Evaluating efficiencies of crop management systems within an Integrated Data Envelopment Analysis for the Marchfeld region in Austria

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***Abstract* - Analyzing the potential of crop yields and the environmental effects of crop management is essential to support policy decisions that foster sustainable agricultural systems. We apply a non-parametric Integrated Data Envelopment Analysis (IDEA) to evaluate technically efficient crop management systems for the region Marchfeld in Austria. Providing a relative efficiency measure, our IDEA model considers positive and negative agricultural externalities like soil organic carbon sequestration, nitrogen emissions and soil sediment losses. Our model is based on simulation outputs from the bio-physical process model EPIC (Environmental Policy Integrated Climate). The integrated analysis reveals that sugar beets and field peas are most often found in technically efficient rated crop management systems. Furthermore, technically efficient rated management systems often include straw removal or lower fertilization rates, or irrigation.**

Introduction

To support policy decisions which foster sustainable agricultural systems it is important to know which crop management systems are technically efficient. We apply an environmentally integrated Data Envelopment Analysis (IDEA) using simulation outputs from the bio-physical process model EPIC (Environmental Policy Integrated Climate) to provide a single efficiency measure for alternative crop production systems in the Marchfeld region. We consider positive and negative externalities of agricultural productions, climate scenarios, and alternative crop management practices such as tillage systems, fertilizer inputs and irrigation water as well as site determining factors like soils, weather, and topography. The analysis focuses mainly on the following research questions: Which crop management systems are technically efficient in Marchfeld? Which site specific characteristics are favorable for particular crop production choices? Which crops are most often found in technically efficient rated crop rotations? How does the efficiency ranking change when various climate scenarios are taken into account?

The model

Data Envelopment Analysis (DEA) is a data driven frontier analysis technique to model operational processes for performance evaluation. It is used to estimate efficiencies of comparable entities, which are called decision making units (DMUs). The DMUs which exhibit best practice performance constitute the efficiency frontier of the group, against which the relative efficiencies of the remaining DMUs are measured to. We apply the concept of technical efficiency which refers to the possibility of the DMU to generate maximum output from a given bundle of inputs. DEA does not require specific functional assumptions on the production function, instead DEA is a non-parametric method which uses linear programming models to construct a piece-wise surface frontier over the observations (Coelli, Rao and Battsee, 2000).

We extend the standard DEA model by integrating undesirable agricultural outputs, like nitrate emissions and soil sediment losses, in the efficiency analysis. Therefore, we call the model an environmentally integrated data envelopment analysis (IDEA). We apply an approach presented by Chung, Färe and Grosskopf (1997) and Färe and Grosskopf (2004):

$$
\begin{aligned}
&\max \beta \\
\text{s.t. } &\textstyle\sum_{k=1}^{K} x_{kn}\,\lambda_k \le x_{k'n} && n = 1,\dots,N \\
&\textstyle\sum_{k=1}^{K} y_{km}\,\lambda_k \ge y_{k'm} + \beta g_{y_m} && m = 1,\dots,M \\
&\textstyle\sum_{k=1}^{K} u_{kj}\,\lambda_k = u_{k'j} - \beta g_{u_j} && j = 1,\dots,J \\
&\lambda_k \ge 0,\ \textstyle\sum_{k=1}^{K} \lambda_k = 1 && k = 1,\dots,K
\end{aligned}
\qquad (1)
$$

In the model there are $k = 1,\dots,K$ DMUs. The set $P(x)$ denotes the set of desirable outputs $y \in \Re_+^M$ and undesirable outputs $u \in \Re_+^K$ which are producible from the input vector $x \in \Re_+^N$. The variable λ is a Kx1 vector giving the distance to the closest technically efficient DMU for each DMU, and β is a constant, which is the efficiency score for each DMU. Technical efficiency is indicated when $\beta = 0$; $\beta > 0$ indicates inefficiency and implies that the DMU can increase outputs without requiring more inputs in order to reach efficiency.

Data description

The efficiency evaluation is based on simulation outputs from the bio-physical process model EPIC. EPIC simulates important bio-physical processes in agricultural land use management and thereby provides model outputs on e.g. crop yields, nitrogen emissions, and soil organic carbon contents. The simulation outputs are mainly based on five thematic datasets addressing bio-physical modeling aspects: (i) land use data, (ii) topographical data,

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(iii) soil data, (iv) cropland management data, and (v) climate data.

For the efficiency analysis in Marchfeld, six crops (winter wheat, spring barley, field pea, sunflower, sugar beet and corn) cultivated within two crop rotation systems have been simulated for 12 management system over 66 years from 1975 to 2040. In our efficiency analysis these management systems constitute our DMUs. The crop management options include three tillage systems (conventional, minimum and reduced tillage), irrigation or rainfed management, with and without straw removal, and three fertilization levels (medium, high, and low input). They are simulated for five representative soil types representing different soil qualitites (soil type 1 to soil type 5) (cp. Schmid et al., 2007)

The EPIC simulations for the period 1975 to 2007 are based on observed weather data in Austria, whereas the period 2008 to 2040 is based on climate change scenarios (Strauss et al., 2009). For the efficiency analysis we use the averages of input and output parameters for the period 1975 to 2007 and for 2008 to 2040, respectively.

The input to IDEA models include nitrogen fertilizer in kg/ha, and irrigation water in mm; desirable outputs include dry matter crop yields in t/ha, dry matter straw yields in t/ha, and topsoil organic carbon stocks in t/ha; and undesirable outputs are total nitrogen emissions in kg/ha and soil sediment losses in t/ha.

To control for the influence of soil types on the efficiency results, we evaluate an efficiency frontier for each of the five soil types.

Preliminary results

Preliminary results for the period 1975-2007 show that for each soil type approx. 25% of all DMUs are rated technically efficient. Our IDEA model for each soil type also reveals that sugar beets, field peas and winter wheat are found in the highest efficiency class to a proportion of approx 30%, 26.7% and 16%, respectively. Sunflower and spring barley are found in the lowest efficiency class with a proportion of 50% and 20%, respectively.

In general, management systems with straw removal yield more technically efficient DMUs than management systems without straw removal. Consequently, additional positive outputs through straw removal (e.g. straw yields and less nitrogen emissions) outweigh likely negative environmental effects such as declining soil organic carbon sequestrations. Table 1 offers details on technical efficient management systems per soil type. Additionally, DMUs which include irrigation systems or low fertilization rates are most often found in technically efficient rated DMUs.

Results for the period 2008-2040, when stochastic climate change is taken into account, reveal that the mean and maximum efficiency values increase for each soil type, indicating decreasing technical efficiency for all crop management systems on average.

Table 1. Proportion of specific management systems of all technically efficient rated management system for each soil type, in percent

Management systems	Soil1	Soil2	Soil3	Soil4	Soil5
Conventional tillage w/ irrigation w/o straw removal	11.9	9.5	13.4	9.0	10.2
Conventional tillage w/ irrigation w/ straw removal	**23.9**	**20.6**	**20.9**	**22.4**	**23.7**
Conventional tillage w/o irrigation w/o straw removal	1.5	3.2	1.5	1.5	1.7
Conventional tillage w/o irrigation w/ straw removal	9.0	15.9	10.4	3.0	1.7
Minimum tillage w/ irrigation w/o straw removal	9.0	9.5	9.0	9.0	10.2
Minimum tillage w/ irrigation w/ straw removal	17.9	17.5	19.4	16.4	16.9
Minimum tillage w/o irrigation w/o straw removal	3.0	0.0	3.0	6.0	3.4
Minimum tillage w/o irrigation w/ straw removal	3.0	3.2	1.5	9.0	5.1
Reduced tillage w/ irrigation w/o straw removal	6.0	6.3	4.5	9.0	8.5
Reduced tillage w/ irrigation w/ straw removal	11.9	11.1	13.4	14.9	16.9
Reduced tillage w/o irrigation w/o straw removal	0.0	0.0	0.0	0.0	0.0
Reduced. tillage. w/o irrigation w/ straw removal	3.0	3.2	3.0	0.0	1.7

Notes: highest values indicated in bold

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