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Agricultural field production in an 'Industry 4.0' concept

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Abstract. Precision Agriculture is a well-established concept in agricultural field production. It has developed over the last three decades. As part of this concept, farmers are used to collect and handle data. Farmers are also used to create solutions for field operations based on their knowledge of diversity and local data.

When compared to classic industrial production, agricultural field operations interact with a biologically-active system. From a production management system point of view, industrial production takes place in close, well-defined environments in which performance data can, to a great extent, be measured by deterministic matters: mass (kg), volume/dimensions (m^3/m), time (sec), etc.

In agricultural operations such as work involving tillage, seeding, fertilising, and plant care, there are by nature a good many possible adjustments available in order to optimise the operation method, plus intensity and timing. The challenge here is to establish the levels of knowledge that are necessary to support the control of the individual and/or graduated, precision-based operations. Within this context, parameters such as, for example, the workability of the soil cannot be defined in terms of a few deterministic parameters. Neither can the operational impact upon the soil which is made by the tools being used. It is assumed that this challenge is part of the reason why the concept of precision agriculture still contains a great deal of unutilised potential. The hypothesis raised by this article is that analysis should be carried out in regard to whether inspiration for the concept of an 'Industry 4.0' can facilitate the establishment of operational solutions in the field of precision farming.

Key words: precision farming, Industry 4.0, precision tillage, spot spraying.

INTRODUCTION

Analysing the synergy between industrial and agricultural production is not new. Agricultural production has already adapted a good deal of inspiration from industrial tools and solutions that have been dedicated and implemented for agricultural systems, such as, for example: lean, digitalisation, ERP(Sap) systems for data management and production planning. Thanks to such steps that have already been taken, agricultural field production has already been prepared for making its '4.0' next step.

One of the main elements in the concept of an 'Industry 4.0' (Creutznacheret al., 2015; Zezulka et al., 2016) is to look at the system as a whole, not only empirically but also by ensuring that all data and measurements are stored and are visible for analysis in one coherent system. This creates the foundation for a robust, database-lead process of prioritisation and decision-making. A central tool in extracting the valuable information from the data pool is the 'big data' approach (Sabarina & Priya, 2015) which can show itself to be potentially valuable in the development of the agricultural system. This implies that all elements in the production chain including production tools and products is assumed to be part of a 'cyber-physical system' (Lee et al., 2015), meaning that all data monitored is measured and communicated to a local cloud and/or the cloud in general. What makes the difference in the 4.0 concept is that the knowledge that is stored and hidden in this pool of data is actively used and analysed in the operational management of the production systems (Stock & Seliger, 2016).

In the development of 'precision farming', it has not been possible to establish the necessary decision support to allow work to be carried out, such as tillage operations, with a local, graduated approach at a commercial scale. This results in resistance to the further development of the concept of 'precision farming' (Pierpaoli et al., 2013). The hypothesis being put forward here that the 'Industry 4.0' and/or big data approach could be even more beneficial when used in this form of system. All of the required information is available via the cloud, which also includes quality measurements of the yield, not only in terms of volume but also including the main characteristics of the quality parameters.

Van Evert et al., 2017 describes how data models can be developed and trained for use in weed control and crop protection. Based on this it can be assumed that similar models can be developed for the potential improvement over the control of other operations in agricultural production. One example covering large-scale potential which deserves to be tested is the hypothesis that beneficial information can be extracted by analysing the links in-between such as, for example, the content of some minerals in the yield and root efficiency in the growing period, and then extracting any information which is suitable for describing the potential need for tillage. Similarly, if the occurrence of weeds and weed seeds are analysed during the harvesting process then a potential link may be discovered to previous herbicide application in the growing period and to the local need for herbicide composition and intensity in the coming year. Within this perspective the concept of 'Industry 4.0' can support the next step of development in precision farming.

Globally the industrialised part of the world has been looking for options in terms of systemising the optimisation of industrial production in order to create more value. The overall goal has been to enable the capability of handling more complexity as described by Walter et al. (2017), in order to be able to meet market trends in which a higher degree of customisation creates more value. This involves the feeling of value for the customer who is in a situation of use/consumption, but it also involves environmental impact and impact upon society in general. For production purposes this challenges the ability to produce the correct scaling, adapting variety, and making changes in design, and there is an even higher focus on quality and environmental/ social impact. This leads to a higher degree of adaptive technology in manufacturing systems, adding value in all chains by transparency and coordination and/or collaboration along the entire chain, horizontally and vertically. This involves a close connection with suppliers to the market and, internally, between the various departments and units, it involves design, testing, production preparation, general production, logistics, validation, and so on. As described by Van Evert et al. (2017), the concept of big data can be expected to form a strong tool to link together isolated models and to extract information from individual sources and sensors.

Within the industry in general, the goal is to develop the production facility by adapting the newest technology and utilising it in an intelligent manner, such that production can be economically beneficial in a dynamic environment with a much greater degree of customisation, demanding scalability (production volume) and high complexity in design variations and design shifts.

In development work which has been controlled by German thinking, this has been defined within the framework of 'Industry 4.0' in a way which is similar to that of the American 'Industrial Internet of Things' and the Japanese 'Robot Revolution'.

In very short-term presentation, Berger et al. (2007) defines 'Industry 4.0' in three elements: Smart Data, Smart Manufacturing, and Smart Workforce. This means that all parameters which are part of the products and production system are digitalised, and data can be collected in one big coherent system which provides the visibility between different products and different production operations/processes. In the industrial context, information is stored, ideally, in the cloud in order to achieve full visibility, and this also allows a connection to be formed between suppliers and customers. The development of technical solutions is progressing at a high velocity, and many new, beneficial production systems are being introduced onto the market. This is a way in which the industry is able to meet the demands of customers for dedicated products and solutions. The task for the industry is to establish a framework so that it can, in a rational way, take the right decisions in a complex context. A summary entitled 'Smart Manufacturing' outlines the means of outputting high valuable products with the most efficient usage of new technology in an adaptive, optimised production system. Even when data can be systemised and structurally analysed there is a need for a 'Smart Workforce' so that an overview can be maintained, one which takes care of operational control and the prioritisation of the more long term decisions.

When looking more specifically into the challenge posed by and the potential offered for agriculture, the image differs a bit, but with substantial similarities (Pierpaoli et al., 2013). In agricultural production, sensors and data harvesting are already well implemented. The workforce is skilled in handling this together with modern advanced production equipment, especially in terms of tractors and implements in the latter case. Production equipment is already designed or prepared for 'site specific' control.

When looking a little deeper in the business models for agricultural field production, this can be divided in two (Busse et al., 2014). The first of these covers large-scale bulk production in which the focus is on value optimisation through high quality output, minimal environmental impact, and achieving cost reductions by planning and optimising operations due to timing, method, and intensity. Farmers running this type of production already cover the advanced equipment that is available on the market. The second business model focuses more on diversity and local sales. Here the distances from farm to customer are typically smaller. There is a higher focus on the diversity in the delivery, the value for the customer, and the environmental and social impact from production.

In this work the focus has been placed on the first business model, covering the bigger production units as the farmers here are the most prepared (Busse et al., 2014). Paustian & Theuvsen (2017) describes how farmers growing more than 100 ha adopt the concept of precision farming and digitalisation, whereas the same tendency is not seen by smaller farmers. Kutter et al. (2011) describes the same tendency for countries like the Czech Republic, Denmark, and Greece. Although it has not yet been developed, it can be assumed that there is also similar potential for smaller enterprises. An argument for this can be the fact that smaller enterprises typically have a close connection with their the customers, and that they therefore have the potential to be able to develop customised products. Walter et al. (2017) describes how smart farming can be the key to handling diversity and the missing deterministic models in the development of sustainable agriculture. Walter et al. (2017) also describes how disruptive solutions can be expected to push development forwards. Busse et al. (2013) describes from a survey amongst German farmers how farmers play a positive role in the adoption of precision farming, but limited adoption is due to a lack of operative systems that can be shown to be valuable in practical use, thanks to significant limitations.

Looking a little deeper into the development stage of precision agriculture, precision agriculture took its first steps during the last few decades of the twentieth century (Pierpaoli et al., 2014), where the environmental impact from agriculture was put into focus. It was probably due to this that the first developments focused on fertilising and spraying. Fertilising had its focus on graduating the applied amount of fertiliser over the entire field, while aiming for the best possible plant uptake and yield. In terms of spraying, the challenge has been to reduce the amount of fertiliser being used. To this end, more appropriate technology has been developed (Malneršič et al., 2016). The concept of patch spraying has taken off thanks to this concept, where the pesticide is applied only in spots in which a specific weed specie/disease is represented (Gonzales-de-Soto et al., 2016). On a minor scale a good deal of effort is being put into the development of adaptive spraying, where the spray is placed precisely on the leaves of the specific weed plant (Tang et al., 2016). The principle behind precision agriculture is also available for tillage operations and seeding, although this is something that has not yet been introduced on a big scale.

The technology for precision agriculture is already to a great extend available on the market. Injection spraying is a system which injects the pesticide into the water in a pipeline to spray nozzles, or a more advanced version involves it being introduced directly for individual nozzles. Alternatively, systems have already been introduced with more pipelines and nozzles in which the individual pipeline can be activated when needed (Gonzalez-de-Soto et al., 2016; Malneršič et al., 2016).

A graduation of fertilising efforts is possible with almost all of the new spreading machines on the market. Here the spray levels are controlled the workings of the machinery, as the spreader normally does not have any subsections.

Implements for tillage operations have, to a broad extend, been developed in sections and with integrated adjustment options. Not much development is required to operate this precision-based method.

The big challenge is the input data for controlling operations. Ideally, this would involve information: how much fertiliser is available, which pesticide is needed, and in which doses - what is the need for tillage operations here, etc. This has been a central topic for research into precision farming. Due to the nature and complexity of the task no unique solutions have so far been found. The information required is not measurable by any unique sensors and neither can it be deterministically calculated.

Since the early twenty-first century, GPS positioning has been accessible for commercial agricultural use. Now it is close to being standard equipment on modern tractors. Through this, systems are available for monitoring positioning and for the storage of additional measurements or control data. From static measurements, information about the soil can be extracted. This can be extended by an online measurement of the soil temperature and humidity. The use of 'Leaf Index' measurements from IR and RGB measurements is well established and is used for measurements of crop density and growth.

Measurements of density and species of weed are still under development, but the available options have increased through the development of drones as sensor carriers (Walter et al., 2017).

At harvest time the yield measurement system has been operational for some years. In this area it could also be possible to measure selected quality parameters.

The overall data handling and production planning processes imply the use of SAP/ERP systems which fully reach industrial standards in terms of visibility and options for cross-linking data.

In developmental terms, until now progress has been controlled by adapting new technologies that can benefit agricultural production. Lindblom et al. (2016) describes how the available precision adaptable technology is utilised in practice, in connection with the available systems for precision-based control. Experience shows that the economical benefits are weak in the current setup. Lindblom et al. (2016) concludes that a stronger implementation of precision agriculture is required for development to be able to reach more sustainable levels of agriculture. It seems that there still is a great deal of potential in the improvements, both in regard to economical and environmental benefits. Turning this into something which can be made operational requires new thinking and dedicated development. This is where the concept of 'Industry 4.0' seems to open up some fresh possibilities. Sheng & Brindal (2012) describes how policy implications can also support development, with dedicated actions being taken by developed countries.

MATERIALS AND METHODS

When looking at agricultural production from a 4.0 perspective, the overall goal could be defined as follows:

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The right form of operation and application on the right spot at the right time. This means that individual operations have to be scheduled and executed at the right time. The planning for this is based on economy, yield, crop quality, and environmental impact in a broad sense.

As part of the basic concept of 4.0 all operations are planned as part of the full production system. The potential in possible developments in terms of the production system are evaluated in a '4.0 Check-Up' by analysing the available options and foreseen costs against the gains, based on the economy and environmental impact. In a broader view, elements such as customer, acceptance, and influence upon society in general could also be analysed, although these areas are not included in this work. From the 'Industry 4.0' perspective, the concept of the 'check-up' is designed to be used for individual companies or production units. In specific use, the check-up also involves 'readiness' for the actual farmer to take the step into utilising 'Industry 4.0'. Following this paragraph are some guidelines and statements which concern agricultural plant production.

Decision support: there are a good many individual solutions, each being of a pretty good level of quality, but each missing the benefits of sharing data (which means using the cloud), and the big data approach. This is an area in which agriculture could learn from systems being used by industry figures. Unfortunately, only the structure and thinking could be transferred, as the agricultural production system involves a good many unknown and stochastically-determined parameters. There is a great deal of value in being able to handle this uncertainty, and in being able to introduce 'big data' thinking.

Data: agricultural operations are characterised by the fact that there are no unique or specific measures or definitions for the needs of individual operations such as tillage or seeding, etc. This is even more of a challenge within the perspective of site-specific operations.

Access to operational technology: the technology in this area is in fact very well developed, and is also very well understood, especially in terms of how to adjust to obtain a local impact in relation to the allocation of fertiliser, pesticide, or other materials.

Potential impacts: the impacts – including potential impact upon environmental and economic issues – have been pretty well analysed in literature.

The Table 1 below covers an example of a systematic description of potentials and the needs for different elements in the production chain in terms of agricultural field production.

Table 1. Potential and needs for different operations in the cropping system: – commercially accessible; – partly accessible/ to be developed; – to be developed

	Tillage	Seeding	Fertilising	Plant care	Harvesting
Potential goal	Being able to carry out tillage operations while only applying the intensity needed locally	Being able to vary the seeding volume to suit the potential and challenges offered by the local soil conditions	Delivering the right amount at the right spot at the right time. Due to potential plant uptake and yield	To adjust the dosage to suit local requirements, and to optimise the timing	To set out the overall planning for harvesting in the any requirements and to ensure an on-time operation. To gather useful information about the yield and other indicators
Access to system for decision support	In principal system support is available when the available information is sufficient	Decision support is commerciall y available	Commercially accessible	Commercially accessible for dose control. Individual plant care or spot spraying in the design phase	Close to being available on a commercial basis

Table 1 (continued)

Access to data needed for decision	Access to data is the missing link	Data possibly accessible, but not on a commercial basis	State-of-the-art, to implement empirical knowledge in the application planning	Data accessible, but hard and expensive to gather	Yield measurements have been implemented for decades. Other sensors have to be defined
Access to operational technology	Technology is developed so that it can adapt to different soil types. But it is not yet equipped with sensors and control systems	Commercially accessible	Commercially accessible	With limitations, accessible for dose control	Commercially available
Potential impact on environ-mental effects	Important. Influences nitrogen uptake, and nitrogen leaks to recipients. Erosion. CO_2 emissions and erosion can be reduced	Moderate. Saving on the need for pesticides	Moderate. Better usage. Moderate saving in nitrogen leaks to recipients	Important. Saving on the consumption of pesticides	Indirectly important
Potential economical impact	Important Fuel-saving	Moderate	Moderate	Important. The cost of pesticides	Indirectly important

RESULTS AND DISCUSSION

The analysis shows a fairly high degree of readiness by farmers. There are central missing elements which, together, means that the concept of precision farming has only shown a very small part of its possible potential. However, despite the missing elements, the framework for enabling precision farming is well established within existing professional systems. There is also a readiness to adapt to the thinking required for 4.0. By using state-of-the-art technology, farmers are able also to implement forthcoming features and solutions for other forms of operations.

Table 1 shows that there is a great deal of potentials both environmental and economic, when it comes to operational spraying and tillage. For both areas the operational technology is already available on the market, or is accessible with minor developmental investment being required. The task of spraying has been a topic for a good deal of the research effort. This is where it is possible to find 'low hanging fruit' solutions such as, for example, spot spraying for problems which show a high degree of stability from year to year (Tang et al., 2016). New research with drone-based scouting also shows promising results for this use. For tillage work there has not been the same level of research, although a substantial level of impact can be expected both economically and environmentally. The common strategy at the field level is to apply the tilling method and intensity required to achieve good results even on the most challenging of spots. As texture and soil conditions often vary locally at the field level, the potential is to apply a more gentle implementation of design and to reduce the intensity levels for substantial parts of the area. As an effect of this, the environmental impact relies on reduced leakage levels of nitrogen which are caused by unnecessary tillage, and a reduction of fuel consumption and CO_2 emissions (Sarauskis et al., 2014; Sarauskis et al., 2017). In the soil, reduced levels of tillage also provided a positive influence when it came to microbiology and the overall fertility of the soil with reduced CO_2 emissions and N-leak. As the cost of fuel is a large element in overall plant production, the introduction of precision tillage would also result in a large economic gain.

As explained, the problem is in the planning, for which the big data approach is proposed as one option when it comes to establishing useful data. For an accelerated start it could be worth analysing the possibility of and potential in utilising the benefits gained from a systematic mapping of soil conditions which is dedicated to the use of tillage planning. Successfully making such a system operational demands operators who are well skilled and who already have experience with the actual soil areas.

Even though the arguments included in this paper are based on overall arguments, it seems to be clear that there is substantial unused potential which could be made operational for wider development and the use of 'precision farming' in field production. It also seems to be clear that there are substantial potentials in applying the principles from 'Industry 4.0' in the further planning and development of this.

It is important to realise that 'Industry 4.0' is more than just a standard for digitalisation, data storage, and data interaction. Equally important is the fact that the concept also implies guidelines for planning and decision-making in a complex and context with a high degree of stochastic parameters. The concept of 'Industry 4.0' can in this way also be a tool which brings the source of any decision back to the farm and the local economy and conditions there. When looking at technology which has been developed for precision agriculture up until now, it can be seen that it has been controlled by the research community, which has much of its focus on the environmental aspects, and by the bigger companies such as the tractor manufacturers who support the use of GPS, field computer systems, etc. Implements for tillage work are to a great extend provided by medium-sized manufacturers who do not have the resources for carrying out development work on the scale of tractor manufacturers.

CONCLUSIONS

From the results and discussion it appears that the concept of 'Industry 4.0' involves a range of positive potentials as the framework for the further development of 'precision farming' for agricultural plant production. The analysis shows, especially in terms of spraying and tillage operations, that there is a great deal of potential which could lead to an improved production economy and to a reduced environmental impact. For both operations the technology is already ready or is close to being ready for use in the precision farming concept in a coarse resolution application. Development activities also have to be dedicated to enhancing the operability of the system and to improving precision/resolution, and thereby the potential offered by the system.

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