Analyzing the Effects of Risk and Uncertainty on Optimal Tillage and Nitrogen Fertilizer Intensity for field crops in Germany*

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Abstract

This study provides a risk analysis of long-term field experiments in Germany (Bavaria) on various field crops (potato, wheat and corn), grown in rotation, under a variety of different

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tillage and nitrogen management systems. The field experiment provided yield and input data for the analysis, and was combined with market data relevant to the case-study region. The emphasis of the analysis is on the interaction between risk and tillage and nitrogen strategies. Over the whole rotation (corn-wheat-potato-wheat), conventional tillage combined with conventional nitrogen rates is optimal, both for risk-neutral and risk-averse farmers. Although more intensive management practices involve higher risk, the increase in risk premium is not sufficient to alter the ranking of strategies for farmers with higher levels of risk aversion. Reducing nitrogen rates would be costly to farmers, especially under reduced or shallow tillage. Decoupled farm subsidies within the expected utility model show that even for a scenario with no subsidies our conclusions do not change.

Keywords: tillage, nitrogen management, risk analysis, expected utility, stochastic dominance, crop insurance

1. Introduction

Both nitrogen and tillage management practices have large impacts on the economic and environmental performance of agricultural systems and both are highly relevant to current discussion on mitigation of and adaption to climate change. Nitrogen fertilizers are one of the key factors determining crop productivity; however, they also have negative impacts on ground water quality because of nitrate leaching, and on climate change through nitrous oxide emissions. Furthermore, the production of mineral nitrogen fertilizers is highly energy intensive. Therefore, efficient use of nitrogen fertilizers is crucial in terms of sustainable crop management.

Systems of reduced tillage have been proposed to reduce soil erosion, increase carbon sequestration in the soil and create cost savings from reduced inputs of machinery, labor, and fuel (Baeumer, 1992; Uri et al., 1999; Weersink et al., 1992). However, opportunity costs (due to yield penalties of reduced tillage systems) must also be taken into account. Furthermore, reduced tillage systems may require higher plant nutrient supply (Carter, 1994; El Titi, 2003), which can lower their positive environmental and economic benefits. Therefore, the optimal tillage strategy for farmers to adopt is not obvious, requiring careful analysis.

Existing literature indicates that nitrogen fertilizer has a risk-increasing effect. For instance Rajsic et al. (2009) found for corn production in Ontario that nitrogen is a risk-increasing input. They concluded that consideration of risk should decrease, rather than increase, a risk-averse farmer's rate of nitrogen application. Another example is a paper from Roosen and Hennessy (2003) who found that risk-averse farmers should use less nitrogen than risk-neutral producers and that the degree of reduction in fertilizer use increases with the agent's level of risk aversion. A number of earlier studies also found that nitrogen is a risk-increasing input in crop production (e.g., Love and Buccola, 1991; Nelson and Preckel, 1989).

So far, only a few studies have investigated risk issues associated with different tillage systems. In a recent paper, Archer and Reicosky (2009) analyzed economic performance (including stochastic efficiency analysis) for different tillage systems in North America. Their results showed that risk-averse and risk-neutral decision makers would prefer the same tillage system. Ribera et al. (2004) have compared conventional and no-tillage farming systems in Texas and found that no-tillage would be preferred in three out of five tested crop rotations assuming a risk-neutral agent. However, for a risk-averse agent, the no-tillage system would be preferred over the conventional tillage systems in all analyzed rotations. Pendell et al. (2007) carried out a risk analysis of no-tillage and conventional tillage systems, different nitrogen intensities, and

sources of nitrogen fertilizers in corn production in northeastern Kansas. Their general result was that no-tillage would be preferred over conventional tillage, and commercial nitrogen fertilizers would be preferred over cattle manure within a wide range of absolute risk aversion coefficients.

The cited articles above show that the effect of risk aversion on optimum tillage management is not as clear as it is for the case of nitrogen management. Furthermore, there is little literature that analyzes the combined effects of tillage and nitrogen management. Therefore, the goal of this paper is to carry out a detailed risk analysis of long-term field experiments for various field crops (potato, wheat and corn) where different tillage and nitrogen management systems were tested. The effect of farmers' risk aversion on the optimal decision will be studied. One of the key objectives of this study is to estimate the extra value to farmers when they receive and respond to recommendations for nitrogen application and tillage systems from models which represent risk aversion (compared to recommendations from models based on an assumption of risk-neutrality). Furthermore, the impact of farm subsidies on decision about tillage and nitrogen management will be analyzed.

In a previous study using the same experimental data, Meyer-Aurich et al. (2009) investigated interaction effects of fertilizer and tillage on yield, profitability and risk. In this paper we aim to overcome a number of limitations in the risk analysis of that study. In contrast to Meyer-Aurich et al. (2009), we account for price risk and for correlations among prices and yields. Furthermore, the farm risk model is adapted more precisely to local conditions. We account for farmers' wealth and farm subsidies when investigating the effect of risk aversion on fertilizer and tillage management and discuss the implications in different economic settings.

2. Materials and Methods

2.1 Data Source

Data were obtained from a long-term experiment, established in 1992 at the Research Station Scheyern 40 km north of Munich in southern Germany (48.50°N, 11.45°E) within the research Network “Agroecosystems Munich” (“Forschungsverbund Agrarökosysteme München”; for more details see Osinski et al., 2005). Average (1995 to 2002) annual precipitation was 943 mm, and average air temperature was 8.2° C (Huber et al., 2005). The soil types can be characterized as loamy to sandy cambisols derived from coarse and fine grained tertiary sediments (Kölbl and Kögel-Knabner, 2004). The crop rotation consists of wheat (*Triticum aestivum* L.) alternated with corn (*Zea mays* L.) and potato (*Solanum tuberosum* L.) (corn-wheat-potato-wheat). For this analysis, we used yield data from three, complete rotation cycles from the years 1994 to 2006. Since potatoes were not harvested in 2002 due to technical problems, 2006 data were used for that year. To reduce the risk of biasing results for or against potatoes, we replaced 2002 yield data for all crops with the results from 2006. Three tillage and three fertilizer treatments were arranged in a randomized split-plot design with three replications. Tillage treatments were randomly assigned to the main plots, which were split randomly by the fertilizer treatments. The assignments of the treatments to the plots have been kept constant since 1992. The plots are 12 m by 12 m in size with 3 m buffer strips between the main plots. The experiment was replicated on four plots to provide response data for each crop in every year.

The investigated tillage systems represent three possible tillage intensities under the existing soil and climate conditions. One is the “conventional tillage” (CT) system with a moldboard

plow and secondary tillage before planting, as is the usual practice in the area. The others are two systems of reduced tillage, which are called “reduced tillage” (RT) and “shallow tillage” (ST) within this article. The difference between the RT and ST system is mainly the depth of tillage. The RT system in the experiment involved plowing with a chisel plow to a depth of 18 cm, while prior to 1999 ST involved cultivation with a rotor tiller in the first 6 – 8 cm of the top soil, switching to a shallow chisel plow since 1999, again to a depth of 6 – 8 cm.

The three N-fertilizer systems can be regarded as usual practice for farmers in that region (N2), one increased level of N fertilizer (N3), and one reduced (N1). The N fertilizer use was an urea ammonium nitrate solution (UAN) with 280 g N kg⁻¹ to all crops. It was applied with a modified boom sprayer (with tubes) to conduct the solution directly to the soil surface. Fertilizer rates were fixed for the cultivated crops, irrespective of credits due to effects of previous crops’ cultivation or mineralization in the soil. To potato, N-fertilizer was applied after planting at the rates 50, 100, or 150 kg N ha⁻¹, for the respective intensities. Corn received 65, 105 or 135 kg N ha⁻¹, while wheat received in total 90, 135, or 180 kg N ha⁻¹ in multiple applications.

The experimental data provide information from a specific rotation in Bavaria which is relevant for the type of cash crop farms modeled in this paper. We believe the data to be relevant to and representative of typical farms in this region. A more detailed description of the experimental site and design is provided by Meyer-Aurich et al. (2009).

2.2 Cost Assumptions

Assumptions for the total production costs of the analyzed tillage systems with the usual practice fertilizer rate (Table 1) are based on the calculations of Meyer-Aurich et al. (2009). Production costs include all variable costs for seed, fertilizer, herbicides, insecticides,

machinery use and labor. Machinery costs were calculated according to the hours of use including costs for insurance, tax and average repair costs. The interest on capital use was calculated at 6%. Reduced fertilizer practice required fewer operations to spread the fertilizer for wheat and corn, which was factored into the machinery costs. Fertilizer costs of 0.91 € kg⁻¹ N, fuel costs of 0.95 € l⁻¹ and labor cost of 15 € h⁻¹ were assumed, according to current production costs relevant for Germany. Additionally, drying cost of 40 € Mg⁻¹ for corn was assumed. For sorting and storing of potatoes 17.20 € Mg⁻¹ was included. Generally, labor and fuel requirements are lower for reduced tillage systems (Uri et al., 1999). However, we included additional costs for operations to improve crop residue incorporation (cornstalk shredder) after corn harvest in the RT and ST systems, which increased production costs for wheat after corn (Table 1). Furthermore, we accounted for the cost of a herbicide application on the wheat stubble in the RT and ST systems in spring after weed emergence.

2.3 Price Assumptions

Time series of Bavarian producer prices from 1997 to 2008 (see Table 2) were used to represent the distribution of prices in the analysis. We are using this price series to represent the probability distribution of future prices. In principle, in order to accurately represent the variance of prices, the appropriate procedure would be to convert nominal prices to real prices by factoring out inflation, and then to remove any significant trend in the real data. For our price series, these two steps effectively cancelled each other out (i.e. there is no trend in the nominal price data). Consequently, we chose to use the nominal data set to represent the future price distribution.

The mean prices are 99.2 € Mg⁻¹, 127.3 € Mg⁻¹ and 120.9 € Mg⁻¹ for potato, wheat, and corn, respectively. Potatoes showed the highest price risk, in terms of the coefficient of variation, of 44.9%. Wheat and corn prices showed almost equal coefficients of variation with 26.4% and 25.4%, respectively.

To analyze correlations between crop yields and prices, instead of the experimental yields, we used annual yields averaged over the region where the experimental site is situated, provided by the Bavarian State Office for Statistics and Data Processing (2009). This was necessary, since the years of the time series of experimental yields do not correspond to the ones of the price date used. Results of the correlation analysis are displayed in Table 3. Interestingly, there is no significant negative correlation between crop prices and crop yields. We could only find a high positive and statistical significant correlation ($R = 0.97$) between corn and wheat prices. Furthermore, all crop yields show a high positive statistically significant correlation.

2.4 Risk Model

To analyze the effect of risk aversion on tillage and nitrogen fertilizer intensity, we used an expected utility approach. Within this framework, the decision maker's objective is to choose the management option which results in the highest expected utility. Utility is calculated within this study by the following functional form with constant relative risk aversion and decreasing absolute risk aversion properties:

$$U = c + dW_t^{(1-R)} \quad (1)$$

where R is relative risk aversion, which in this formulation is constant for changes in wealth, W_t is total wealth. Parameters c and d are constants that do not affect the ranking of the different

analyzed management options (O’Connell et al., 2003). For this study, we use $c = 0$ and $d = 1$. This functional form is selected on the basis of empirical evidence showing that decision makers tend to have decreasing absolute risk aversion at higher wealth (e.g. Hamal and Anderson, 1982). Values of R were chosen on the basis of empirical evidence and theoretical arguments in the literature. A number of studies using econometric approaches to estimate relative risk aversion of farmers have been published, including studies producing estimates of 1 to 2 (Antle, 1987), zero to 2 (Bardsley and Harris, 1987), and 1 to 3 (Myers, 1989). Other ranges for relative risk aversion suggested in the literature have included 0.5 to 1.2 (Newbery and Stiglitz, 1981), zero to 4 (Little and Mirrlees, 1974; Hamal and Anderson, 1982), and approximately 1 (Arrow, 1971). From this literature, it appears that values between zero and 4.0 should capture the risk attitudes of most farmers, so that is the range used within this study. A relative risk aversion coefficient of 0 corresponds to a risk-neutral decision maker whereas a coefficient of 4 represents a very risk-averse agent.

The model represents price and yield risk. Expected utility for a rotation consisting of l crops is calculated according to equation (2) for a specific tillage and nitrogen management system:

$$E(U(W_t)) = \sum_{k=1}^n \sum_{j=1}^m U \left[W_{in} + S + \sum_{i=1}^l (NR_{i,j,k} * A_i) \right] * prob(j) * prob(k) \quad (2)$$

where W_{in} is initial wealth and S are farm subsidies. Based on published data, we assume, for an average cash-crop farm of 54.2 ha size in the area of the experimental site, an initial wealth W_{in} of 20,694 € ha⁻¹ and farm subsidies S of 22,990 € year⁻¹ (Bayerisches Staatsministerium für Landwirtschaft und Forsten, 2008). A_i is the area of crop i . Net returns for crop i (NR_i) are represented by a discrete distribution, indexed by j for different prices and by k for different yields. Net returns of each crop are calculated by subtracting total production costs (Table 1) from gross returns (Eq. 3).

$$NR_{i,j,k} = Y_{i,k} * P_{i,j} - C_i \quad (3)$$

$Y_{i,k}$ is yield of crop i in yield state k , $P_{i,j}$ is market price of crop i in price state j , and C_i is production cost of crop i , including operating costs, labor costs and capital costs for the machinery used.

An empirical distribution of crop prices based on historical data (see Table 2) was used to simulate $m = 2000$ random crop prices based on the empirical cumulative probability function using the RiskCumul function implemented in @RISK (Palisade Corporation software, Ithaca NY USA). Each of the random observations was assigned a probability of 0.0005. The statistically significant correlation of 0.97 between corn and wheat prices (see Table 3) was modeled using the define correlation option in @RISK. To represent yield risk we use a time series of 12 years of actual experimental yields. Prices and yields are assumed to be independently distributed, since no statistically significant correlation could be found in the correlation analysis (Table 2).

For ease of interpretation of the results, we converted the expected utility values to certainty equivalent (CE) values by taking the inverse of the utility function (Eq. 4).

$$CE(W_t) = U^{-1}(E(U(W_t))) \quad (4)$$

By definition, a risk-averse producer would be indifferent between receiving the certainty-equivalent value with certainty, and accepting a random draw from the risky distribution. For risk-averse decision makers, CE consists of the expected value of returns minus a risk premium. A utility-maximising decision maker also maximizes their certainty equivalent.

3. Results and Discussion

The minimum, expected, and maximum values of net returns are displayed in Table 4 for the analyzed nitrogen and tillage systems, as well as the probabilities of negative net returns. The latter are derived from the cumulative distributions functions. A detailed analysis of variance of crop yields and net returns for deterministic crop prices is provided by Meyer-Aurich et al. (2009) for this experimental data. In the following sub-sections, we first report on results for the impact of tillage and nitrogen management on expected net returns (the risk-neutral case), and then on risk. Subsequent sub-sections report on the effect of risk aversion on optimal tillage and nitrogen management, the impact of farm subsidies on tillage and nitrogen management decision making, and the benefits for risk-averse farmers of receiving advice from models that represent risk aversion, rather than risk neutrality.

3.1 The effect of tillage and nitrogen management on expected net return

For the full rotation, the system with the highest mean net return of 30 € ha⁻¹ is conventional tillage with standard nitrogen fertilizer practice (CT_N2). In expected-value terms, conventional tillage is optimal for two of the three fertilizer rates (other than high) and high fertilizer is optimal for two of the three tillage systems (other than conventional). Thus, from the perspective of a risk-neutral farmer, it is not worth moving away from conventional tillage unless nitrogen rates are increased, and it is not worth increasing nitrogen rates unless conventional tillage is abandoned. It is never worth reducing nitrogen rates, especially under reduced or shallow tillage.

Results for individual components of the rotations show that broadly similar patterns of results for tillage and nitrogen apply (with minor variations) to potatoes, corn, wheat after corn, wheat

after potatoes. Notably, the enterprises other than potatoes are found to be unprofitable. To some extent, negative profits in non-potato years may be necessary as part of a profitable potato production system. In the context of the total farm household income, it is important to note that farm subsidies of 22,990 € year⁻¹ are not included in the expected net returns given in Table 4. However, the opportunity cost for labor of 15 € h⁻¹ is included. This means that, in addition to the net return figures in Table 4, the farm household receives a payment for labor. For example, conventional tillage demands on average 13 hours ha⁻¹ of labor for the full rotation (see Table 1). Thus, additional revenue of 195 € ha⁻¹ will contribute to the total farm household income, as payment for labor supplied.

3.2 The effect of tillage and nitrogen management on risk

Risk is indicated in three different ways in Table 4: as the standard deviation of net returns, as the probability of negative net returns, and as the minimum net returns. While related, these indicators of risk are not equivalent and do not necessarily have the same implications for risk management. Minimum net returns will not be discussed in depth. We simply note that the fact that the strategy with the highest expected returns does not have the highest (least negative) minimum net return, suggesting that risk aversion could have an effect on decision making.

For the full rotation results, we note that the strategy with the highest expected profit (CT_N2) also has the lowest probability of a negative profit. Also, for reduced and shallow tillage, systems with higher nitrogen rates tend to be less risky (using this risk criterion). Overall, there is little or no trade-off between expected profit and this measure of risk. Further, if the farmer moves away from conventional tillage, higher nitrogen rates have a risk-decreasing effect. This latter conclusion differs from a number other studies dealing with risk and nitrogen rates (Love and Buccola, 1991; Nelson and Preckel, 1989). We comment more on this below.

The third measure of risk included in Table 4 is the standard deviation of profits. In this case, the strategy with the highest expected profit also has the highest risk, consistent with previous findings about the relationship between profit and risk for nitrogen inputs. Across the three tillage systems, there is a trend for variance of profits to increase with increasing nitrogen rates, particularly moving from low to normal rates. Notably, the standard deviation of profit does not differ greatly between the systems, indicating that risk aversion will not play a major role in decision making in this case. Only shallow tillage with low nitrogen has a standard deviation of profit that differs by more than 10 per cent from the system that maximizes expected profit. There is no striking difference between the riskiness of different tillage systems, apart from the shallow tillage-low nitrogen case noted above (Fig. 1).

3.3 The effect of risk aversion on optimal tillage and nitrogen management

Given the results in sections 3.2, we expect the impact of risk aversion on this management problem to be minor. We would expect a slight tendency to favour lower nitrogen rates as risk aversion increases.

The first method used to assess risk aversion is first and second degree stochastic dominance (Hadar and Russell, 1969; Hanoch and Levy, 1969). This allows strategies to be compared without making specific assumptions about the risk attitudes of decision makers, other than that they are risk-averse to some degree (second degree stochastic dominance) or that they prefer more income to less (first degree stochastic dominance). Using this method, we find that the CT_N2 strategy dominates CT_N3 and ST_N1 by first degree stochastic dominance. However, neither of the stochastic dominance criteria is able to distinguish between CT_N2 and the

remaining six strategies. Because of the very general nature of the stochastic dominance criteria, it sometimes has low power to discriminate between strategies, as we observe here.

The second method used to assess risk aversion is the comparison of certainty equivalents (CEs) for alternative strategies. This is equivalent to comparing strategies on the basis of expected utility (i.e. it provides exactly the same ranking of strategies). It requires the specification of a particular functional form for utility. This approach is similar to ‘stochastic efficiency with respect to a function’ (see Hardaker et al., 2004). As noted earlier, we assume that utility follows a constant relative risk aversion function (Equation 1). Results for CE are shown in Figure 2 for different levels of relative risk aversion. Notably, the ranking of these strategies is not affected by the degree of risk aversion – a highly risk-averse decision maker would rank the options identically to a risk-neutral decision maker.

The figure shows that any risk-averse decision maker would prefer the same strategy as that which maximizes expected profit: (CT_N2). Also, as before, the second and third best strategies are RT_N3 and ST_N3. That is, in this farming system, differences in risk aversion between farmers would have no impact on optimal decisions about tillage method and nitrogen management. The reason for this is that there is little difference in the standard deviation of income (and therefore little difference in risk premium) for the different systems. As noted earlier, standard deviation of profit varies from 397 for the ST_N1 system to 466 for the CT_N2 system. Other than ST_N1, all systems have standard deviations within 7 per cent of that for CT_N2.

These findings are consistent with the results of Archer and Reicosky (2009) who found that risk-averse and risk-neutral decision makers would prefer the same tillage system. In this study, for a different farming system, we additionally find the same result for nitrogen management.

The second important result is the modest slope of the certainty-equivalent-functions in relation to risk aversion (Figure 2). For highly risk-averse farmers, the risk premium (around 20 € ha⁻¹ year⁻¹) is large relative to the expected profit of the optimal system (30 € ha⁻¹ year⁻¹) but is small relative to the range in expected profits between systems. This contributes to the result that there is no crossing of CE functions (i.e. no changes in ranking of strategies at different levels of risk aversion), although if differences between systems in the standard deviation of income had been large enough, crossing could have occurred.

Figure 2 reinforces that cutting nitrogen rates would be a very costly strategy for farmers, irrespective of risk considerations, especially in a shallow tillage system. Expected income losses for the ST_N1 system are approximately twice as large as the second worst system.

3.4 The impact of farm subsidies on tillage and nitrogen management decision making

In theory, farm subsidies that are decoupled from production have no influence on management decisions of risk-neutral farmers, including decisions about tillage and nitrogen fertilizer intensity. However, for risk-averse farmers, even decoupled subsidies might have an impact on tillage and nitrogen fertilizer intensity since they alter a farmer's wealth. Consequently, farm subsidies change the expected utilities of management options (see Eq. 3) and may ultimately influence their ranking. A change in ranking may occur when the amount of subsidies is high enough to shift total wealth into an area where the utility function shows a quite different slope compared to the situation without subsidies.

In order to analyze the impact of farm subsidies on the optimal farming system in this case study, we examine a rather extreme scenario where farm subsidies are cut from 22,990 € per year (for the average cash crop farm of 54.2 ha in the study area) to zero. Even for this scenario,

the presence or absence of farm subsidies does not affect the optimal farming system under high risk aversion. Table 5 shows that the presence or absence of farm subsidies has very little impact on the impact of risk aversion on *CE*. When relative risk aversion is increased from 0 to 4, the risk premium increases by around 14 to 20 € ha⁻¹ year⁻¹ in the presence of subsidies, and by only very slightly more in the absence of subsidies. Overall, the absence of farm subsidies has no impact on tillage and nitrogen management decision making under risk aversion for the specific local farming conditions modeled here.

However, if we use structural data of large cash crop farms, the impact of subsidies on risk premiums can be much larger. For example, in Brandenburg, in the eastern part of Germany, the average farm size is 260.5 ha with an initial wealth of only 967 € ha⁻¹ and decoupled farm subsidies *S* of 68,251 € year⁻¹ (average in total per farm) (BMELV, 2010). For illustrative purposes, we modified the model to use these data, combined with experimental data presented in this paper. In the presence of decoupled farm subsidies and high relative risk aversion, CT_N2 shows the highest *CE*, while in the absence of these subsidies RT_N3 has the highest *CE*. This shift occurs because removing subsidies reduces wealth and thereby increases absolute risk aversion, prompting a move away from the most risky strategy, CT_N2, to a slightly less risky option. Table 5 shows that, because of their impacts on absolute risk aversion, farm subsidies have high impacts on *CE* in this scenario. When relative risk aversion is increased from 0 to 4, the risk premium increases by between 250 and 312 € ha⁻¹ year⁻¹ in the presence of subsidies, and by between 376 and 476 € ha⁻¹ year⁻¹ in the absence of subsidies.

3.5 The extra value from models which represent risk aversion

In the introduction we foreshadowed that we would address this question: “What is the extra value to farmers when they get recommendations for nitrogen application and tillage systems from models which represent risk aversion, compared to models based on the assumption of risk neutrality?” This can be answered (for a specific level of risk aversion) by calculating the difference between certainty equivalents of the strategies derived from the two models. For the situation we have analyzed (whole rotation), the cost of using a risk-neutral model is zero, since CT_N2 is the efficient strategy for a risk-neutral as well as for a highly risk-averse farmer (see Fig. 2). Clearly, in this case, there is no additional benefit to a risk-averse farmer from receiving recommendations based on a risk-averse model, since the recommendation from a risk-neutral model is identical. This result is very consistent with the findings of Pannell et al. (2000) who concluded that for most decision problems modeled by agricultural economists, the extra value to decision makers from representing risk aversion is small.

To illustrate a case where modeling risk aversion would make a difference to management, we make a hypothetical change to the profit-maximising management option, CT_N2, increasing the variance of net returns from 466 to 932, while leaving unchanged the variance of all other farming systems (see Fig. 3). This is consistent with the common case where there is a tradeoff between expected profit and risk. The consequence is that, for relative risk aversion levels greater than 1.9, the RT_N3 strategy now has a higher CE than does the CT_N2. In other words, RT_N3 would be preferred by more risk-averse farmers. Thus, a model that accounts for risk aversion would generate more valuable advice for highly risk-averse farmers in this case. However, even in this hypothetical examples involving large differences in the riskiness of strategies, the benefits to farmers would be modest, amounting to a maximum of 11 € ha⁻¹ year⁻¹

¹ for a coefficient of relative risk aversion of 4 (Fig. 3), reinforcing the general conclusion of Pannell et al. (2000).

Studies often show that the optimal farming strategy under risk aversion differs from that under risk neutrality (e.g. Lien et al., 2006; Acs et al., 2009). However, it does not necessarily follow that the benefits of adjusting farm management recommendations to match a farmer's risk aversion level will generate large benefits. Testing this requires the approach used here – comparison of certainty equivalents for the optimal risk-averse and risk-neutral strategies. Risk analysts rarely make this comparison.

4. Conclusion

The purpose of this paper was to analyze the effect of risk and uncertainty on optimal tillage and nitrogen fertilizer intensity. For both risk-neutral and risk-averse farmers, the optimal tillage/nitrogen strategy is to use conventional tillage and standard nitrogen rates, followed by reduced tillage and shallow tillage with increased nitrogen rates. These were the only strategies that earn a positive expected net income.

Considering results for the whole rotation, we conclude that lower nitrogen intensities result in lower expected profits and a higher probability of negative net returns. Although lower N rates do have relatively low standard deviations of income, they have lower certainty equivalents because the advantage of their lower risk premiums is outweighed by the disadvantage of their lower expected profits. If farmers shift from conventional to reduced or shallow tillage, it is optimal to also increase nitrogen applications above the currently used rate, and the cost of reducing nitrogen rates is increased.

Using the probability of a negative net return as a risk measure, higher nitrogen and tillage intensities are risk-reducing. On the other hand, based on the standard deviation of income, more intensive nitrogen and tillage practices are risk-increasing, consistent with past research. However, the extent to which risk is affected by these farming practices is generally small.

For that reason, the ranking of strategies is completely unaffected by the degree of risk aversion of the farmer. Although risk premiums do increase with increasing risk aversion, they do so at almost the same rate for each strategy examined here, so that rankings do not change. Conventional tillage with usual fertilizer practice is the dominant strategy for the whole range of analyzed relative risk aversion coefficients from 0 (risk neutrality) to 4 (very risk-averse). For this case study, the cost to risk-averse farmers from using a model that represents risk neutrality, rather than risk aversion, is zero. This result holds even for a very risk-averse farmer. Even for a hypothetical scenario where we have drastically increased the riskiness of the dominant conventional tillage with usual nitrogen management scenario, the extra value of representing risk aversion in the decision model amounts to only 11 € ha⁻¹ for a very risk-averse farmer.

The conclusions of the study are not sensitive to the amount of subsidies farmers receive. Even a total cut of decoupled subsidies has no effect on optimal nitrogen and tillage management under risk aversion.

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Table 1.

Cost structure of the different tillage systems for the cultivated crops for usual practice nitrogen rate N2.

Crop	Tillage system*	Production costs	Labor requirement
		€ ha ⁻¹	h ha ⁻¹
Potatoes			
	CT	2579	27.3
	RT	2555	26.9
	ST	2524	26.4
Corn			
	CT	1178	7.2
	RT	1154	6.7
	ST	1124	6.2
Wheat			
	CT	979	8.2
	RT (after corn)	998	8.8
	RT (after potatoes)	955	7.7
	ST (after corn)	947	7.8
	ST (after potatoes)	903	6.8

*CT, Conventional tillage (Moldboard plow); RT, Reduced tillage (Chisel plow); ST, Shallow tillage (Shallow chisel plow).

Source: Meyer-Aurich et al. (2009) based on KTBL (2006)

Table 2.
Annual average Bavarian producer prices for potato, wheat and corn
1997-2008.

Year	Potato	Wheat	Corn
	€ t ⁻¹		
1997	79.6	122.2	109.6
1998	139.8	119.0	110.5
1999	62.9	121.4	117.5
2000	44.1	120.6	110.0
2001	116.9	115.6	107.8
2002	77.8	112.4	104.7
2003	119.5	131.9	134.3
2004	44.9	94.6	89.7
2005	91.3	96.2	102.6
2006	205.0	130.8	138.1
2007	101.3	225.9	209.2
2008	107.9	136.6	117.2
Mean	99.2	127.3	120.9
Standard Deviation	44.6	33.6	30.7
Coefficient of Variation	44.9%	26.4%	25.4%

Source: Reisenweber and Goldhofer (2009)

Table 3.

Correlation matrix (Pearson's r) of crop yields and crop prices for the period 1997-2008.

		Yield			Price		
		Potato	Wheat	Corn	Potato	Wheat	Corn
Yield	Potato	1.00	0.66*	0.78	-0.19	0.20	0.08
	Wheat		1.00	0.61	-0.28	0.05	-0.07
	Corn			1.00	-0.35	0.12	-0.06
Price	Potato				1.00	0.20	0.31
	Wheat					1.00	0.97
	Corn						1.00

*Bold values indicate statistical significance at the 95% level.

Table 4.

Minimum, expected, and maximum values, and probability of negative net return from cumulative distribution functions under conventional (CT), reduced (RT) and shallow (ST) tillage systems and reduced (N1), usual practice (N2), and increased (N3) nitrogen fertilizer rate.

Crop/ Rotation	Tillage/ Nitrogen System	yield		Prob. of a negative net return per ha	Min.	Net Return		Standard Deviation
		Mean	Standard Deviation			Mean	Max.	
		t ha ⁻¹				€ ha ⁻¹		
Full Rotation	CT_N1			0.603	-810	-36	1878	448
	CT_N2			0.534	-840	30	2140	466
	CT_N3			0.569	-866	-4	2074	462
	RT_N1			0.633	-818	-71	1779	435
	RT_N2			0.569	-810	-1	1957	461
	RT_N3			0.545	-836	21	2055	461
	ST_N1			0.722	-847	-166	1655	397
	ST_N2			0.632	-824	-75	1867	436
	ST_N3			0.552	-822	8	2031	460
Potato	CT_N1	40.54	9.46	0.373	-1913	713	7681	1661
	CT_N2	42.67	9.33	0.339	-1845	840	8543	1732
	CT_N3	42.56	9.33	0.360	-1955	785	8283	1730
	RT_N1	39.29	9.76	0.394	-1934	638	7314	1640
	RT_N2	41.60	10.20	0.367	-1929	779	7932	1734
	RT_N3	42.35	10.01	0.361	-1946	791	7818	1744
	ST_N1	35.17	9.00	0.457	-1913	339	7321	1482
	ST_N2	38.39	10.36	0.410	-1914	551	8302	1645
	ST_N3	41.87	10.42	0.366	-1927	785	8275	1753
Corn	CT_N1	8.88	2.01	0.940	-818	-438	941	256
	CT_N2	9.91	2.15	0.917	-860	-401	1019	281
	CT_N3	9.98	1.88	0.927	-855	-422	976	268
	RT_N1	8.87	1.85	0.942	-779	-415	880	248
	RT_N2	9.58	2.10	0.916	-817	-402	988	274
	RT_N3	10.36	2.06	0.909	-824	-368	1055	284
	ST_N1	7.30	2.09	0.960	-831	-507	799	238
	ST_N2	8.56	1.89	0.949	-826	-453	869	245
	ST_N3	9.42	2.21	0.924	-829	-413	919	275
Wheat after Corn	CT_N1	5.32	1.14	0.900	-595	-271	772	192
	CT_N2	6.25	1.51	0.853	-604	-201	1001	243
	CT_N3	6.46	1.81	0.835	-736	-216	1022	277

	RT_N1	4.81	1.01	0.958	-627	-352	626	171
	RT_N2	5.80	1.34	0.896	-648	-277	877	218
	RT_N3	6.42	1.45	0.878	-623	-241	1116	238
	ST_N1	4.39	1.12	0.969	-633	-354	502	177
	ST_N2	5.23	1.41	0.885	-637	-296	846	217
	ST_N3	5.76	1.55	0.878	-622	-270	988	240
Wheat after Potato	CT_N1	6.31	1.27	0.815	-515	-147	1021	216
	CT_N2	6.93	1.49	0.705	-590	-117	1061	247
	CT_N3	6.89	1.86	0.768	-731	-163	1142	285
	RT_N1	6.06	1.25	0.812	-501	-154	886	210
	RT_N2	6.85	1.28	0.722	-541	-103	1033	226
	RT_N3	7.21	1.42	0.769	-604	-100	1142	243
	ST_N1	5.74	1.52	0.785	-551	-143	952	233
	ST_N2	6.45	1.31	0.759	-506	-101	1092	221
	ST_N3	7.02	1.30	0.682	-534	-71	956	231

Table 5.
Average change (€ ha⁻¹) in certainty equivalent due to an increase in relative risk aversion (RRA) from 0 to 4

	Bavaria		Bavarian field trial data & structural data from Brandenburg	
	with subsidies	without subsidies	with subsidies	without subsidies
	€ ha ⁻¹			
CT_N1	18.1	18.8	283.8	397.6
CT_N2	19.6	20.3	305.1	446.7
CT_N3	19.3	20.0	311.9	475.5
RT_N1	17.1	17.8	276.1	392.3
RT_N2	19.2	19.9	298.5	420.0
RT_N3	19.2	19.9	300.1	426.3
ST_N1	14.3	14.9	249.8	375.9
ST_N2	17.2	17.9	274.6	393.1
ST_N3	19.1	19.8	298.3	427.8

Fig. 1. Cumulative probability functions of net return (€ ha⁻¹) under conventional (CT), reduced (RT) and shallow (ST) tillage systems and reduced (N1), usual practice (N2), and increased (N3) nitrogen fertilizer rate for the full rotation.

Fig. 2. Certainty equivalents ($\text{€ ha}^{-1} \text{ year}^{-1}$) as a function of relative risk aversion for the whole rotation under conventional (CT), reduced (RT) and shallow (ST) tillage systems and reduced (N1), usual practice (N2), and increased (N3) nitrogen fertilizer rate.

Fig. 3. Certainty equivalents (€ ha⁻¹ year⁻¹) as a function of relative risk aversion for the whole rotation.