MODELLING FARM-ECONOMIC AND ENVIRONMENTAL EFFECTS OF REDUCED TILLAGE - WITH FOCUS ON PESTICIDE USE

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Abstract

Reduced tillage is an increasingly popular farming method in many parts of the world. In some countries it is used on 50% of the total arable area, but in Denmark the area with reduced tillage is only 10%. The benefit from reduced tillage is less labour use and lower machinery costs per ha, but there are also environmental benefits as e.g. reduced phosphorus losses and CO_2 emissions. The economic results calculated are based on the DOP II farm economic model, covering arable farms on clay soil. The conclusion is that reduced tillage increases profits by 67 € per ha and there is also a reduction in the use of fuel and in the nitrogen surplus. When no increase in use of pesticide is allowed, the increase in profit from reduced tillage is still 65 € per ha as the change towards spring crops in the reduced till system in itself reduces the pesticide use. Reduced tillage is expected to increase in Denmark, however, experience shows that it might not be a successful strategy for all farmers.

Keywords: *Reduced tillage, no tillage, costs, pesticide use, profit, environmental effect*

Introduction

In recent years, the use of no-tillage or reduced tillage systems has increased in several parts of the world. In the US, the use of reduced tillage has increased to about 41% of the total agricultural area in 2004, of which 23% was no tillage (Omonode et al., 2006). The zero-tillage or no tillage system is a system with no cultivation from harvest to seeding, whereas reduced or low tillage systems here refers to a system where a conventional mouldboard plough is not used.

In Norway it is estimated that 50% of the total area is cultivated using no or reduced tillage systems (Øygarden and Grønlund, 2006). In comparison the uptake of reduced tillage in Denmark is only 10 % of the total agricultural area (Sandal, 2006 and ECAF, 2003).

From the perspective of the individual farmer, the business of producing food must be profitable, so the farmer will look for the most profitable option. Reductions in cereal prices have lead to further investigation on how to reduce costs. Using no tillage or reduced tillage can help reduce the cost of machinery and labour, whereas the use of, e.g., pesticide can go up. The use of reduced tillage systems can especially benefit large farms and help to promote a further increase of farm sizes.

From the perspective of the society, reduced tillage might provide some additional environmental benefits. These effects might be reduced nitrogen leaching, lower CO2 emission, and reductions in soil erosions. This is important as soil degradation due to erosion and compaction is one of the major problems affecting around 16% of the agricultural area in Europe. (ECAF, 2003).

The objective of this paper is to look at the economic benefits from reduced tillage based on review of literature and to model the economic return from reduced tillage systems on arable farms in Denmark. Firstly, the paper reviews the economic effects that reduced tillage has on yield and use of resources (pesticides, machinery and labour). Then the model used for analysing the effect of reduced tillage in

Denmark is presented. In contrast to most other analyses, the model approach allows for an optimization in order to achieve the optimal crop rotation and pesticide use with reduced tillage. The article finishes with an evaluation of the prospects of reduced tillage in Denmark.

Review of production and environmental economics

Analyses of the effect of reduced tillage systems is mainly based on a comparison with conventional tillage systems with the same crop rotation and in most cases the same application of nitrogen. A key factor in many articles is the effect that reduced tillage has on yield.

Riley (1998) has shown that, based on long-term trails in Norway, there is a tendency towards higher straw yields but no effect on crop yields of no-tillage. Riley (1998) also found that there was no difference in the nitrogen fertilizer requirement as a consequence of no-tillage. Sanchez-Giron (2004) has also shown that there were no statistical difference in yields based on a 16-year long field experiment using conventional and no tillage systems in semiarid central Spain. Based on a 6-year trail, covering corn, cotton and soybean (irrigated and non-irrigated) in Arkansas, US, Parsch (2001) also concludes that the yield is the same. Al-Kaisi et al. (2005) found no difference in yields in a corn-soybean rotation based on trails using different reduced tillage systems in the US. The experiences from Denmark seem to support the above findings, however, it is expected that there in certain years might be a significant reduction in yields (Sandal, 2006).

Looking at the semiarid and subtropical conditions, the paper by Smart and Bradford (1999) concludes that conservation tillage resulted in greater economic returns than conventional systems due to greater yields in dryer years. Whereas Janosky et al. (2002) concluded that there is no difference in yield due to tillage systems in semiarid locations (Washington State). Sánchez-Girón et al. (2004) arrive at the same conclusion with respect to Spain based on 16 yrs field experiment.

Production costs and economic return

The productions costs related to use of pesticides is higher when switching to no-tillage systems, but machinery and labour costs are often lower. In Zentner et al. (2002a), the conclusion, based on a 12-year period, was that costs were not affected by tillage practises as the savings in labour, fuel and machinery costs were equal to the increase in pesticide costs. The tillage systems were conventional, low and zero tillage practices. The gross return was largely unaffected, but conventional tillage was the lowest. The herbicide use was 2-3 three times as high as for conventional cropping systems in the analyses carried out by Parsch et al. (2001). The analyses were based on plots.

Al-Kaisi and Yin (2004) conclude, based on field experiments, that no-tillage had equal or slightly better economic return than the reduced tillage systems analysed, based on soybean and corn.

The conclusions in several papers (e.g., Smart and Bradford (1999) and Sims et al. (1998)) is that reduced tillage resulted in greater economic returns than conventional systems due to greater yields in dryer years and due to lower machinery and labour requirement.

Other papers conclude that the gross return was largely unaffected by choice of tillage practices, Zentner et al. (2002a). Juergens et al. (2004) have shown that the income from spring wheat with no tillage was economically competitive with traditional winter wheat (summer fallow) although the risk measured in standard deviation over 5 years was three times as large.

Some papers report a lower economic return from reduced tillage mainly due to high costs related to large amounts of pesticide being used, e.g., during the long summer fallow time period in the US. (Dhuyvetter and Kastens, 2005). Whereas Fortune et al. (2002) found lower level of diseases in winter wheat in their reduced cultivated plots. The yields were not affected by choice of tillage system.

It seems that there probably will is an increase in pesticide use when converting to no or reduced tillage. In some cases perhaps there is a higher pesticide use than necessary, but this may be required to avoid long-term diseases and to ensure the long term yield level.

The effect of lower labour use will affect the income in different countries differently. It is likely that the effect will be larger in western Europe as these countries have higher wages per hour and relatively high labour intensity per hectare, compared to the US.

With respect to risk, the conclusion is that the risk is roughly the same based on a total risk index, measuring the variation in yields or gross margin over time for conventional and no tillage systems (Sánchez-Girón et al. (2004), whereas Zentner et al. (2002b) found that the degree of risk was lowest for reduced tillage.

Several papers discuss the fact that no and reduced tillage looks promising from a farm perspective, but that the implementation amongst farmers in the same countries is limited (e.g. Filipovic et al., 2006, and Ribera et al., 2004).

Value of environmental benefits

Several environmental benefits from conservation or no-tillage systems are proposed. Often reduction in CO_2 emissions, erosion and high storage of nitrogen leading to lower nitrogen leaching is mentioned. It is also clear that the herbicide use increases as mentioned above (e.g. Parsch et al. (2001).

In an analysis from Croatia, it is shown that the CO_2 emissions are reduced by 35-43% using reduced tillage systems and that no-till gave a reduction in CO_2 emissions of 88%, mainly due to the lower use of fuel (Filipovic et al., 2006).

In Norway no-till has been used to reduce soil erosion (Øygarden and Grønlund, 2006). It is estimated that 24% of the total agricultural area has a high or very high risk of erosion. In 2006 low tillage was used in almost the entire risk or high risk erosion area in Norway. This is equal to 50% of the entire agricultural area.

Another aspect is the choice between limited or continues no-till which is analysed in the US by Omonode et al. (2006). The basic assumption is that no-till increases accumulation of soil organic carbon (C) and total nitrogen (N). The findings suggest that many farmers plough their field before a specific crop, also called rotational tillage. The findings suggest that the amount of Carbon and Nitrogen stored was higher under long-term no-till than rotational tillage. Furthermore, rotational tillage seems to have an effect on Carbon storage. The N in top soil is higher in no-tillage systems than in rotational tillage systems, which suggests that a one-year change does have an effect on N in top soil. In analyses carried out by Al-Kaisi et al. (2005), the conclusion was that no-tillage and chisel plough can be an effective strategy in increasing C and N in top soil, without significant adverse effects on corn and soybean yields.

Materials and Methods

The results in the literature are mainly based on field trials, and, in some cases, farm results. In many cases, the field trials have exactly the same crop rotation for conventional rotation and reduced tillage. This gives a clear basis for comparison, but the disadvantage is that it might not be the most economical crop rotations which are used in the two cases.

Dhuyvetter and Kastens (2005) discuss the use of simulated budgets against farm data. Both have strengths and weaknesses. Simulated costs have clear connection between system and operation, but hidden costs and income might be left out, e.g., machinery costs for machinery which is used less. In general, the difference in cost between the two is assumed to be limited.

Model concept used

In order to evaluate the farm economic and environmental potential from reduced tillage in Denmark, reduced tillage is being incorporated in the farm economic crop production model, normally used by Institute of Food and Natural Resources (FOI) to evaluate pesticide and water protection plans. The model is called Farm Economic Crop Producing Model (DOP II) (Ørum, 2003 and 2007).

In order to handle reduced tillage, the model is able to deal with problems related to crop rotation and pesticide use, and economics of size related to, e.g., machinery capacity, labour intensity, with respects to conventional as well as reduced tillage systems. Furthermore the model is able to estimate the effect on changes in crop rotation when switching to non-tillage systems as the profit is optimised.

In the analyses here is has been decided to implement the reduced tillage systems in a way that crop yields can be maintained. The necessary precautionary actions and measures are based on Sandal (2006), Farminfo (2006) and experiences from a Danish project, CENTS (Olesen, 2006). More than two years of continuous winter wheat is no longer an option and winter wheat after winter wheat is treated with extra fungicides to avoid *Fusarium* and DTR. (*Dreschlera tritici-repentis*). Furthermore, all crops are treated with herbicides (Roundup) immediately before or after sowing.

In order to handle the expected increasing (seed) grass weed problems, extra herbicides are used when winter grain (winter wheat, winter ray, and winter barley) is followed by winter grain. Seed grass weed is considered a problem in 50 percent of the fields. For oat, spring barley, and peas, supplementary stubble harrowing (a 20-40 cm deep harrowing/pearling) is added to improve the soil structure, whereas supplementary stubble harrowing for winter wheat is added to improve the mouldering of stubble and straw.

In the case of reduced tillage, crops are established by using heavy disc coultered seeders which are typically used by Danish farmers using reduced tillage. It is estimated that the overall cost of the seeding cultivator and the disk seeder is of the same magnitude. The investment in a harrow seeder is higher than the disk, but maintenance costs are lower.

Farm types and capacities

The potential of the reduced tillage systems is analysed for arable farms on clay soil (jb7-8) with no animal production. For analysis regarding pig farms see Ørum et al. (2007). The systems are analysed for six combinations of labour and machinery capacity A-E (see appendix 1), combined with farm sizes in terms of rotational area, varying from 50 to 1.200 ha.

The type and size of the selected machinery is based on the most commonly used setup and is proposed by the Danish Advisory centre. (Sandal (2006) and Farminfo (2006). The rest of the machinery equipment, not influenced by the farm size and choice of tillage system, is not shown in the table, but included in the total depreciated value.

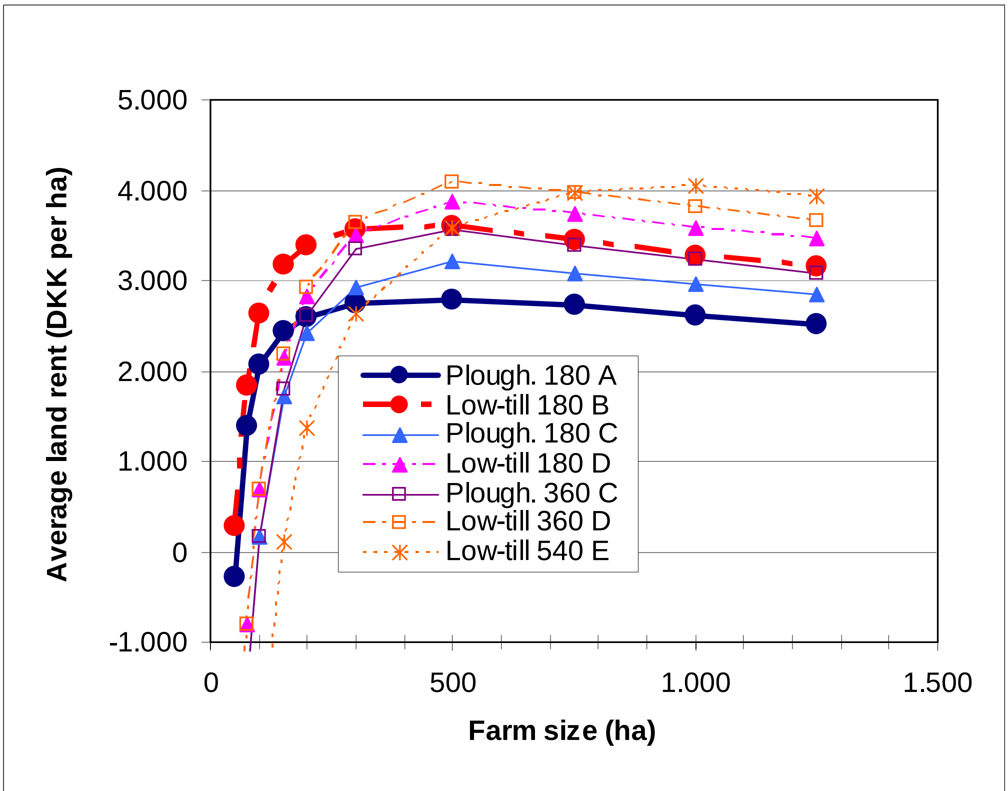
The systems A and B have a limited machinery capacity, and the systems C, D, and E have a higher machinery capacity, but maximally one plough, one combiner, one heavy stubble harrow, etc. Systems A and C are suitable for the ploughed systems (Plough.) whereas the B, D and E system have capacities which are suitable for the reduced tillage systems (Low-till). The capacities have a depreciated value of approximately 0.2 to 0.5 million €. These values equal 66% of the value of equivalent new machinery.

In the analyses, the figures 180, 360 and 520 represent man hours available in each of the two critical periods for ploughing, stubble harrowing and sowing in the spring, and in August and September. The 180, 360 and 540 hours, respectively, correspond to one, two, and three full-time farmers/employees available for the crop production operations in each of these two periods.

Results

The results (Ørum et al, 2007) show that the arable farms using the most efficient machinery are more profitable and can save a lot of labour hours compared with smaller arable farms with an old, low machinery capacity. Small and middle sized non-specialised arable farms, can increase the average land rent by 270-400 € per ha by employing the most efficient (high capacity) machinery and reduced or low tillage. Of this total gain the change towards low-till technology accounts for around 65-70 € per ha. The reduced or low tillage system is profitable even for small arable farms (above 100-200 ha). The remaining 200-335 € per ha is achieved through the use of larger machinery.

Figure 1: Average land rent from low and traditional tillage systems for different farm sizes.



Source: Ørum et al. (2007).

Using machinery with a higher capacity can save 3-8 labour hours per ha, whereas the low-till technology alone can save 0.5-1 labour hours per ha. The reduction in labour use in combination with a higher machinery capacity will probably encourage farmers to farm more land. The reduced tillage technology will help to maintain a relatively higher marginal land rent for an increasing farm size compared to the tilled systems. This confirms the hypothesis that reduced tillage technology is a further incentive in the change towards larger farms. This benefit can also be obtained through the forming of farming cooperative where machinery is shared.

In practice as well as in the model, some extra efforts (extra harrowing, pesticides, etc.,) and crop rotation restrictions are carried out to stabilise and maintain the yields in a low-tillage system. In the long run these additional efforts might be reduced with increased management skills. However, the estimated profitability of 65-70 € per ha is effected very little by such savings, or extra efforts needed. This means that without compromising the profitability of the low-till system an even greater use of stubble harrowing and more pesticides than required in the calculations can be performed, just as the total yield drop in spring barley can be afforded every fifth year.

Crop rotation and environment

This analysis shows that a winter wheat, spring barley, winter barley, winter rape crop rotation in most cases is optimal, independent of conventional (ploughed) or low-till technology. The share of winter wheat, winter rape and pea is around 25% in most crop rotations. In some cases the share with spring barley increases to more than 50%, and the winter barley is no longer included.

Reduced tillage was expected to result in a large increase in pesticide use. The good mix of crops in the crop rotation (with no more than 25% winter wheat and a healthy combination of spring and winter cereals and broad leaved crops) has helped to limit the additional pesticide use in the low-till system to 0.4 TFI (Treatment Frequency Index), which is an increase of 25%. Despite this, the level of pesticide use is well above the goal set up within the Danish Pesticide Action Plan. Nevertheless, the low-till pesticide use can be brought in line with the Danish Pesticide Action Plan for a subsequent cost of 2-3 € per ha. It means that the low-till system will be competitive even in cases where no increase in the use of pesticides is allowed.

The reduced tillage technology will reduce the farm's fuel consumption by 15-20% (10-15 l diesel pr. ha) and reduce the middle-sized farm's nitrogen surplus (field balance) by 10-20 kg N per ha, on arable farms.

Conclusions

The use of reduced tillage is increasing in the world and the calculations here indicate that it is also profitable for Danish farmers to increase the use of reduced tillage. There does not seem to be significant reductions in yields from reduced tillage. The analyses show that the largest improvement in profitability comes from using more efficient large-scale machinery, but the reduced tillage system increases in itself the profits by 67 € per ha. The advantages are lower labour and machinery costs, just as the area which can be handled in the peak periods is increased. Environmental effects are reduced CO_2 emissions and erosion, whereas the effect of tillage system on N-leaching is uncertain. An increase in pesticide use has to be expected, but the analyses show that reduced tillage with no increases in pesticide use is possible and profitable. It is likely that the use of reduced tillage will increase in the years to come, but experience also shows that if a farmer can not adjust to the change in farming practices after a 2-3 year conversion period, he is probably better off going back to conventional tillage systems.

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Appendix 1 Selected machinery equipment and total depreciated machinery equipment value

	Tilled A	Reduced till B	Tilled C	Reduced till D	Reduced till E
Harrow	Heavy cultivator	Heavy cultivator	Heavy cultivator	Heavy cultivator	Heavy cultivator
Plough	Four- furrow plough	-	Eight-furrow plough (semi mounted)	-	-
Sprayer	Normal sprayer	Normal sprayer	Trailer sprayer	Trailer sprayer	Trailer sprayer
Sowing	3 m Rotor-set + sowing machine	4 m disk seeder, heavy	4 m tine seeder	4 m disk seeder, heavy	4 m disk seeder, heavy
Tractor I	60 kW	80 kW	100 kW	100 kW	80 kW
Tractor II	60 kW	40 kW	60 kW	60 kW	80 kW
Combine	Combine harvester 3,6 m (12")	Combine harvester, 3,6 m (12")	Combine harvester, 10 m (30")	Combine harvester, 10 m (30")	Combine harvester, 10 m (30")
Total depr. value (mio. €)	0,2	0,2	0,34	0,3	0,53

Notes : 1 € = 7,4 DKK