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Research paper

Ecological diversification is risk reducing and economically profitable – The case of biomass production with short rotation woody crops in south German land-use portfolios

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ABSTRACT

As bioenergy plants, short rotation woody crops (SRWC) feature high biomass productivity and provide positive external effects, such as reduced soil erosion, increased soil life, and reduced nitrate leaching. However, they are not widespread in intensive cropping systems due to long investment periods and perceived economic disadvantages (low profitability and high risk). Nevertheless, the perceived uncertainty as the main barrier of adoption has not been addressed sufficiently, since the economic risk of SRWC has not been quantified and compared with conventional crops extensively. Another shortcoming of recent economic evaluations is that they are based on mutually exclusive comparisons of alternative investments. In fact, SRWC can be considered an asset of agricultural portfolios, whereby diversification effects are expected due to different ecology, products, and markets. To address these shortcomings, we quantified the economic risk of SRWC and conventional crops and applied the Modern Portfolio Theory to evaluate the economic diversification effects of SRWC at the farm level in a low- and a high-yielding study region in Bavaria (Germany). In SRWC-crop comparisons, SRWC showed the lowest economic risk of all crops compared and gross margins which were competitive with most alternative crops. Furthermore, the correlation of the gross margins of SRWC and agricultural crops compared was relatively low. Therefore, the inclusion of SRWC into existing farm production plans offered economic diversification, increasing the profitability at farm scale, while lowering risk. Thus, diversifying cash crop rotations with SRWC is an effective risk-management instrument that can furthermore provide positive external effects.

1. Introduction

The demand for woody biomass is increasing worldwide, for both material and for energetic use [1,2]. At the same time forests, the main source for woody biomass, are diminishing, and this decrease makes it more difficult for resource managers to provide woody biomass sustainably. Forest area dropped by 6.8 million ha per year, equal to 0.16% between 1990 and 2010 [3]. This drop was accompanied by increased greenhouse gas emissions [4] as well as loss of biodiversity and livelihood [3]. Given these trends, it is important to find sustainable solutions that meet the increasing demand for woody biomass yet maintain natural forests and reduce the pressure on natural forests.

Woody biomass for energetic uses is experiencing a renaissance [5], which heats up markets further. About 8% of the global final

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energy consumption is supplied by bioenergy [5], accounting for 1.9bn m^3 (i.e. 1.9×10^9 m^3) of the 3.5bn m^3 wood harvested [6]. To meet the increasing demand for energy from biomass, woody and non woody biomass production is extended to agricultural land. Such biomass production is competing with food and feed for land resources [7]. Already 3% of worldwide non woody crop production on agricultural land is used as bioenergy and the land devoted to bioenergy is projected to increase substantially in the 21st century [5,8]. Such a land use change to grow biofuel has environmental and economic benefits as well as costs. On the one hand, bioenergy crops grown on marginal lands can mitigate GHG emissions [4,9]. Particularly perennial lignocellulosic crops can store carbon, above- and belowground [10,11]. Furthermore, bioenergy from decentralized energy supply chains provides energy security, labor, and diversified income in rural areas [12]. On the other hand, possible negative impacts include land consumption of bioenergy crops, carbon losses due to indirect land use change [4], intensified agricultural practices along with enormous nitrous oxide emissions [8], and lower water quality and quantity. To meet the increasing demand for biomass, we need sustainable systems for biomass production.

Short rotation woody crops (SRWC), fast growing tree species grown on agricultural land, have a higher productivity than long-rotation forest systems grown on forest land [13,14]. Compared with annual crops, SRWC are more environmentally beneficial: first, the production of biomass is energy efficient [15,16] because SRWC require few working steps and little to no pesticides and fertilizers. This extensive production system causes low nitrate leaching, leads to increased water quality [17], and positively affects soil life [18,19] and soil quality [10,20]. Second, SRWC with poplar or willow are richer in species than conventional arable land [11,21]. Despite these benefits, SRWC adoption is not widespread in North America and many European states [15] such as in southern Germany.

The low adoption of SRWC has been attributed mainly to economic and socio-economic reasons [22–26]. The economic reasons are high upfront establishment costs, long payback periods, lack of established markets, scarcity of land, and low or uncertain profitability. The socio-economic reasons are farmers' perceptions and unfamiliarity with SRWC. While farmers are familiar with conventional crops and are experienced with the level of and variability of gross margins (GMs), they lack comparable experience with SRWC. Hence, farmers perceive SRWC as more uncertain [27] and less viable than conventional agricultural crops. This perception, combined with the long land commitment and long payback periods of SRWC, leads to adoption restraints.

Recent economic studies provide no clear answer regarding the economic competitiveness and risks of SRWC. Hauk et al. [22] reviewed 37 economic evaluations of SRWC: 16 studies identified SRWC as economically competitive and only two quantified economic risk. Overall, these economic evaluations of SRWC have three shortcomings. First, they compare SRWC with just one or a few alternative crops instead of considering all relevant alternative land use options (i.e. analyzing crop portfolios of practical relevance). Second, they neglect or underestimate risk, yet SRWC and conventional agricultural crops are subject to market and biophysical (yield) risk. Third, they do not take into account diversification, yet farmers usually grow several crops with different ecologies, products, and markets, which has the potential to lead to ecological and economic diversification [28]. To advance the field of economic evaluation of perennial crops and to provide reliable decision support for land-use decision makers, all potential alternative crops need to be taken into account and the economic risks as well as the effects of mixing crops (portfolio diversification) need to be quantified. An approach that is capable of fulfilling these requirements is the Modern Portfolio Theory (MPT). The concept of economic diversification was first mathematically described by Markowitz [29] and later refined (see, e.g. Sharpe [30]). MPT is applied widely in the financial sector for stocks and bonds [31] and there is evidence that MPT is an appropriate method to optimize land use allocation (see, e.g. Refs. [32–39]). However, this approach has not yet been used to explore economic diversification effects by mixing SRWC into conventional agricultural portfolios. If SRWC improves economic diversification in existing agricultural crop portfolios, this would provide an economic motivation for the ecological diversification of farm enterprises by SRWC (Fig. 1).

In order to contribute to a more realistic understanding of the economics of SRWC and to provide land use decision makers with reliable decision support under risk, we quantified economic performance and economic risk of SRWC and alternative crops. To analyze the economic effects of mixing perennial woody crops into portfolios of conventional agricultural crops (i.e. a farm-level analysis), we applied the expected value-variance framework, based on the MPT [29,40]. These economic effects were demonstrated at four selected model farms in southern Germany. The following research questions lead our analysis:

(I) How high are the expected annualized gross margin of SRWC and its standard deviation compared with selected agricultural crops?
(II) Do positive economic effects occur if farmers biologically diversify their agricultural portfolio by perennial woody crops?

2. Material and methods

The economic analysis of conventional agricultural crops and perennial woody crops, was performed in two steps, the first step evaluates at the crop level, the second step at the farm level. The first step was a classic economic analysis and a comparison of crops based on common economic target figures (i.e. a comparison of mutually exclusive crops). In contrast to recent studies that rely on price and yield assumptions for only one given year (see e.g. Hauk et al. [22] and El Kasmioui & Ceulemans [41]), this study analyzed the economic performance of each crop based on actual yield and price data for the last ten years. Consequently, we were able to evaluate economic performance, and to analyze the yield and price related economic volatility (risk) of crops (see section 2.1).

The second step was an economic analysis and economic optimization at the farm-level. To determine at farm-level the economic effects of growing a portfolio of SRWC and several conventional annual crops, we used MPT to determine the economic effects of mixing crops (economic diversification).

2.1. Economic analysis of conventional crops and SRWC

To analyze and compare the economic viability and risks of agricultural crops and SRWC, and to demonstrate the economic effects of SRWC within an agricultural portfolio, we chose one high-yielding county, Aichach (AIC), and one low-yielding county, Wunsiedel (WUN), in Bavaria (Germany). For each county we selected two common farm types that focus on crop production: one type with standard cash crops (cereals and maize) and one type that can additionally grow the highly profitable crop potato, due to good soil properties. All crops with a share of more than 5% of the cropland per county [42] were considered standard crops in each study region and thus included in the assessment.

The profitability of agricultural crops was analyzed based on gross margins for conventional crops by subtracting variable costs