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Financial and environmental performance of integrated precision farming systems

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Financial and environmental performance of integrated precision farming systems

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Abstract

Variable Rate Application (VRA) and auto-steering have a wide potential to improve agricultural performance, ranging from improved use of crop nutrients, increased crop quality, reduced overlaps and better production economy. In order for the use of inputs to be lessened and for the adverse effects on the environment to be diminished, more and more focus is put on site-specific application of fertilisers, pesticides and irrigation water. However, the cost of implementing these single technologies are often quite high compared with the benefits. Therefore, a comprehensive methodology approach that facilitates the understanding of investments, costs, and benefits can provide an overview of the most feasible pathways for farmers to implement Precision Agriculture (PA) and may offer the chance to significantly enhance the level of adoption of the most suitable technologies. The objective of this study is to describe an overall integrated methodology approach to support cost-benefit analysis related to PA. The methodology will embrace 2 sets of evaluations referring to (1) financial performance and (2) environmental impact. A financial analysis and environmental performance study is based on the estimation of differential cash flows from selected PA technologies with description of life time, input costs and expected benefits in relation to location and in-field variability. A number of scenarios and their financial and environmental performance are presented either as single technologies or as a combination of different technologies. Key outputs are Net Present Value with selected environmental indicators such as change in fuel application, pesticides and water use compared with conventional practices from other similar technologies. Findings from this study indicate that PA is mainly beneficial to large scale farms as well a combined and integrated application of different tools.

Introduction

Farming employs a wide range of technologies and practices that require continual assimilation and assessment of new knowledge (Oreszczyn et al., 2010), and the adoption and the implementation of new agricultural equipment is essential for farmers to remain competitive in their business. Variable Rate Application (VRA) and auto-steering have a wide potential to improve agricultural performance, ranging from improved use of crop nutrients, increased crop quality, reduced overlaps and better production economy. In order for the use of inputs to be lessened and for the adverse effects on the environment to be diminished, more and more focus is put on site-specific application of fertilisers, pesticides and irrigation water. However, the cost of

implementing these single technologies are often quite high compared with the benefits. Therefore, a comprehensive methodology approach that facilitates the understanding of investments, costs, and benefits can provide an overview of the most feasible pathways for farmers to implement Precision Agriculture (PA) and may offer the chance to significantly enhance the level of adoption of the most suitable technologies.
Several studies have indicated that it is possible to reduce overlap by using guidance technologies such as lightbar or autosteering. When applying centrifugal spreaders it may be difficult to reduce N application but with boom spraying and liquid fertilizers of N or even slurry distribution with boom sections it should be possible to reduce overlap with 5-7 % (or even higher values) by using auto-guidance systems (Batte and Ehsani, 2006); according to the same authors, saving of spraying materials increases proportionally to un-overlapped area. To stay on the safe side, in this study it was assumed 3 % reduction of agricultural input savings due to the improved precision of fertilization and reduced overlap.

Auto section control on the N spreader can reduce overlap when turning on headlands; this feature is particularly relevant when the field shape shows sharp angles which otherwise would give an overlap with conventional systems. Some studies indicate that the reduced overlap is about 5 % for using pesticides (Pedersen and Pedersen 2018) but it might be smaller with N application. Other studies indicate that the reduced overlap with autosteering combined with reduction on the headland is about 5-10 %. Lyngvig, Hørfarter and Knudsen (2013) and Petersen, Hansen and Øllgaard (2006). The real potential is case-bounded and depends on the actual field shape and headland size relatively to the entire field size. In this study we assume a 3 % reduction of agricultural input savings due to the use of automatic section control.

Several approaches have been developed to make prescription maps for variable rate fertilizer application. Some technologies focus on prescription maps based on a biomass index and Normalized Difference Vegetation Index maps from sentinel satellite images and others are based on tractor mounted and realtime N-sensors like the Yara N sensor. Others are based on farmer own observation and previous years yield maps and targeted soil samples. In a Danish study of potential increase in yield from variable rate N application with N-sensors in winter wheat, shows modest results with yield increase close to zero (Berntsen et al., 2006). A similar study from Australia in wheat found an average yield increase at 0.8 % with variable rate treatment (compared with uniform application) over two years (Mayfield and Trengove, 2009):

The objective of this study is to describe an overall integrated methodology approach to support cost-benefit analysis related to PA. The methodology will embrace 2 sets of evaluations referring to (1) financial performance and (2) environmental impact.

The overall approach covers a broad number of precision agriculture technologies (PATs) that are integrated in a web-app designed in the ICT-Agri ERA-NET project PAMCOBA. The aim here is to guide farmers about their decisions to invest in selected precision agricultural technologies on their farm depending on crop rotation and farm size. In this study an example of this study is given for targeted N application in a traditional cereal crop rotation.

Methodology

The methodology will embrace 2 sets of evaluations referring to (1) financial performance and (2) environmental impact. A financial analysis and environmental performance study is based on the estimation of differential cash flows from selected PA technologies with description of life time, input costs and expected benefits in relation to location and in-field variability. A number of scenarios and their financial and environmental performance are presented either as single technologies or as a combination of different technologies. Key outputs from the integrated study are Net Present Value (NPV) with selected environmental indicators such as change in fuel application, fertilizers and water use compared with conventional practices from other similar technologies. The selected examples presented here focus on variable rate fertilizer application combined with auto-steering and section control on the fertilizer spreader.

In order to compare the modelled site-specific fertilization with uniform application of nutrients we assume a N rate of 150 kg N^{-1} and a N price of 4 € kg^{-1}. Farm revenues are taken as equal to 2500 € ha^{-1} based on a cereal crop rotation. About economic life, a cut off period of 6 years with null residual value and a discount rate equal to 1% (risk free) were assumed. In formulating these assumptions we have decided to switch the risk burden from the discount rate to the economic life and to the residual value of the investment for two reasons: first, the cost of purchasing equipment is relatively low, being affordable by the majority of farms without need of external investors, and secondly, interest rates are very low at present time. That should not prevent us from paying attention to technological risk, but this is already taken into the economic life, which normally reaches 10-12 years, here accounted to 6 years, and the residual value, now zeroed. A 5-year straight line mortgage is assumed to model amortization. About fuel consumption, in this study is assumed a fuel price of 1.50 € l^{-1} (diesel), and an average fuel consumption for the Real-time kinematic (RTK)-GPS equipped tractor of 39.5 l ha^{-1} that is consistent with the median fuel consumption of 79 l ha^{-1} measured by Lorencowicz and Uziak (2009) for all farm activities. However, it is assumed that this consumption implies that fuel savings relate to both fertilization and other related activities with the RTK-system performed with the same tractor. These assumptions are consistent with a conventional cropping system in arable farming.

In this study we model three systems characterized by increasing effectiveness in fertilization activity in a common cereal crop rotation (see table 1). In particular, System 1 consist of a variable rate (VR) fertilization spreader, i.e. a solid or liquid spreader, including prescription software, proper flow sensors, and a base GPS system characterized by a relatively low accuracy (about 60 - 100 cm). In addition, System 2 includes further an integrated auto-steering system that is comparable with a precision RTK-GPS guidance technology with a high accuracy (2-3 cm). System 3 finally includes the previous features plus an auto section control.

Table 1 – Site-specific equipment

System 1	VR fertilizer spreader
System 2	VR fertilizer spreader, RTK-GPS guidance technology

System 3	VR fertilizer spreader, RTK-GPS guidance technology and auto section control

Each of the PATs reported in table 1 shows a cost structure in which the following cost items are represented: a purchase price (€), and possible annual fees due to external service support (€ $year^{-1}$); common market values for the systems considered are shown in Table 2. The investment cost is the sum of the purchase prices of each technology considered within each system and does not include annual fees, which affect the differential yearly revenues in the net present value (NPV) calculation. Furthermore, here is assumed a 5-years straight amortization. The economic values showed in table 2 are thought to be appropriate for a 50ha farm; accordingly, when farm size is increased, investment cost should be properly re-adapted. To model this aspect of scale economies it was decided to adopt the "0.6 rule" in the economics literature (Tribe and Alpine, 1986): this rule has its origins in the relationship between the increase in equipment cost (i.e. investment) and the increase in capacity (i.e. farm size) given by $I_i/I_{i+1} = (F_i/F_{i+1})^{0.6}$. Accordingly, the investment cost for a 100 ha farm (i.e. I_{i+1}) is calculated considering the former value of the farm size, i.e. 50 ha, and the relating investment cost (see table 2).

Table 2 – Cost structure of the site-specific equipment

	Purchase prices (€)				**Investment (€)**	**Annual fees (€ $year^{-1}$)**	**Amortization (€)**
	VR fertilizer spreader	GPS technology	Guidance technology	Auto section control			
System 1	7300	2086	-	-	9386	0	1877.2
System 2	7300	6417	4078	-	17795	800	3559.0
System 3	7300	6417	4078	2500	20295	800	4059.0

To model the economic benefits in this study two scenarios were considered: Scenario A, characterized by limited benefits arising from the adoption of the selected PATs and Scenario B, slightly more optimistic. Table 3 shows the base cost reductions, in terms of input used, considered for both scenarios and for each system. It was decided to stay as much as possible on the safe side by adopting reductions that range from 1.5 % (Scenario A) to 3.0 % (Scenario B) even though some contributions in scientific literature suggest even higher saving rates. For instance, Bourgain and Llorens (2006) experimented with variable rate applications of N obtaining a 11.1% saving of the agricultural input, and Casa et al. (2011) experienced a 22% of nitrogen savings; both of these studies were based on cereal crops and uniform and variable rate applications were based on practically same yields.

About fuel savings we have assumed saving rates equal to 4.0 and 5.0 % respectively for System 2 and System 3; with no fuel saving considered for System 1 because GPS system is regarded as less accurate than RTK-systems. Fuel saving is not limited to the fertilization activity, but to the assumed activities of the RTK-GPS equipped tractor at 50 % of total fuel consumption per ha. Increased yield benefits are considered to be joined for three years, from year 1 to year 3, before becoming steady in years 4, 5 and 6. In addition it is assumed a yields increase with 1 % for the base VR fertilization system (system 1) and 2 % of increase for both systems 2 and 3. Even though these values are regarded as fairly conservative, considering that similar systems that are comparable to system 1 gave yields of 1.4-1.5% (see Bourgain and Llorens, 2006).

Table 3 Yearly benefit structure of the systems

Agricultural input savings (N)						
	Base cost reduction (%)		w/ RTK-GPS, autosteering	w/ Auto section control	Total saving (€ ha^{-1})	
	Scenario A	Scenario B			Scenario A	Scenario B
System 1	-1.5%	-3.0%	-	-	9.0	18.0
System 2	-1.5%	-3.0%	-3.0%	-	27.0	36.0
System 3	-1.5%	-3.0%	-3.0%	-3.0%	45.0	54.0

Fuel savings		
	Fuel use (%)	Total saving (€ ha^{-1})
System 1	-0.0%	-
System 2	-4.0%	2.37
System 3	-5.0%	2.96

Yield benefits				
		Differential revenues (€ ha^{-1})		
	Yield increase (%)	Year 1	Year 2	Year 3-6
System 1	+1.0%	25.0	25.3	25.5
System 2	+2.0%	50.0	51.0	52.0
System 3	+2.0%	50.0	51.0	52.0

Results

Figure 1 below shows the results of the financial analysis (NPV) of the three systems for farm sizes ranging from 50 ha to 500 ha with respect to scenarios A and B.
When only considering scenario A it appears that the base system (system 1) is clearly unprofitable for every farm size considered, reaching the worst performances between 350 and 400 ha and tending to a loss of about 12.5 k€. The lowest costs are found at 50 ha (-6.7 k€). System 2 is profitable only for relatively large farm holdings (about 450 ha), with a peaking profit of 5.9 k€ at 500 ha. System 3 shows a positive NPV for a farm size greater than 200 ha, ranging from 2.1 k€ to 36.6 k€ at 500 ha.
In scenario B with more favorable boundary conditions it appear so that all systems are profitable already at 250 ha. System 1 is on balanced position at 250 (0.3 k€) and still

unprofitable until 200 ha while system 2 is convenient for farm size greater than 250 ha. System 3 also provide a positive NPV at 150 ha (3.7 k€) and increases the expected economic benefit almost linearly until 500 ha (55.0 k€).

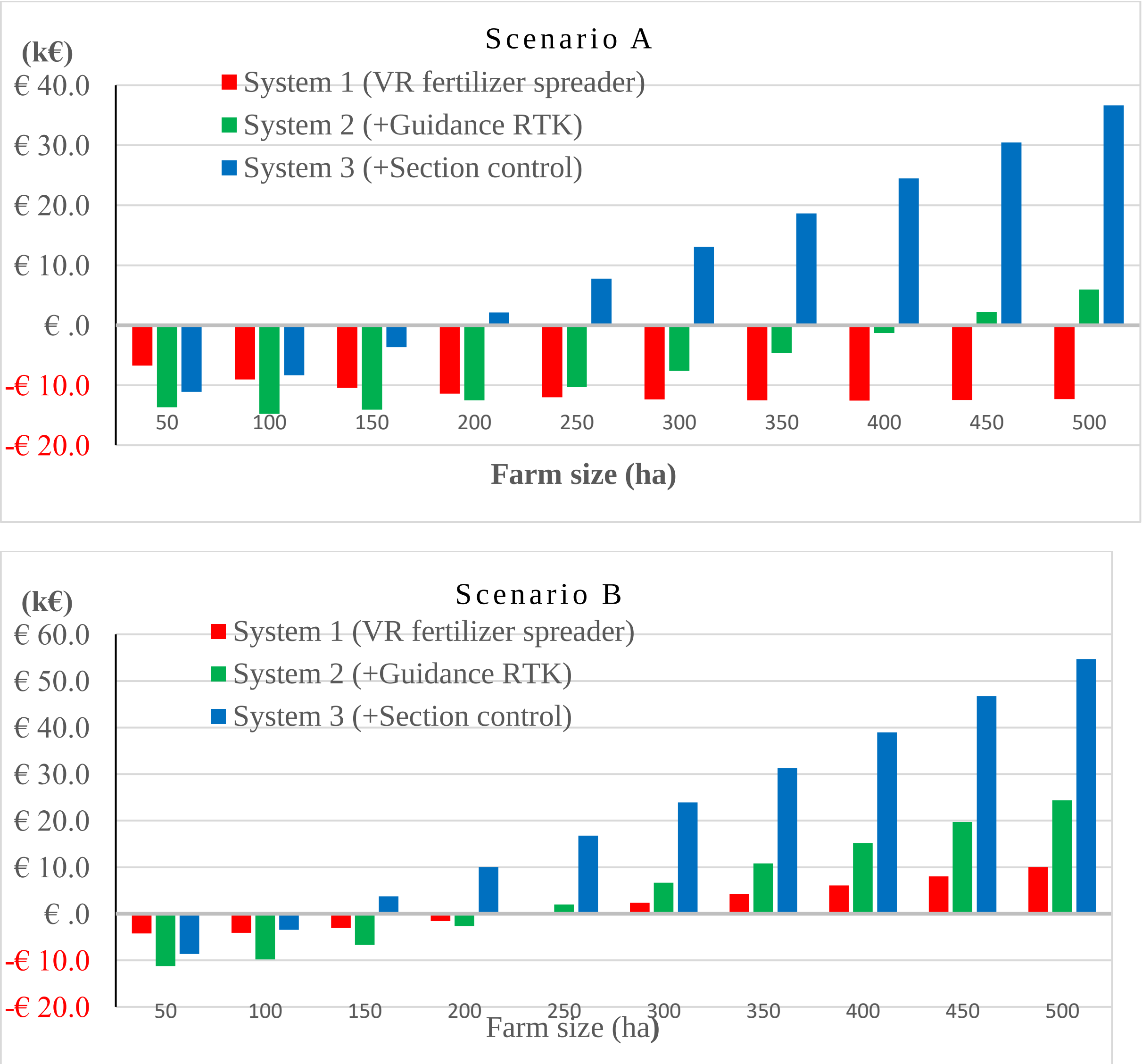

Figure 1 – NPV of investments on systems 1, 2 and 3

In general, the most advanced system composed by state-of-the-art technology (i.e. system 3) shows higher scale advantages that vastly outweigh the relatively high initial investment. On the contrary, less innovated systems that allows to execute site-specific treatments with limited accuracy are at the risk of becoming unprofitable in case of not favorable environmental contingencies, for almost every farm extension.

The largest item in the cost-benefit analysis is the saving of agricultural inputs, that is, in this study, nitrogen. Prescinding from its price charged to the customers, it may be interesting to highlight the potential mass amounts of its saving. Figure 2 shows the average kilograms of nitrogen annually saved as result of performing a site-specific N-fertilization by adopting each of the systems considered, according to, respectively, Scenario A and B. As one can note the kilograms of nitrogen potentially saved per unit area vary in the range 2.25 – 4.50, assuming an average application of 150 kilogram per hectare. Direct benefits both in terms of operating cost savings and in reduced environmental impact become relevant for large farms, for instance on 100-ha farms nitrogen savings are in the range 225 – 450.

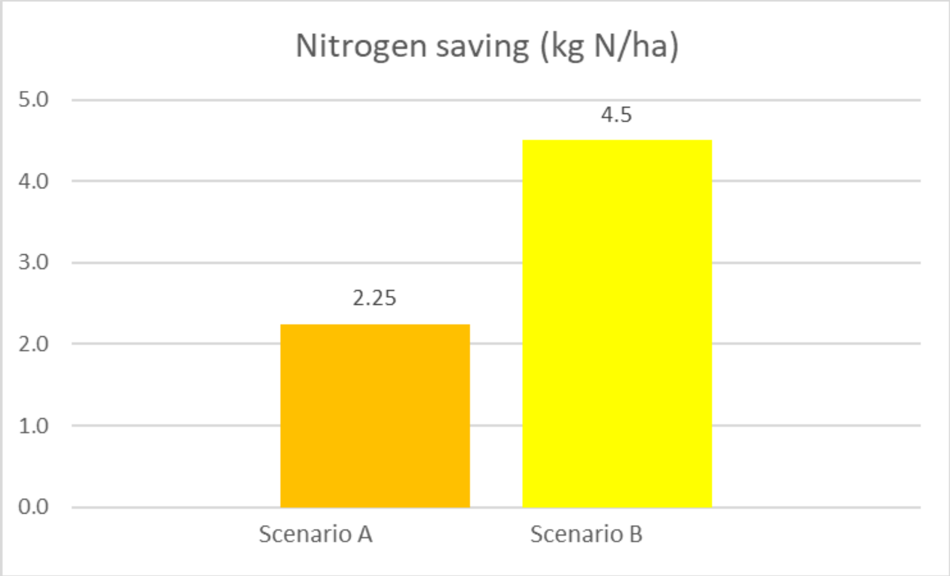

Figure 2 – Nitrogen savings

Finally, each of the systems considered allow to save fuels with resulting environmental benefits in terms of reduced air emissions. Taking as a reference the emission factor of diesel engines, that is 2640 g CO_2 l^{-1}, we have estimated the amount of CO_2 yearly saved, equal to 4.2 and 5.2 kg ha^{-1} respectively for system 2 and 3. In this study we have not considered the impact on nitrate leaching from reduced N application. It is however likely that by limiting overlap of N application it is possible to reduce overall N leaching at the root zone with selected precision farming technologies compared with uniform application. Depending on the location and crop varieties it may also be possible to gain additional benefits from better grain quality such a higher average protein content which again may provide an additional price premium.

Conclusions

Findings from this study indicate that precision agriculture that is targeted nitrogen application is mainly beneficial to large scale farms as well a combined and integrated application of different tools.

A first condition for gaining a financial benefit from implementing VRA is that it requires some spatial heterogeneity in the field. VRA provides little financial net-benefits if the field are homogeneous without variation in crop growth conditions. With little or no variations the GPS-systems will only provide minor net-benefits. However, autosteering and section control on fertilizer spreaders appear to be a viable solutions for many large scale farms. Overall, the financial benefits are modest for a number of single technologies but it seems likely to obtain a benefit from combining the use of technologies on large scale farms.

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