 4–6. Specifically, in Table 3 we report results calculated at the centre of each price interval (minimum price, most likely price and maximum price), whereas in Tables A8 and A9 as well as in Figs. 4–6 we show the IRR calculated for several price values of the three intervals.

In the first case (Fig. 4) the juice price takes values in the interval [500; 723.6] and a small farmer (210 ha) never obtains a positive IRR. Hence, the Green Biorefinery option is never convenient for a small farmer. The IRR is even too low to be calculated in a standard formula (Fig. 4, Table A8). As we increase the farm size to 420 ha, we always get a positive IRR. However, the estimated IRR is always below the IRR estimated for scenario (a) and (b). We can conclude that with a low juice price, the profitability of the Green Biorefinery scenario is not given when compared to the other two scenarios. This finding applies for both analysed farm sizes; however, we should recall that the probability that the real juice price fell within the minimum price interval is just 5%.

The picture changes significantly if we consider the most likely price interval (Fig. 5). Specifically, for a small farm of 210 ha, any juice price higher than 944 € t^{-1} will assure the farmer a profit. On the contrary, any juice price below this threshold provides no economic incentive to the farmer to opt for the Green Biorefinery scenario. The Green Biorefinery scenario only displays an IRR above

Table 3
Cost-benefit analysis of the Green Biorefinery scenario.

	Farm size 210 ha			Farm size 420 ha		
	Minimum price	Most likely price	Maximum price	Minimum price	Most likely price	Maximum price
Costs (€)	5093358.22	5093358.22	5093358.22	5599216.44	5599216.44	5599216.44
Benefits (€)	3507672.30	6810879.30	11150859,3	7015344.60	13621758.60	22301718.60
Net benefits (€)	−1585685.92	1717521.08	6057501.08	1416128.15	8022542.15	16702502.15
Net present value (€)	−1304714.27	804456.76	3575630.38	589892.98	4808235.04	10350582.27
Cost-benefit ratio	1.59	0.81	0.5	0.87	0.44	0.27
Internal rate of return (%)		15%	41%	12%	49%	87%

Assuming a 5% discount rate and 10.7% taxes.
Min price: juice = 615 €/t; Most likely price: juice = 1300 €/t; Max price juice = 2200 €/t whereas cake price is constant and equals 29 €/t.

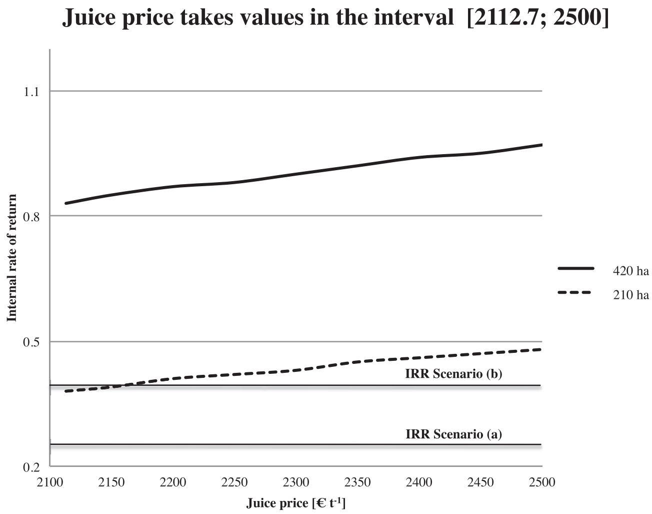

Fig. 6. IRR for various juice prices (maximum price interval).

the one obtained in scenario (a) whenever the juice price exceeds 1650 € t^{-1}. Hence, the investment risk is still high. For a medium sized farm the estimated IRR is above the one obtained in scenario (a) whenever the juice price exceeds 850 € $t^{-1}$and exceeds the one obtained in scenario (b) any time the juice price is above 1125 € t^{-1}. As it seems, in the most likely price case, the Green Biorefinery scenario is performing relatively well and, for a medium sized farm, it is most likely to be superior to scenario (a). Also compared to scenario (b) the price span for press juices where the Green Biorefinery scenario can be more profitable is high. Recalling now that there is a probability of 90% for the juice price to belong to the interval, we can conclude that this is a rather relevant finding of our investigation.

We conclude our analysis looking at the third price interval (Fig. 6) — i.e., the maximum price to be included in the interval [2112.70; 2500.00]. In this case, the Green Biorefinery scenario is almost always dominating the other two scenarios, independently of the farm size. The IRR for a small farm at a juice price of 2200 € t^{-1} is the same as for scenario (b). For a small farm, the IRR ranges between 0.38 and 0.48 whereas for a medium size farm the IRR ranges between 0.83 and 0.97. These figures are indeed very high and should be interpreted with caution. In fact, when interpreting these results one should bear in mind that the probability that the juice price exceeds 2112.70 €/t are very slim. Moreover, and most importantly, we should recall that in our analysis some costs that are constant for all rotations (like the rental fee for the land or machinery that is needed in the cultivation process of all scenarios) were not included. The drawback of this approach is that the IRR in the scenarios is not comparable with reality, because of the exclusion of baseline costs. However, the IRR comparability between the three scenarios is still sound, because baseline costs in all scenarios would be the same.

5. Conclusions

As outlined in the introduction, the aim of this paper was to quantify how profitable fodder legume production is, compared to more common market crop systems and, subsequently, to assess the impact of Green Biorefineries on this profitability. To address these research questions we conducted a cost-benefit-analysis based on field data collected in the Federal State of Brandenburg (Germany). It should be mentioned that, although the case study refers to a very specific area, results are more generally applicable since there are strong morphologic similarities (e.g. fodder legumes share of overall arable land) among our case and Europe overall. Our study concentrated on small (210 ha) and medium farm (420 ha) sizes — big farms being explicitly excluded, as they are not that common in Europe — and compared three scenarios, which involve crop rotations with: (a) only market crop production, (b) legumes for fodder production, and (c) legumes as Green Biorefinery feedstock.

Our empirical investigation showed that including fodder legumes only for fodder production and soil improvement (i.e., scenario b) has a higher IRR than the pure market crop rotation (i.e., scenario a). This would be the case whenever a farmer produces fodder for her/his own cattle or purchases the fodder close by the farm. For higher distances, the potential profit for alfalfa silage would be lower, due to higher transportation costs.

Moreover, results reported in Section 4 show how the production of fodder legumes becomes even more profitable when the Green Biorefinery scenario is considered: the additional investments associated with the Green Biorefinery scenario can pay off for a medium sized farm within three years for the most likely press juice price. However, for the minimum price at both farm sizes and the most likely price at a small farm size, the investments doesn't pay off within the project lifetime of 21 years. Indeed, a key issue associated with the robustness of our results is the lack of available data on press juice price as well as on possible significant fluctuations. To get around this problem we associated a triangular distribution based on the minimum price, the most likely price and the maximum one — this allowed us reducing the risk of misjudgement of the press juice price. According to the results of the CBA model, high profits were obtained for a farm size of 420 ha in Green Biorefinery scenario. However, also in the case of a small farm the Green Biorefinery scenario showed to be profitable, but with a high investment risk.

6. Discussion and limitations

We shall now discuss in this final section some potential drawbacks associated with legume production, which might hold back farmers from switching to fodder production, as well as some general limitations associated with our study. When interpreting our findings, one should be very careful and take such obstacles in due consideration.

We start considering lower yields and yield stability as well as the potential disadvantage associated with the loss of knowledge on legume cultivation among farmers. This, in turn, might increase the probability of mistakes in cultivation and therefore reduce farmers' willingness to switch to fodder production (Kuhlman and Linderhof, 2014). The main (not strictly economic) advantage of the market crop rotation (scenario a) is therefore that it is an established way of cultivation, a fact which results in high stability as well as high flexibility for farmers. On the contrary, the perenniality of fodder legumes impedes the direct annual serving of the market, which reduces profits especially in years with high cereal prices.

Farmers need to be aware of these drawbacks in legume cultivation; however, the CBA model in this study shows the potential which legume production does hold. Overall, on less fertile soils, the integration of legume cultivation seems to deliver gains, linked mainly to the soil improvement and to the increased yield potential of the succeeding crops (Adams et al., 1970). Beyond this cost-benefit type of reasoning, there are at least two, more general, arguments in favour of fodder legume production. First and foremost, as discussed in Section 2, there are general environmental sustainability effects as fodder legumes have a potential to mitigate various adverse effects of agricultural production on the environment – considering that legumes are preferable when ecological integrity, food security and fossil energy input are taken into account. Moreover, fodder legumes make farmers less dependent on fertilizers and pesticides, reducing their production costs and their vulnerability to market fluctuations for production input. This latter point can become a crucial issue if prices for nitrogen fertilizer rise – a scenario which is likely to occur within the next decades due to the high energy demand in the production process (Vance, 2001).

On a more general level, a growing awareness to the intrinsic unsustainability of the current economic model has contributed to the emergence of the idea that modern society should move towards a greener society following an imminent paradigm shift from a fossil fuels economy to a biobased one. Such a major change entails a socio-technical transition, involving the co-evolution of social, economic and technological relationships (van den Bergh et al., 2011). This transition from an old and stable production paradigm to a new one is mostly characterised by uncertainty and higher levels of risks. Our study is nested within this broad framework, providing some preliminary insights into the technological and economic feasibility of Green Biorefinery for farmers, hence starting reducing the risk and uncertainty spectrum typically associated with radical changes.

As we show, the Green Biorefinery technology allows farmers to produce fodder legumes with profits. Moreover, for the press juices, results from field trials are promising and show that the quality of the output as fermentation medium is very stable over the year and comparable to MRS[11] (Papendiek et al., 2015). This could increase the cultivation figures linked to fodder legumes and lead to a more sustainable, less fossil-based agricultural production. Furthermore, an increase in cultivation figures for legumes will reduce the extent of the drawbacks associated with legume production: on the one hand, new breeding can increase yield and yield stability, while on the other hand the knowledge on cultivation can be acquired again.

Although promising, these results, from data collected at two study sites in the same federal state in Germany clearly need to be replicated and validated to allow drawing more general conclusions. Further crops need to be investigated so that farmers can cultivate the fodder legume most suitable for the specific soil and climate conditions.

For Green Biorefineries, there have been studies for example in Austria (Kromus et al., 2004), Denmark (Andersen and Kiel, 2000) and Ireland (O'Keeffe et al., 2009) focussing on the bioengineering processing of the biomass and potential products.

We are aware that we neglect the engineering part and that the cost-benefit analysis is only based on one part of the costs, namely the farmers site. Field data on press juice prices would make the study far more robust. However, by means of triangular distributions, we tried to account for price uncertainties in the market. The added value of this study is that farmers can estimate what price must to be paid for the press juice to be profitable for their farm features.

A further issue to be considered refers to the potential size of the market for press juices. In fact, as discussed in this paper, the on-farm produced alfalfa press juice can be used as fermentation medium in the production of lactic acid (Papendiek and Venus, 2014). However, farmers could also find other buyers for the green press juices as there are probably many more fields of application for the juice, which have not been explored yet (e.g. proteins for the production of feed for non-ruminants bought as substitute for imported soy meal. See (Thomsen et al., 2004). Indeed, the potential size of the market for press juices is only roughly estimated in this study. In particular, examples for fields of application are named and for lactic acid a development forecast is given. However, a detailed demand forecast, based on data from industries, is needed to verify the assumptions.

Finally, it is worth reasoning on the relevance of processing the green biomass rapidly after harvest, preventing uncontrolled fermentation processes from taking place and keeping the quality of plant metabolites high (Thomsen et al., 2004). That speaks for a decentralized processing. Regional biomass processing centres (RBPCs), in our case producing lactic acid, would allow a quick processing and low transport distances (Carolan et al., 2007). However, the final PLA production will be probably organized in large and sophisticated factories. The very first processing (pressing) of the fresh biomass should be located on the farm because of the heavy weight and large volume. The pressing reduces the juice quantities that need to be transported by more than 50% (Venus, 2006). The impact of value chains those are adapted to the specific characteristics of fresh green biomass on the economic profitability and the sustainability of resource processing still needs to be explored.

All in all, this study is only the beginning of research on this topic. First experiments have been performed to find out if press juices from fodder legumes are a proper feedstock for biochemical processes and if an economically sound processing is possible. We provide evidence that alfalfa is an interesting alternative feedstock for industrial uses. However, more research is needed (e.g. on the mixture ratio of press juices and sugar source for the most efficient exploitation of the plants) and we hope this study will stimulate and pave the way to such new investigations.

Acknowledgements

Networking support provided by the COST Action TD1203 "Food Waste Valorisation for Sustainable Chemicals, Materials and Fuels (EUBis)" is kindly acknowledged. Moreover, the assistance provided by Teresa Gehrs in proof-reading the article and the financial support granted by the Leibniz Centre for Agricultural Landscape Research are gratefully acknowledged.

Annex

Table A1
straw recovery in the scenarios.

Scenario	Crop	Straw recovery (%)
State-of-the-art scenario without fodder production	WB	80
	WRA	–
	WR	76
State-of-the-art scenario with fodder production/Green Biorefinery scenario	WR	61
	AL	–
	WB	75
	WR	76
	WRA	–

† WB, winter barley; WRA, winter rape; WR, winter rye; AL, alfalfa.

[11] MRS is a stable, well-known fermentation medium but costs are just too high to be an economically sound feedstock for the large-scaled production of lactic acid.

Table A2
fertilizer and pesticide demand in the scenarios.

Scenario	Crop	Fertilizers (kg ha^{-1})[a]	Pesticides (low intensity)[b]
State-of-the-art scenario without fodder production	WB	120–180 N	Fungicide, herbicide, Plant growth regulator
	WRA	190 N, 50 S	Fungicide, herbicide, insecticide
	WR	130–170 N	Fungicide, herbicide, Plant growth regulator
State-of-the-art scenario with fodder production/Green Biorefinery scenario	WR	130–170 N	Fungicide, herbicide, Plant growth regulator
	AL yr 1	80 N, 200 Mg Lime	–
	AL yr 2	200 Mg Lime	–
	AL yr 3	200 Mg Lime	–
	WB	–	Fungicide, herbicide, Plant growth regulator
	WR	130–170 N	Fungicide, herbicide, Plant growth regulator
	WRA	190 N, 50 S	Fungicide, herbicide, insecticide

[a] Sources: BayWa Deutschland; for alfalfa fertilizer demands were taken from the field trials in Brandenburg.
[b] Source: Bavarian State Research Centre for Agriculture; for alfalfa pesticide demands were taken from the field trials in Brandenburg.

Table A3
costs for specific working steps over project lifetime of 21 years for state-of-the-art scenario without fodder production.

Working step	Unit	Costs (€)[a]	Occurrence	Used machinery[a]	Notes
Seeding	ha	2941.94	Annually	Rotary harrow + seed drill 2.5 m, 67 kW	
Fertilizing	ha	1619.21 to 1905.76	According to demand	Front loader, 1750 daN, mineral fertilizer shovel, 75m^3, 67 kW, three-way tipper tailer, 14 t, 67 kW	
Pesticide use	ha	3070.27	According to demand	Mounted pesticide sprayer 18 m, 1500 l; 67 kW	
Corn threshing (incl. transport)	ha	3499.91	Annually	Complex 2 harvester, 8500 l, 200 kW, cutting system, 6 m, double tractor each 18t, three-way tipper tailer, 83 kW	
Straw processing (incl. transport)	ha	1285.98	Annually for cereals	Round baler, 1.5 m, 275 kg/bale, 67 kW, double tractor each 8t, three-way tipper tailer, front loader, 1750 daN, bale spike, 67 kW	Rape straw stays on the field

[a] Sources: Used machinery and costs for machinery, labour and diesel. KTBL tool; Seed and pesticide prices, Bavarian State Research Centre for Agriculture; Fertilizer prices, Bauernzeitung for Brandenburg, Mecklenburg Western Pomerania and Saxony Anhalt.

Table A4
costs for specific working steps over project lifetime of 21 years for state-of-the-art scenario with fodder production.

Working step	Unit	Costs (€)[a]	Occurrence	Used machinery[a]	Notes
Seeding	ha	2039.70	when crop changes	Rotary harrow + seed drill 2.5 m, 67 kW|seed drill 3 m, 67 kW	
Fertilizing	ha	1260.10 to 1358.35	According to demand	Front loader, 1750 daN, mineral fertilizer shovel, 75m^3, 67 kW, three-way tipper tailer, 14 t, 67 kW	
Pesticide use	ha	1689.45	According to demand	Mounted pesticide sprayer 18 m, 1500 l; 67 kW	Not necessary for alfalfa
harvest (incl. transport)	ha	7844.78	Annually. for alfalfa 3 times a year	Complex 2 harvester, 8500 l, 200 kW, cutting system, 6 m, double tractor each 18t, three-way tipper tailer, 83 kW | Rear mower, 2.1 m, 45 kW, retrival with self-propelled forage harvester, swath deposit, 3 m, 45 kW; 250 kW, double tractor each 14 t, three-way tipper tailer, 67 kW	Corn threshing for cereals and rape | mowing. swathing and chaffing for green biomass
Straw processing (incl. transport)	ha	842.81	Annually for cereals	Round baler, 1.5 m, 275 kg/bale, 67 kW, double tractor each 8t, three-way tipper tailer, front loader, 1750 daN, bale spike, 67 kW	Rape straw generally stays on the field
Silage production	ha	559.43	Directly after legume harvest	Wheel loader, 13.5 t, 105 kW, lightweight shovel, 4m^3	Compacting in concrete silo

[a] Sources: Used machinery and costs for machinery, labour and diesel, KTBL tool; Seed (except alfalfa) and pesticide prices, Bavarian State Research Centre for Agriculture; Seed prices alfalfa, Deutsche Saatgutveredelung AG; Fertilizer prices, Bauernzeitung for Brandenburg, Mecklenburg Western Pomerania and Saxony Anhalt.

Table A5
costs for specific working steps over project lifetime of 21 years for the Green Biorefinery scenario.

Working step	Unit	Costs (€)[a]	Occurrence	Used machinery[a]	Notes
Seeding	ha	2039.70	when crop changes	Rotary harrow + seed drill 2.5 m, 67 kW|seed drill 3 m, 67 kW	
Fertilizing	ha	1260.10 to 1358.35	According to demand	Front loader, 1750 daN, mineral fertilizer shovel, 75m^3, 67 kW, three-way tipper tailer, 14t, 67 kW	
Pesticide use	ha	1601.10	According to demand	Mounted pesticide sprayer 18 m, 1500 l; 67 kW	Not necessary for alfalfa
harvest (incl. transport)	ha	7844.78	Annually. for alfalfa 3 times a year	Complex 2 harvester, 8500 l, 200 kW, cutting system, 6 m, double tractor each 18t, three-way tipper tailer, 83 kW |Rear mower, 2.1 m, 45 kW, retrival with self-propelled forage harvester, swath deposit, 3 m, 45 kW; 250 kW, double tractor each 14t, three-way tipper tailer, 67 kW	Corn threshing for cereals and rape | mowing. swathing and chaffing for green biomass
Press juice production	ha	734.48[b]	3 times a year	5 Screw presses, each with a throughput of 5 t/h	
Straw processing (incl. transport)	ha	842.81	Annually for cereals	Round baler, 1.5 m, 275 kg/bale, 67 kW, double tractor each 8t, three-way tipper tailer, front loader, 1750 daN, bale spike, 67 kW	Rape straw stays on the field
Silage production	ha	345.43	Directly after alfalfa pressing	Wheel loader, 13.5t, 105 kW, lightweight shovel, 4m^3	Compacting in concrete silo

[a] Sources: Used machinery and costs for machinery, labour and diesel, KTBL tool; Seed (except alfalfa) and pesticide prices, Bavarian State Research Centre for Agriculture; Seed prices alfalfa, Deutsche Saatgutveredelung AG; Fertilizer prices, Bauernzeitung for Brandenburg, Mecklenburg Western Pomerania and Saxony Anhalt.
[b] Source: Costs for machinery, labour and diesel, VETTER Maschinenfabrik GmbH & Co,KG, Kassel/Germany.

Table A6
Costs for constant working steps in all scenarios.

Working step	Unit	Costs (€)[a]	Occurrence	Used machinery[a]
Ploughing	ha	83.63	When crop changes	10 shares, 3.5 m, 102 kW
Rolling	ha	20.36	When crop changes	10.25 m, 67 kW
Glean ciscel ploughing.flat	ha	29.61	When crop changes	ECODYN, 3 m, 67 kW

[a] Source: KTBL tool.

Table A7
Total costs and benefits over project lifetime of 21 years for the crops in all scenarios.

Costs € ha^{-1}	Winter barley	Winter rape	Winter rye	Alfalfa
Seeding	[a]1182.77 [b,c]506.90	[a]885.76 [b,c]379.61	[a]873.42 [b,c]748.64	[b,c]404.55
Ploughing	[a]585.41 [b,c]250.89	[a]585.41 [b,c]250.89	[a]585.41 [b,c]501.78	[b,c]250.89
Rolling	[a]142.52 [b,c]61.08	[a]142.52 [b,c]61.08	[a]142.52 [b,c]122.16	[b,c]61.08
Ciscel ploughing	[a]207.28 [b,c]88.83	[a]207.28 [b,c]88.83	[a]207.28 [b,c]177.67	[b,c]88.83
∑ (land preparation costs)	[a]2117.97 [b,c]907.70	[a]1820.97 [b,c]780.41	[a]1808.63 [b,c]1550.25	[b,c]805.35
Fertilizers	[a]451.55 to 623.48 [b,c]0.00	[a]722.37 [b,c]309.59	[a]445.28 to 559.90 [b,c]381.67 to 479.92	[b,c]568.84
Pesticides	[a]996.59 [b,c]427.11	[a]1201.90 [b,c]515.10	[a]871.78 [b,c]747.24	[b,c]0.00
∑ (growing costs)	[a]1448.14 to 1620.07 [b,c]427.11	[a]1924.27 [b,c]824.69	[a]1317.06 to 1431.68 [b,c]1128.91 to 1227.16	[b,c]568.84
Corn production	[a]1097.53 [b,c]478.52	[a]1287.16 [b,c]551.64	[a]1115.22 [b,c]955.91	[b,c]0.00
Straw production	[a]642.99 [b,c]291.68	[a]0.00 [b,c]0.00	[a]642.99 [b,c]551.13	[b,c]0.00
Legume production	[a,b,c]0.00	[a,b,c]0.00	[a,b,c]0.00	[b,c]5858.72
Silage production	[a,b,c]0.00	[a,b,c]0.00	[a,b,c]0.00	[b]559.43 [c]345.43
Juice production	[a,b,c]0.00	[a,b,c]0.00	[a,b,c]0.00	[a,b]0.00 [c]734.48
∑ (harvest. transport & processing costs)	[a]1740.52 [b,c]770.19	[a]1287.16 [b,c]551.64	[a]1758.21 [b,c]1507.04	[b]6418.15 [c]6938.63
∑ (production costs)	[a]5306.63 to 5478.57 [b,c]2105.01	[a]5032.40 [b,c]2156.74	[a]4883.90 to 4998.52 [b,c]4186.20 to 4284.45	[b]7792.35 [c]8312.82
Machinery investment and Maintenance € ha^{-1}	[a,b,c]0.00	[a,b,c]0.00	[a,b,c]0.00	[a,b]0.00 [c,d]14583.33 [c,e]7291.67
Benefits € ha^{-1}	[a]6776.00 to 7682.50 [b,c]3267.30 to 3684.00	[a]7875.00 to 8148.00 [b,c]3375.00 to 3492.00	[a]5852.00 to 6965.00 [b,c]5016.00 to 5970.00	[b]14400.00 [c]80610.00

[a] State-of-the-art scenario without fodder production.
[b] State-of-the-art scenario with fodder production.
[c] Green Biorefinery scenario for a juice price of 1300 € t^{-1} and cake price of 29 € t^{-1}.
[d] 210 ha farm size.
[e] 420 ha farm size.

Table A8
IRR for a farm size of 210 ha at various juice prices (cake price equals 29 €/t).

Case 1: The juice price takes values in the interval [500.00; 723.60]									
Juice price € t^{-1}	500	720							
IRR	**n.a.**	**n.a.**							
Case 2: The juice price takes values in the interval [723.60; 2112.70]									
Juice price € t^{-1}	723.6	860	865	870	900	944	1000	1050	1100
IRR	**n.a.**	n.a.	−0.09	−0.07	−0.03	**0.00**	0.03	0.06	0.08
Juice price € t^{-1}	1150	1200	1250	**1300**	1350	1400	1450	1500	1550
IRR	0.1	0.11	0.13	**0.15**	0.16	0.18	0.2	0.21	0.23
Juice price € t^{-1}	1600	**1650**	1700	1750	1800	1850	1900	1950	2000
IRR	0.24	**0.26**	0.27	0.28	0.3	0.31	0.33	0.34	0.35
Juice price € t^{-1}	2050	**2100**							
IRR	0.37	**0.38**							
Case 3: The juice price takes values in the interval [2112.70; 2500.00]									
Juice price € t^{-1}	2112.7	2150	2200	2250	2300	2350	2400	2450	2500
IRR	**0.38**	0.39	**0.41**	0.42	0.43	0.45	0.46	0.47	**0.48**

Table A9
IRR for a farm size of 420 ha at various juice prices (cake price equals 29 €/t).

Case 1: The juice price takes values in the interval [500.00; 723.6.0]									
Juice price € t^{-1}	500	550	600	615	650	700	720		
IRR	**0.03**	0.07	0.11	**0.12**	0.14	0.18	**0.19**		
Case 2: The juice price takes values in the interval [723.60; 2112.70]									
Juice price € t^{-1}	723.6	750	800	850	900	950	1000	1050	1100
IRR	**0.19**	0.21	0.23	0.26	0.29	0.32	0.34	0.37	0.4
Juice price € t^{-1}	1150	1200	1250	1300	1350	1400	1450	1500	1550
IRR	0.42	0.45	0.47	0.49	0.52	0.54	0.56	0.59	0.61
Juice price € t^{-1}	1600	1650	1700	1750	1800	1850	1900	1950	2000
IRR	0.63	0.65	0.67	0.69	0.71	0.73	0.75	0.77	0.79
Juice price € t^{-1}	2050	**2100**							
IRR	0.81	**0.83**							
Case 3: The juice price takes values in the interval [2112.70; 2500.00]									
Juice price € t^{-1}	2112.7	2150	2200	2250	2300	2350	2400	2450	2500
IRR	**0.83**	0.85	**0.87**	0.88	0.9	0.92	0.94	0.95	**0.97**

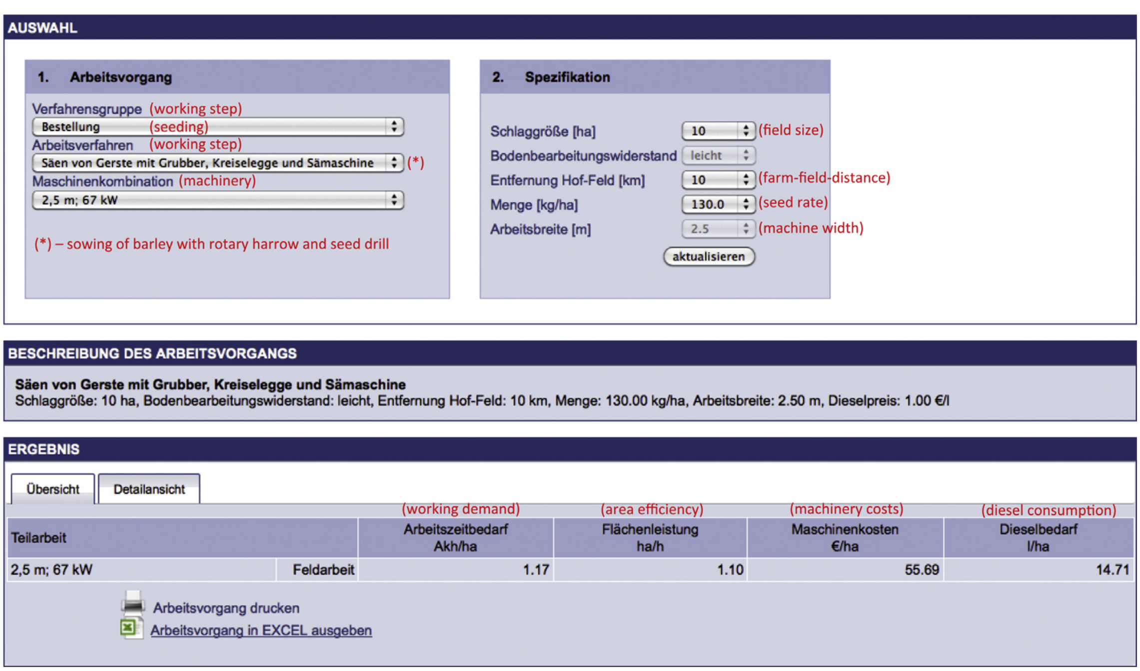

Fig. A1. KTBL database set up exemplary on the working step seeding.

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