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Implications of subsidiary cropping and tillage system on economics and production risk

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Abstract

Subsidiary cropping and mulch systems as well as conservation tillage may induce multiple positive agro-ecological effects, increasing resilience and yield stability of cash cropping in organic farming systems. As this may also implicitly affect production economics and risk potential, the paper at hand evaluates two year crop-rotations from empiric field data, considering costs and revenues of production as well as yield effects based on stochastic risk simulation. Absolute profitability as well as risk potential substantially varies between cropping systems and locations and does not necessarily display a definite preference of conventional/reduced tillage or subsidiary cropping systems. However, a temporal expansion of the period under observation considering long-term effects of soil fertility enhancing management practices may illustrate their risk-reducing potential as well as the necessity to handle them as long-term investments with instant expenses and subsequent economic returns.

Introduction

Obviously, the use of fertilization and plant protection with instant effects on plant growth and health is severely restricted in organic farming systems. Therefore, with regard to the broadly discussed sustainable intensification of (organic) agriculture (Niggli et al. 2008, Royal Society 2009) other measures need to be taken into account that focus on the improved utilization of agro-ecological effects in order to ensure yield stabilizing or even increasing framework conditions. For organic cash cropping, these measures include e.g. intercropping such as cover crop or mulch systems (Hartwig and Ammon 2002) as well as reduced tillage systems (Pittelkow et al. 2015) with multiple ecological, but also economic effects. The economic evaluation of different tillage systems is dependent on field and empirical data from experimentally operating research groups. However, deterministically deduced statements from field trials, needed for farm consultancy, are extremely restricted by local and site-specific framework conditions as well as annual effects, leading to a wide range of results. Therefore, in the economic analysis at hand we integrated the variability of input parameters as stochastic effects applying Monte-Carlo-simulation. The results derived from risk simulation represent a much more realistic picture of integrated empiric and economic evaluation and allow for an improved basis of decision-making for practitioners.

Material and methods

The economic and risk assessment presented in this paper is based on empiric findings regarding the adaptation of inter/cover crop and mulch systems in conventional (*CT*) and reduced (*RT*) tillage

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systems in two-year crop rotations from the EU funded *OSCAR* project *Optimising Subsidiary Crop Applications in Rotations* (2012-2016). We focus on the organically managed trial locations of Kassel University (KU, Germany) (winter wheat-potato), Organic Research Centre (ORC, United Kingdom) (winter wheat-spring barley) and Norwegian Institute of Bioeconomy Research (NIBIO, Norway) (winter wheat-spring barley). Risk simulation of crop and tillage systems is based on the cost-benefit calculation methods according to Olson (2003) and KTBL (2016), the key economic figure being the *net return after charge for unpaid labour and management as well as an interest charge* (NR). Agricultural standard data to calculate labour and machinery costs (KTBL 2016) were used to complement the site-specific data. A yield dependent adjustment of machinery costs was considered.

For risk analysis, probability distribution functions (PDF) were estimated for yield parameters (main crop and grain straw) as well as sorting and storage losses (potato) based on the field data, using the Microsoft Excel based risk software @RISK (PALISADE 2010). The best fitting distributions were selected based on the χ^2 statistics. Depending on data availability and location between eight and 16 single data sets could be used to fit the distributions. The probability distributions were truncated at 0 kg yield per ha at the lower end as well as at the maximum yield values observed in the respective field trials of the different locations in order to avoid improbable yield assumptions. PDFs of grain yields were correlated with their respective straw yield data. Depending on the data structure, the fitted PDFs comprised of *Gamma*, *Weibull*, *BetaGeneral*, *Pearson*, *LogLogistic*, *InvGauss*, *Triangular* and *Uniform* distributions, entering a Monte Carlo simulation in order to display probability distributions of the net return expressed in € ha^{-1} a^{-1}.

Results and discussion

The impact of soil cultivation and subsidiary cropping on yields and economics appear to be quite dependent on cropping system as well as annual effects of each trial location (Table 1). Comparing the tillage systems *CT* and *RT* (with the mean net return (NR) displaying the static profitability, and the standard deviation (SD) showing the variability of results from stochastic risk simulation), *CT* systems are mostly more profitable than *RT* systems in all locations (based on higher main crop yields). However, for KU, RT brassica/oat and vetch systems display a lower SD and therefore lower risk potential, and for ORC, the gap between *CT* and *RT* systems is rather small for both NR and SD. For the NIBIO location, except for the control N50 system (fertilized with dried chicken manure, equivalent of 50 kg N ha^{-1}), all *RT* systems show a similar or lower risk potential (SD) than *CT* systems. Comparing the subsidiary cropping systems, adverse effects depending on the location can also be noticed. At KU, subsidiary cropping systems are predominantly more profitable than the control system in both *CT* and *RT* systems, however, often with a higher risk potential. At ORC, in *CT* systems the control system displays highest *NR*, in *RT* systems the leguminous subsidiary crop systems dominate the brassica and control system. At NIBIO location, in both low and high N fertilization groups the white clover system is most profitable but medium or most risky compared to the other cropping systems or control.

An important factor which has not been considered in the evaluation above are long-term nutrient and carbon effects induced by subsidiary crops, contributing to soil fertility and yield potentials, especially in N limited organic farming systems. Nitrogen provided either by storage in plant biomass or N_2 fixation is often not available immediately but throughout an entire crop rotation. Therefore, yield effects of subsidiary crop nitrogen is most likely only marginally represented in the two-year OSCAR crop rotations. A monetary evaluation of the nitrogen provided by the respective subsidiary crops (price per kg N results from the production costs of the respective subsidiary crops divided by the amount of N provided by the subsidiary crop) may increase the additional value of subsidiary crops for the entire crop rotation by up to 160 (ORC) and 280 € ha^{-1} a^{-1} (NIBIO), respectively. The N input by dead mulch may even account for 875 € ha^{-1} a^{-1}, together with the N value of the cover crop resulting in additional N fertilizer value of 1130 € ha^{-1} a^{-1} for KU location.

Table 1: Net return (NR) (€ ha^{-1} a^{-1}) and Standard deviation (SD) of inter/cover crop and mulch systems in conventional and reduced tillage systems for three European locations (Germany, UK, Norway)

Kassel University (Germany) (winter wheat – potato)

SC[a]		White clover	Subt. clover	Brassica/oat	Vetch	-	-
CT[b]	Mean NR[d]	9.401	9.300	10.322	10.832		
	SD[e] (σ)	1.740	1.989	2.063	2.497		
RT[c]	Mean NR	7.626	9.829	8.691	9.392		
	SD (σ)	1.916	2.042	1.225	1.709		

Organic Research Centre (UK) (winter wheat – spring barley)

SC		Control	Brassica	Black Medick	Brassica/ Black Medick	-	-
CT	Mean NR	4.176	3.944	3.884	3.836		
	SD (σ)	470	472	546	388		
RT	Mean NR	3.226	2.734	3.307	3.257		
	SD (σ)	557	708	518	534		

NIBIO[f] (Norway) (winter wheat – spring barley)

SC		Control N50[g]	Vetch N50	White clover N50	Control N100	Vetch N100	White clover N100
CT	Mean NR	1.142	584	1.291	796	767	1.181
	SD (σ)	145	183	244	372	241	261
RT	Mean NR	557	417	821	575	653	889
	SD (σ)	215	191	197	146	154	199

[a]Subsidiary crop; [b]Conventional tillage; [c]Reduced tillage; [d]Net return (€ ha^{-1} a^{-1});[e]Standard deviation; [f]Yield values from spring barley restricted to mean values from second trial repetition due to crop failure in first trial repetition; [g]kg Nitrogen ha^{-1} from dried chicken manure

Conclusions

The presented results do not easily allow for general conclusions on economic advantages concerning profitability and risk for certain tillage or cropping systems mainly due to different trial conditions at the several locations as well as annual effects. Nevertheless, certain tendencies can be derived from the economic evaluation. *RT* systems usually imply lower management costs, which, however, could mostly not be exploited in favour of a better profitability due to often lower yields in the *RT* systems, which, however, may stabilize over time. Risk analysis indicates that reduced tillage may help to decrease production risks in some locations (e.g. partly at NIBIO and KU), but may also increase variability of results for other locations (ORC).The consideration of long term effects of integrated subsidiary crops, such as nutrient availability (nitrogen) or soil fertility (carbon) could substantially improve the economic feasibility of reduced tillage as well as subsidiary cropping systems. The increase of physical and economic productivity while at the same time generating eco-system services (e.g. carbon storage) would perfectly fit into the concept of *eco-functional intensification*. In order to be able to truly determine the advantages or disadvantages of different tillage or cropping systems future analyses should incorporate long-term trials that will show the long-term effects of nutrient availability and soil fertility. The adaptation of soil properties from *CT* to *RT* systems is usually a multi-annual process, and, despite the challenges with weed control and spring nitrogen mineralization (especially in organic *RT* systems), yields potentials may not necessarily be lower than in *CT* systems (Mäder and Berner 2011), which, however, could not always be displayed in the short-term trials at hand.

Incorporating long-term beneficial effects into the evaluation will essentially also be reflected in the economic sustainability of reduced tillage and subsidiary cropping systems. Consequently, the adaptation of reduced tillage systems or subsidiary crops to improve soil fertility and stabilize or even increase long-term productivity, from an economic point of view, must be seen as a regular investment, where expenses incur instantly and economic returns often only pay off after several years.

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