Fulfilling Economic and Ecological Demands in Crop Production with Information Driven Technologies in Land Use – Precision Farming as a Key-Stone for Integrated Land- and Water Management

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Condensed abstract: The 'precision technologies' are an essential set of tools for local resource management, actually developed for modern agricultural land use. This approach basically provides information driven management and it is judged as a key technology in developing sustainable land use systems. Not only will it provide site adapted economic land management technologies with exceptional good response to environmental sensitivities and potentials. It also will be very beneficial to link primary production with the value chain for food products through information flows. In addition methods for integrative site analysis and land management are on their way into practical land use.
Key words: land use, sustainability, crop management, precision farming, environment

1 INTRODUCTION

In modern agricultural land use, the new technology of precision farming (synonyms: precision farming, site specific farming) will become a common technology of land use within the next years. Especially well run farming enterprises will use this technology to increase their economic effectiveness through better information management, knowledge use and specific adapted cropping techniques.

The technology of precision farming[1] allows adjusting the cropping practices for the cultivated plants according to the growth potentials for the crop on a field. These potentials are located irregularly over fields and landscapes and thus could hardly be handled by the farmer up to now. In addition the new technology will make it possible to regard much better the different environmental sensitivities and potentials of a field in the context of a landscape. A production technology, which can supply exact position information, store and retrieve local application information (i. e. site adapted farming, precision farming) can support the integration of environmental quality goals into land use technologies. With easy steps in the technical adjustment of crop management it is possible to reduce the emissions of plant nutrients into adjacent ecosystems like surface and ground waters. It also is possible to adjust the crop canopy according the local water supply within a field.

Developing precision farming and putting it into action needs an interdisciplinary and integrative approach. In addition the implementation into practical farming will only be possible with an integrative thinking by the farmers – the crop production is related to the site specific potentials and all crop management steps are linked with each other and should be observed accordingly (Fig. 1). Both levels of integrative action are helpful for implementing ecological aspects in today's crops production.

The definition of the regional and local environmental goals as well as the definition of the proper actions in the crop production will be a joint and iterative process of farmers, environmentalists and conservationists. This participial and iterative approach in conjunction with a modern information technology is currently the only possible way, how the concept of sustainable development for land use could truly be put into action. This approach can be termed technically as '*integrated resource management*' and with respect to rural areas as '*integrated land and water management*'.

2 SCIENTIFIC BACKGROUND AND PROBLEM-SETTING

As a technical aid for management of land resources as well as crop stands with precision farming, new sensors for determining the state of crop and soil, geographic information systems (GIS) as well as GPS satellite navigation will be used. The agricultural bus system (*LBS*, or *ISO-Bus)* supports this type of crop production by offering the appropriate electronic interface for tractors and equipment, which is necessary to control the management measures. The information basis (methods, software) necessary for an economic use of this technology as well as

[1] precision – 'the quality of being reproducible in amount or performance' (WordNet 1.7, Princeton 2001)

the necessary cultivation principles for plant production is subsequently be developed and tested in agricultural land use practice (BOOTLINK et al. 2002). Only in this way the preconditions soon will be available in order to create new and economic production processes for agricultural land use with this technology (BONGIOVANNI & LOWENBERG-DEBOER 2002). Besides this, precision farming will offer through innovative products (appliances, software, tools) chances for the agricultural engineering industry or the agro industry in general. In addition it will allow additional functions in a new agricultural service sector. This form of management is an additional important step towards the improvement of agricultural "good technical practice" and a keystone for sustainable development in land use (WERNER 2003).

Many fields (i. e. areas used for farming, plots) have very large differences in their natural preconditions for plant development and growth (local site characteristics or resources, i. e. the interacting effects of soil, relief, local climate and their neighbouring influences onto growth conditions). These differences can be related to soil or relief as well as being a result from cultivation measures (soil tillage, straw management, erosion etc.). They cause uneven plant stands and thus differences in crop yields. The actual cultivation practices of farmers can take into account these local differences only to a limited extent. The farmer adapts his practices (tillage, sowing, fertiliser application, plant protection etc.) to an average site quality for the field). The location or plant stand differences within the field have remained unexplored. Therefore, where parts of the field with high yield potentials are concerned, the potential is not exploited. On the other hand, areas with low fertility are, for example, oversupplied with fertiliser. This is an inefficient resource use and leads to economic losses but also to potential ecological problems. In addition, long-term efficiency of resource-use in production is a major goal in the sustainability track (DE WIT 1992).

Subdividing the fields into uniform sub-fields according to local site differences is mostly not feasible because of farm-organisation and economic constraints (e. g. field size and form). Furthermore, the differences in site quality often appear within a few metres and are therefore small-scale. Relevant site quality differences can be found within short distances in moraine terrains, lowland areas with random waterway impacts and low mountain areas. These regions have a high share of agricultural land use in Central Europe. To these are added agricultural-related differences in site and crop stand. These are resulting from differences in the activities and quality of cropping measures. But also ditches for pipes, tilling of old paths, filling of trenches etc. cause small-scale differences of site properties within the fields. These often cause effects for many years on plant stand and yield development of the crops.

Technical development has had ready for some years a satellite navigation instrument, which creates important preconditions so that these differences in fields can be taken into account during tillage in a targeted way. But there are still no generally valid, transferable rules and principles according to which sowing, fertiliser and pesticide use can be adapted to site differences with proper cropping measures. In addition, each cropping measure must especially be consistent with the other agronomic activities in the set of cropping measures for one crop and for the crop rotation (Fig. 1). Only such consistent or integrated measures can ensure high economic efficiency and broad ecological performance (AUERNHAMMER et al. 1995).

Transferring of such an integrated system as precision farming into practical land use is hampered through missing plausible rules in crop production, as well as the lack of data on the economic viability of this technology. This leads to an actually still low acceptance of precision farming by farmers (JÜRGENS 2002). Also the technical equipment for applying site-specific measures is often only available as prototypes. On the other side, not few farmers prefer technologies, which are more convenient in practical land use because of low costs in management (LOWENBERG-DEBOER 2002).

2.1 Basics in spatially differentiated, site specific Crop Production

With the satellite based position technology and additional information systems by electronic maps or new sensors in the travelling device on the field (board-computer, control-units) the cropping measures can be selected and done according the site potentials within fields and in dependence of the farmer's decisions (EARL et al. 1996). This '*information driven land use management*' includes all steps of crop production, from soil cultivation until harvest.

Natural resources regarded in land use are not distributed spatially uniform within the landscape. Therefore any technique that can be used to respect such local differences will support environmental protection or providing beneficial actions for nature and environment.

This new technology allows a spatially more precise action in crop management and some farmers who use it are more precise than before. Therefore this new technology is currently named *site specific farming* or *precision farming*. But this technology is more than just a new management system for farmers. It also offers simple technical steps for including environmental quality goals into the crop management practices. It also helps providing the growing information flow into and out of the value chain for food products. Therefore this technology is an essential new step of land use management into sustainable land use.

More and more equipment for crop production will be supplied with the necessary technology for precision farming (on-board computers, sensors, controllers, GPS-receivers, flow through scales etc.). In Table 1 the usefulness of spatially differentiated measures for the crop management as well as for the environment are identified. For most of these cropping practices a differentiation in measures is feasible and sensible. To differentiate the cropping measures across a site-heterogeneous field it is necessary to have principles or rules, how these measures should be differentiated in quantity and quality (WERNER 1990). The necessary production rules can be derived from the current agronomic knowledge. With this it will be possible to differentiate most of the cropping measures. With several interdisciplinary projects some of these rules and algorithms are developed[2].

In the near future the current research activities will provide also complete procedures for automatic data acquisition of crop and soil conditions and support the agronomic decision making as well as the information flow with the value chain (BOOTLINK & VERHAGEN 1997). New sensors will probably allow differentiating cropping measures according to actual soil or plant conditions 'on the go' (online-sensors). That means, the decisions are automatically done during crossing the field (VISCARA ROSSEL & MACBRATNEY 1997)

Table 1. Possible site specific variation of crop production measures and the relevance of such site specific measures for crop production and environmental protection (from WERNER et al. 1999)

Cropping measure	**Varying effects on yield formation**	**Relevance for**	
		Crop production	Environment / nature
Primary soil tillage	Depth	++	+
	Intensity	+++	++
Sowing	seed bed preparation	++	+
	sowing rate	+++	++
	Distribution of plants over the field area	++	0
	sowing depth	+++	0
Fertilisation	nutrient type	++	+++
	nutrient amount	+++	+++
Weed control	type of weed control	0	++
	Selection of herbicide and additions	++	+++
	Spraying rate	+++	+++
Application of	type of action	+	+++
Insecticides	Selection of pesticide and additions	+	+++
Fungicides	Spraying rate	+++	+++
Plant growth regulators	Application rate	+++	++
Work flow	action control (trafficability due to soil moisture etc.)	+++	+
	Production related information flows	+++	0
	Supervision of the farm	+++	+++

0 = no relevance; + = weak influence, ++ = moderate influence, +++ = strong influence

The actual general criteria of best management practices in crop production is to adopt the growth and yield formation of a crop (Fig. 1) onto the site specific growth potentials and actual conditions (HEYLAND 1991, WERNER et al. 2000b). The main goal is to build a crop stand that (i) is best suited to the site (and thus the specific growth conditions) and (ii) still has the ability to be controlled with usual cropping measures (nitrogen fertilisation, growth regulators; irrigation etc.). The latter (ii) is necessary, when during crop growth unexpected situations cause changes in the desired crop development. A crucial point for this ability is the correct plant and tiller density (Fig. 1).

2 f.e.: www.preagro.de

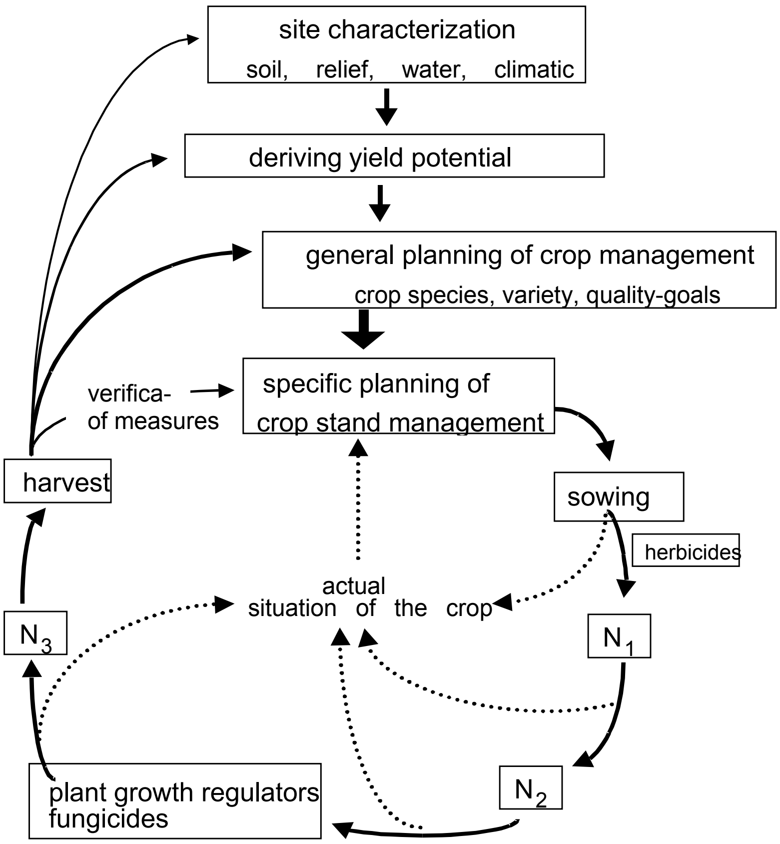

Figure 1. Crop management principles in site specific farming as applied by the joint research project *preagro* (example: small grain production, e. g. winter-wheat) (from: WERNER et al. 2000a)

2.2 Goals of joint R+D-projects to develop Integrated Systems for management of Land and Water Resources

The primary intention of interdisciplinary projects for research and development in technologies for integrated land use is to design decision support systems for local resource management based on rules or algorithms for the appropriate land use management. These systems should support the use of site specific cropping measures in plant production as software. The economic viability of this technology as well as the possibility for consideration of ecological aspects should be assessed. In essence the following steps are necessary in this respect:

- Identification, description and defining the site characteristics, spatially distributed within the landscape.
- Derivation of the crop growth potentials and the ecological sensitivities corresponding to the different site characteristics of such sub-units, delineating 'hot-spots'.
- Development of algorithms or rules for sound organisation of resource management according to the site characteristics, actual and expected crop-growth, economic and ecological criteria of such sub-units.
- Design and develop efficient and cheap management of gathering data or information and their interpretation.
- Analyse the effects of site-specific resource management on agricultural business with respect to economic and organisational processes.
- Analysis of site-specific resource management with respect to the potential effects onto the environment and towards nature conservation goals.
- Development of practical suggestions for integration of environmental and nature conservation goals by spatially organised resource management and site specific farming.
- Integration of algorithms and data processing into computer-based management systems (Software)
- Support in education, transfer and support of the new technology within the community of land users.

3 PRECISION FARMING AND SUSTAINABLE DEVELOPMENT

Sustainable development is a concept that integrates goals of economy, ecology and social demands into human economic activities. When it will be applied to specific human economic activities it is very necessary to define the system boarders. When the concept of sustainable development is used on agriculture, these system boarders have to include objects like watersheds, moving animals, biotopes and activities on single fields or in farms. Therefore the system boarders have to be in minimum that of regions (WERNER 2000).

This means, that sustainability cannot be related to single fields or farms. Therefore we state to address *sustainable development of land use* instead of the term of a 'sustainable development in agriculture' (agriculture is a physical and economic integral part of a landscape or a region and therefore can never be sustainable alone) (WERNER & BORK 1998).

How precision farming interferes with intentions of sustainable land use development is not yet analysed well (BONGIOVANNI & LOWENBERG-DEBOER 2004). Some preliminary thoughts deal with the potentials to reduce the environmental impact of agriculture through applying the approach of site specific and spatially differentiated cropping systems (e. g. AUERNHAMMER et al. 1995, BLACKMOORE et al. 1994).

3.1 Precision farming and the aspects of *Economy* in the sustainability concept

It is obvious, when precision farming will lead to a lesser amount per area with seeds, fertiliser, pesticides or any other cropping measure, than this could reduce production costs. If this will also enhance economic efficiency is not yet clear enough (ENGLISH 1998). Some first results (Tab. 2) show a substantial reduction of nitrate leaching (17 % till 25 %) when applying precision farming techniques in fertilisation in comparison to a uniform fertiliser application.

Especially the overall costs of such a technology (e. g. equipment, information gathering) and the exact benefits (yields, labour reduction, profits) are not determined completely yet (HAMMOND 1993). There is not yet enough experience with this new technology and especially too few farms use this technology at the moment.

In the development of new technologies for land use it is very important to head for such solutions that use our resources more effectively. This can probably only be reached with high yields and adopted inputs (DE WIT 1992). This would be easily possible with the described system of precision farming.

The willingness of farmers to introduce new goals is sufficient when they can be told the economic effects of the desired changes in their activities (JÜRGENS 2002). This rarely can be done, when a specific intention (e. g. for ecology) should be followed in a certain farm. A new method to generate different options in alternative cropping systems for farmers and conservationists is the multi-objective optimisation approach (WERNER et al. 1997, WERNER & BORK 1998). This procedure also allows to analyse the costs and ecological effects of different cropping technologies (ZANDER & KÄCHELE 1999). Therefore this system could also be used in future to analyse the benefits of precision farming for the economic as well as for the ecological intentions.

Table 2. Impact of the site specific fertilisation on nitrate leaching in comparison to uniform fertilisation (simulation studies, large scale areas) [from REICHE et al. 2002]

Clay content (%) [0-60 cm soil depth]	area (%)	site specific N-fertilization within the field		uniform N-fertilization on all of the field	
		N-fertilizer (kg N/ha*a $^{-1}$)	N-leaching-losses (kg N/ha*a $^{-1}$)	N-fertilizer (kg N/ha*a $^{-1}$)	N-leaching-losses (kg N/ha*a $^{-1}$)
northern Mecklenburg-Vorpommern					
3	41	184	55	199	72
10	42	199	22	199	34
16	12	214	11	199	12
12	5	198	10	199	10
Flächengew. Mittelwerte		194,5 (98%)	**33,6** (74%)	199 (100%)	45,7 (100%)
northern Schleswig-Holstein					
4	22	184	39	199	52
7	29	199	44	199	58
17	15	214	59	199	64
21	34	230	23	199	23
	averages	208,5 (99%)	**38,0** (83%)	199 (100%)	45,7 (100%)

3.2 Precision Farming and the aspect of *Ecology* in the concept of Sustainable Development

3.2.1 Precision Farming as the carrier for the Integrated Land Use Approach

The integration of ecological goals into agricultural land use is a difficult process. Economic obstacles (VERHAGEN 1995) several problems, lack of scientific understanding of relevant processes, insufficient information of farmers as well as conservationists, missing technologies as well as unfounded objections prevent, that a more ecological agricultural land use takes place in practical farming.

A major constraint in the integration of environmental quality goals into crop production systems is the lack of interest to apply an integrative approach in crop management (HEYLAND 1991). An economic and environmentally sound crop production has in general to regard the yield potential of the field (site potential) and to respect the environmental sensitivities and development possibilities of the fields (HEYLAND 1996). The result of such an approach will result in crops that are build according the average yield expectations and the ecological goals of a field (site and environment-specific land use). This crop production measures (sowing, fertilisation, pesticide application etc.) are interrelated and interact in their intensities. The primary goal is to design a crop stand that fits best to the site and the production goals of the farmers.

Unfortunately this type of thinking is available mainly in the academic level and text books. But it rarely is applied in practical agriculture (LÜTKE ENTRUP et al. 1995). Reasons for this are to some extend the missing methods, that help the farmers to decide which strategic and tactical steps have to be done on such an integrated cropping system.

The technology of precision farming is only feasible with a set of information processing software that is specifically developed for agricultural land use. Especially necessary are decision support systems, that allow farmers to decide the specific cropping measures on heterogeneous fields (GOENSE et al. 1996). These decisions are more difficult than the averaging approach for whole fields. New agronomic knowledge as well as algorithms to apply the knowledge has to be put into user-friendly software.

3.2.2 Precision Farming enables advantages for abiotic environment and nature

Potentials for developing specific habitats or supporting species within landscapes are not distributed uniformly over space. In many open landscapes the soils, the vegetation canopy and the surface relief cause gradients in the water- and thus matter or energy-flows. Along these gradients the biodiversity has the greatest chance to develop the most. Current agricultural activities tend to equalise such gradients by controlling water distribution over space and by additional nutrient supply. From the standpoint of crop management it could be reasonable to have uniform growth potentials for the crop at the whole field. But uniform conditions in soil- and air-moisture as well as uniform nutrient availability cause uniform conditions for the vegetation and thus uniform habitats for the fauna. A loss in biodiversity is to be expected.

Therefore one possibility to enhance biodiversity in agriculturally used landscapes is to protect or to develop the local differences in the water, nutrient and energy-distribution across a landscape. The current technologies for crop production do not allow differentiating measures (fertilisation, pesticide application etc.) according the given or desired spatial pattern of potentials or ecological sensitivities. The exact position on the field and the knowledge about the appropriate measure at that position are necessary to perform a spatial differentiated crop production.

With the new technology of precision farming it will be possible to organise the cropping measures differently across the fields. By satellite supported positioning (Global Positioning System – GPS) the exact position of a farming equipment can be determined on any field (KRÜGER et al. 1994). The computer technology additionally allows to store local site information and also hints for the appropriate measure for each distinguished site within a field. Modern equipment for cultivation, seeding, fertilisation and spraying (BROWN & STECKLER 1995) can be controlled through a board-computer on the tractor or any other machine.

Such a technology allows the implementation of spatial distributed environmental quality goals into crop management. To do so, it is necessary first to determine the local ecological sensitivities that should be regarded in the crop production or the potentials that should be developed. This step has to be done by local authorities which know the regional and local ecological demands. In addition it is necessary to define all those crop measures that are helpful to achieve the local, site specific environmental quality goals. This step can be done by regional experts and with the experience of farmers and regional conservationists.

The map of sensitive areas in the fields and the catalogue of suitable cropping measures are stored in the board-computer in an appropriate way. When passing the field for applying a cropping measure, the computer takes the GPS-position and looks at the electronic map for the specifically suggested action at that location. The appropriate action will than take place either manually through the driver or automatically through the board-computer.

When such a system would be implemented in practical farming, it would be beneficial for direct payments for farmers when doing specific nature conservation activities. The precision farming technology would allow achieving in a very efficient way the proper action for the desired environmental quality goal and at the exact place. In addition the GPS-technology can document the activities so that they can be used for control or payment purposes as well as for communicating information on the production process with the value chain for food products.

3.3 Precision farming and the *social* aspect in the sustainability concept

During the introduction of this technology into the agricultural business it will be necessary to have additional services (for data gathering, data handling, strategic planning for cropping measurements and the preparation of application maps) and this will create new high quality jobs on farms and in new enterprises (LOWENBERG-DEBOER 2002, ROBERT & IREMONGER 2003). Such new services for agricultural enterprises are already starting to grow in Germany.

On the long run however, also this new technology – as almost any other technical innovation – will reduce the number of people that are employed in the primary production activities of the agricultural business. This will offend the social aspect in the concept of sustainable development to some extend. With techniques of virtual land consolidation, using precision farming techniques (AUERNHAMMER & MAYER 2000, AUERNHAMMER et al. 2000), it will be possible support agricultural land use also in small scale farming as well as in general agricultural services. Thus by helping farmers to survive in an economy, that will be more difficult in the future, it will ensure the existence of these enterprises, their income and thus will support farmers, employees and their families. Therefore the social aspect of sustainable development is not violated with this new technology.

3.4 Comparing Precision Farming with other approaches and in the Concept of Sustainable Land Use

When designing and analysing new land use concepts they have to be compared with potential alternatives. Often the technology of precision farming is compared with *integrated crop management* or with *organic farming*. Such a comparison is not feasible. Precision farming is a set of different techniques, machinery and software based information systems. It easily can be called a new *management system* for crop production. All of these techniques and equipment can be used and will be used both from integrated crop management as well as from organic farming (FRICKE & HEß 2002). Therefore comparisons are only feasible between crop management systems with or without the application of techniques from precision farming.

Comparing crop management systems on their impact onto sustainable development of land use needs first to define those indicators that show the state of sustainability (MÜLLER et al. 2002). For agricultural production several sets of such indicators are available, but no common and accepted set is defined in literature yet (WERNER & BORK 1998). For this study, a set of relevant indicators was defined (see Fig. 2). To conduct the complex sustainable impact analysis with these indicators, it is necessary to have enough information on the impact of the specific crop management systems onto the indicators. Unfortunately there is only a very limited amount of information available, how different cropping systems, especially precision farming show an impact into these indicators (BONGIOVANNI & LOWENBERG-DEBOER 2004, WERNER 2003). Therefore the comparisons have to be done with expert judgement relying on the sparse information in literature.

From Fig. 2 it can be derived, that organic farming can perform in land use better than integrated farming on some indicators. When comparing integrated farming with the use of precision farming techniques (IF + PF), most indicators show better results than IF itself and also better results than organic farming. This better performance can be seen especially in indicators of the abiotic sector in the environment. This is true mainly because of the site adapted application of agrochemicals and a better resource management. It can be assumed, that this can also be found with the water resource itself. Until now, no scientific analysis is available for this yet.

When applying precision farming techniques also in organic farming, most indicators show even better results (Fig. 3).

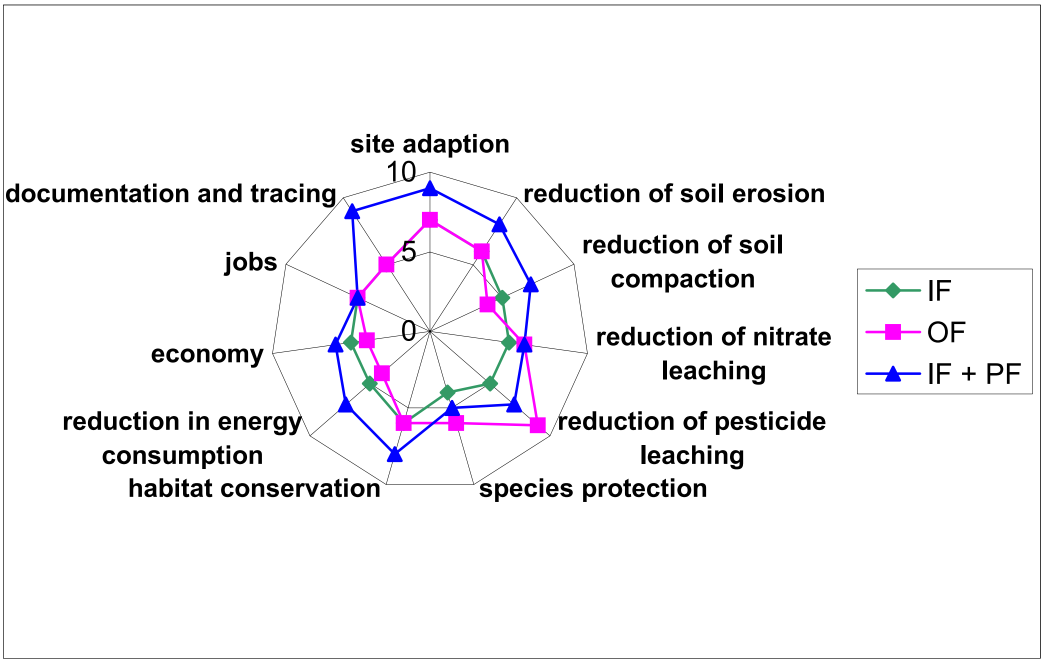

Figure 2. Impact of the crop management strategy ‚*integrated farming*' (IL), ‚*organic farming*' (OL) and ‚*integrated farming with precision agriculture*' (IL + PA) onto indicators of sustainable development in agricultural land use
(qualitative assessment based on expert judgement according to the actual available knowledge in literature; mark1 up to mark 9; mark 9 = best state)

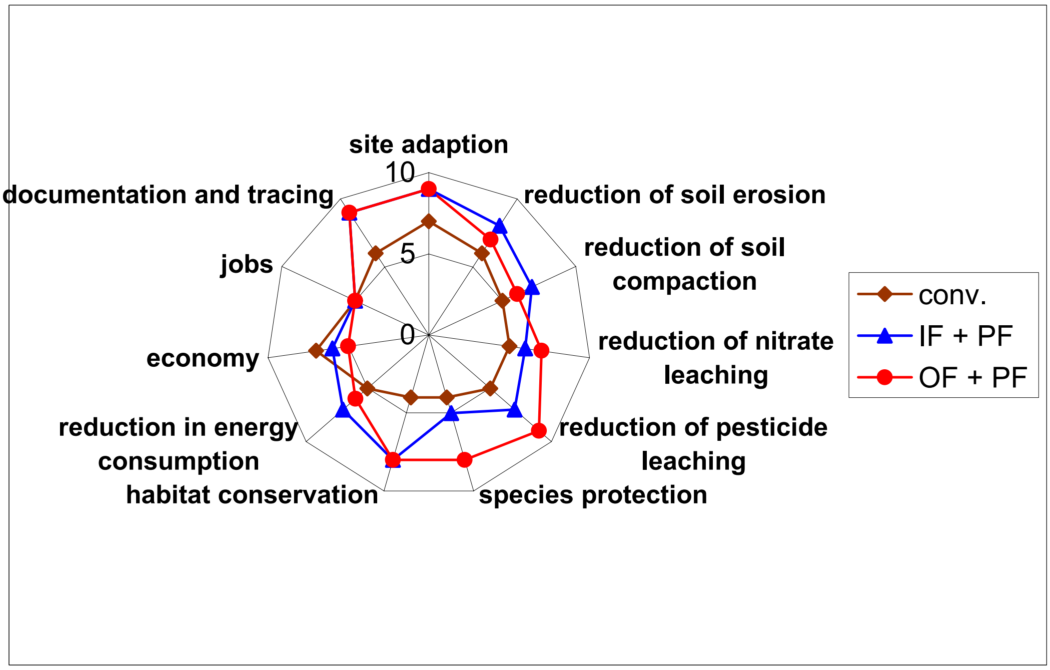

Figure 3. Impact of the crop management strategies '*conventional farming*' (conv.), ‚*integrated farming with precision agriculture*' (IF + PF) and *organic farming with precision agriculture*' (OF + PF) onto indicators of sustainable development in agricultural land use
(qualitative assessment based on expert judgement according to the actual available knowledge in literature; mark1 up to mark 9; mark 9 = best state)

4 CONCLUSIONS

Due to the benefits for the farm economy, for the environment and on the long run for the region and its people, the technology of precision farming can bring a substantial step for land use towards a more sustainable development in land use. Local resources can be easier managed properly, due to detailed and abundant information and specific control possibilities

The activities concerning research and development related to precision farming have to be done jointly with several scientific disciplines. The scientific activities in the field of precision farming will force scientists of different disciplines and methodological approaches to work together (BUCHLEITER et al. 1997). This will be a great chance for the agricultural sector to be in forefront when developing new strategies for the concept of sustainable development.

An interdisciplinary, integrative development and the use of a proper and well designed technology of precision farming will be one of the major steps in the next decades to put agricultural land use onto the track of sustainable development.

The definition of the regional and local environmental goals (PLACHTER & WERNER 1998) as well as the definition of the proper actions in the crop production have to be a joint and iterative process of farmers, environmentalists and conservationists. They should be accompanied by representatives for the regional development. Thus all aspects of the sustainability concept: economy, ecology, social responsibility could be handled at the same time. Solutions that do not sufficiently fit to all or one of theses criteria would lead to a recurrent review of the pre defined goals and the existing or planned frame conditions. All these steps have to be done by the relevant groups and their representatives on the regional as well as on the federal or state level. This participial and iterative approach (WERNER et al. 1997) is currently the only possible way, how the concept of sustainable development for land use could be put into action.

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