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Developing new cropping systems – which innovative techniques are required?

Jens Karl Wegener, Lisa-Marie Urso, Dieter von Hörsten, Till-Fabian Minßen, Cord-Christian Gaus

The agricultural sector is faced with sweeping changes arising from various challenges of economic, ecological and social nature. With a persistent prolongation of the recent technical development path, these challenges cannot be mastered in future. Therefore, it is necessary to put the plant cultivation system as well as the for operational design necessary processes under close scrutiny to achieve the demanded sustainable intensification of agricultural production. Against this backdrop, this requirement profile for a plant production in the future is defined, the resultant challenges formulated and individual aspects of an alternative production system are considered how, with the help of modern techniques, new alternatives in plant production can be explored. The focus therefore is first of all to satisfy the basic necessities of cultivated plants together with superordinate requirements and restriction particularly with regard to structures. This will provide the basis for the required process technologies for a site-specific farm management. This is in contrast with previous practice, by which i. a. the technique development in uniform farm-management leads to the increasing size of fields.

Keywords
Optimal stand space, cropping system, sustainable intensification, autonomous machinery, precision farming, site specific management, sensor technology, cross compound sowing, digital farming

The agricultural production has been faced with major changes due to increasing resource depletion, ongoing structural change, ever-growing cost pressure and increasingly adverse impacts of climate change (Balmann and Schaft 2008, IPPC 2011). Furthermore, agricultural production systems are under progressing social critique. They are held responsible for negative effects on the environment like e.g. increasing loss of biodiversity, nitrate pollution of groundwater as well as pesticide residues in surface waters and in food (SRU 2016). Also the ever-growing field size of a more and more industrialized agriculture with its comprehensively noticed agricultural deserts does not longer coincide with demands of society in terms of local recreation, leisure activities and unspoiled nature. On top, constraints of a growing world population results in needs of yield increases coupled with worldwide declining agricultural areas, which, taking into account the currently low price levels for many agricultural products and increasing market volatility, shall be designed sustainable (Lorenz 2005). In this conflict situation the question about how to solve the above mentioned problematic issues in agricultural production by considerable adaptations and changes of current forms of production arises.

The Senate Commission of Agroecosystems Research of the DFG (German research foundation) has in 2014 given its opinion in a contribution paper on the issue of sustainable and resource-efficient enhancement of surface area productivity (Wolters et al. 2014). It was formulated the thesis that a sustainable intensification of plant production (Figure 1, shift of 1→4) can only be reached by innovations. This is caused by a declining of the marginal benefit of an increasing resource use

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to further yield increases with established methods (Figure 1, shift of 1→2). The Commission i. a. concludes that the sustainable increase of agricultural plant production is reasonable with regard to the landscape context and figures that out as a future interdisciplinary research focus. Further comments on this priority were small-scale and temporal diversifications of cultivation system as well as the inclusion of edge structures and habitats as an element of this strategy. It remains unsettled with which practically relevant instruments agricultural landscapes can be designed, so that the aims of biodiversity conservation and sustainable intensification of agricultural production can be equated.

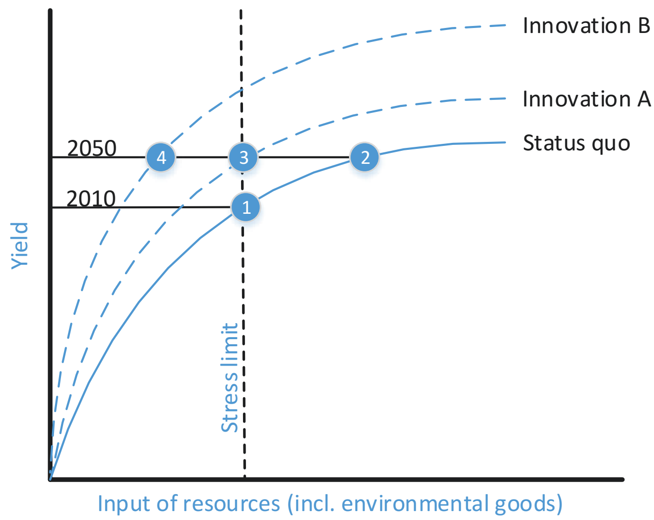

Figure 1: Relationship between input of resources for cropping and the achievable yield. If the stress limit is reached (1) a further increase of area productivity (2) with conventional strategies (e. g. more plant protection products or fertilizer) is not an option. The exemplary predicted yield expectation for the year 2050 can only be reached with equal (3) or reduced environmental impact (4 = sustainable intensification) on basis of innovations (Wolters et al. 2014)

In consideration of the problems and challenges mentioned above, as well as the necessity of innovations (Figure 1) to achieve a sustainable intensification of agricultural production under consideration of different goals and conflicts, the problem to be solved is nothing less than a new thinking about cropping systems.

Until today, the cropping systems have aligned with process engineering, which is required for agricultural management. In simple terms the objective has been, to cultivate a crop per field in a, as large as possible, geometrically simple structure equipped with low obstacles, which can be managed with ever-larger and more powerful machinery as effectively as possible. This dogma of a uniform agriculture has, in the past, more or less subordinated to any possible development of plant production (Auernhammer 2001).

With new technological developments like e. g. those which emerge from digitalization of agriculture or the option of the use of autonomous machines, in future it will be possible to adapt technology to optimal plant cultivation measures with simultaneously inclusion of the landscape in the shaping of sustainable production systems. Engineering needs to get an instrument of agriculture and should not determine the way of how production systems work. The questions that arise in this context relate to how an optimal cropping system looks like. This points to requirements and special challenges for the technical implementation which are explained in the following.

The aim of this article is to present a framework for a new cropping system which could meet the above mentioned requirements and to derive the technical needs for its agricultural use. The next step is to clarify the prospects and possibilities but also the limitations and risks which arise from new technologies for the implementation of the future cropping systems.

Requirements for an optimal cropping system in the context of a sustainable intensification

The crop has specific requirements for optimum growth. These are clear in their basic requirements. Furthermore, there are requirements and restrictions, which act on the growth and must be considered. These are described in more detail below.

Basic requirements of cultivated plants

The basic requirements of cultivated plants can be reduced to a few parameters:

- sufficient light
- sufficient space (above and below ground) and as little competition as possible
- adequate and timely water supply
- sufficient soil quality, texture and fauna
- adequate and timely nutrient supply
- healthy crop rotations
- if necessary, crop protection

As part of the development of a new cropping system, the basic requirements of cultivated plants have to be satisfied in order to ensure optimal growth and to use growth factors efficiently (Mitscherlich 1922). Both the design of the plant production system and the process engineering adapted to it should promote the mentioned parameters as much as possible.

Requirements and restrictions at field level

In addition, there are further requirements and restrictions that should be taken into account in plant production in the sense of a natural and eco-design of agricultural production systems at the field level (Christen and O'Halloran-Wietholtz 2002). These include e. g.

- General reduction in the use of chemical plant protection products to the required minimum
- Avoid the spread of agrochemicals during the application to non-target areas
- Strengthened soil protection by avoiding (multiple) crossings, especially with heavy wheel loads
- Closer attention to weather conditions (such as wind, rain, solar radiation) and further time-dependent events occurring in nature (e. g. bee flying) in the management of the production areas

Requirements and restrictions at the landscape level

In addition, however, there are also structural requirements and restrictions with regard to a natural and eco-design, arising on a larger landscape level (Christen and O'Halloran-Wietholtz 2002).These include e. g.

- Development of structures adapted to natural geographic and climatic conditions (e. g., consideration of locally changing soil qualities, intelligent use of high and low productivity surfaces)
- Creation of structures which restrain wind and soil erosion as well as shifting of material even under changing climatic conditions (for example, severe rain events) (orientation of the cultivating lines, reinvestment or recultivation of old ditches or landscape features such as hedges)
- Creation of refuges and buffer zones, which lead to a biotope network and strengthening of biodiversity and ecosystem services in agricultural landscapes.
- Positive influence on the landscape by smaller structures

The structural parameters mentioned are to be promoted and reconciled at field and at landscape level (Christen 2009).

For the implementation of the aforementioned requirements for a future production system, cropping systems have to be rethought, as already mentioned. It is highly probable that these new systems will no longer be able to be fully managed with the current process engineering and that there will also be a need for new technologies. These technological aspects and agronomical challenges have already been intensively discussed at a workshop under the BÖLN project "Developing new cropping systems with autonomous agricultural machinery" (Braunschweig 21–22 April 2016). Possibilities have been worked out as to how different processes in agriculture from the soil cultivation to the harvest could also be designed with small autonomous machines.

Challenges for the implementation of a new croppingsystem

Optimum growing space distribution

In order to reduce the competition between the crop and at the same time to provide the individual plant more light, a cross compound sowing would basically make sense. This arrangement maximizes the above and below ground level growing space of the individual plant and leads to further positive effects (Griepentrog 1999, Götz and Bernhard 2008, Demmel et al. 2010). On the one hand, the required seed quantities are reduced by thinner stands. This would e. g. reduce the number of seeds of wheat stock from the actual 220–240 to 150–180 seeds per m^2 when the latter is drilled in a cross compound design with the same sowing distance in each direction. Secondly, less seed is equivalent to less seed dressing entering the soil. Thinner stands would also have phytosanitary advantages. This happens because a potentially better aeration reduces the spread of fungal pathogens and even weeds are suppressed by better and more uniform population development. This would also reduce the use of plant protection products. In addition, a cross compound sowing facilitates mechanical weed control because it can be carried out from different directions (Figure 2). Thus, even without great sensor technology an intra-row weed control with simple and known hoeing tools would be possible. A georeferenced sowing technique with very high deposition accuracy, also in depth, is required to implement the cross compound sowing.

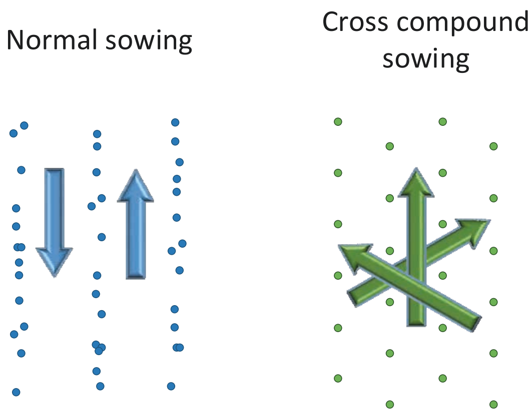

Figure 2: Comparison of potential machining direction on basis of cross compound and normal sowing

Fertilization

The targeted fertilization of subplots based on the real crop demand can already be partially implemented (e.g. target application of nitrogen using a N-sensor). However, the resolution of the realizable subplots is comparatively rough. In an ideal cropping system the application of fertilizers takes place in a very small scale, ideally in a high resolution up to the level of the individual plant (Dölger and Gerwers 2014). The fertilizers are applied according to the weather conditions over the entire growing season depending on the specific needs of each crop. Thus, for crops such as maize and wheat e.g. the partial applications and application times can be expanded. For sugar beet and oilseed rape different strategies would be necessary due to the nutrient requirements. During the application, the application technique used should place the fertilizer in such a targeted way that it is completely as possible absorbed by the crop. This reduces the loss of fertilizer to other places (ground water, surface runoff, etc.) (Taube et al. 2013) and, consequently, dramatically reduces the environmental impact of it. Nutrients, which are absorbed by the crop predominantly through diffusion, can be placed next to the rows. All other nutrients absorbed by the crop via mass flow should be specifically placed in the soil. This must be done in such a way that the root growth is positively influenced by the nutrient, e.g. in terms of stability and water supply. For the implementation, techniques for a high-resolution information gathering must be developed, e.g. directly via sensor technology, indirectly via information intersection or their combination. It is also necessary to develop techniques which allow a more precise site-specific deposition of fertilizers on and also into the soil.

Crop protection

Also with regard to crop protection, a reduction to the absolute minimum must be sought. This amount should be as in the case of fertilization. It extends to very small-scale applications up to individual plant treatment, which is just controlled when required. This implies that plant diseases are detected and treated early, before they spread over a large area. Here, a sophisticated combination of sensor-based inventory diagnostics and forecasting tools is needed in order to detect at an early stage whether the established threshold has been exceeded.

Production areas

Most agricultural production areas are not homogeneous in their properties. They have in the area e. g. different types of soil, which have an influence on the yield level and the water supply. A future cropping system should consider such and other impact-specific differences (e. g. height profiles, areas with erosion potential, geographic orientation, etc.) in the context of production maximization. Spot farming is a basic way of considering small-scale differences. The idea is to divide an area into autonomous spots with largely homogenous properties. These spots will be then cultivated according to specific characteristics with different crops and crop rotations. The definition of the spots can be conceivable e. g. based on soil maps or site-specific yield maps. From the insertion of these (and possibly also further) data, spots with different properties can be identified in a field level. For spots with high yield levels or good soil structure, for example, a site-specific crop rotation (e. g., sugar beet-winter wheat–maize-winter wheat) can be implemented. On spots with lower yield levels, another site-specific crop rotation (e. g., oilseed rape-rye-maize-rye) can be implemented. Spots with very low yield levels could be deliberately targeted as refuges or buffer zones, e. g. with flowering plants or, where appropriate, for protection against erosion, with landscape elements.

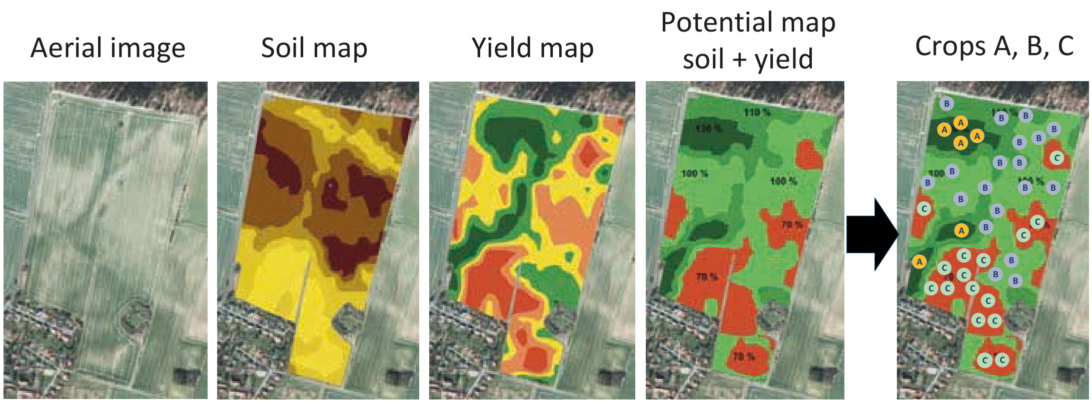

Figure 3: Example of crop cultivation in spot farming taking into account small-scale differences in arable land (according to Claas 2016)

Technical possibilities for implementing spot farming

Technical implementation

The actual agricultural process engineering will not be able to fully implement the outlined possibilities of Spot farming. For this reason it has to be examined with which new and well-known approaches the realization of the desired goals can be successfully implemented. In this context, upcoming technologies on precision farming and sensor technology (Zhang et al. 2002), autonomous agricultural machines and non-chemical crop protection (Bosch 2015) will play a role in the future.

Today a lot of information are already available e. g. on small-scale differences in the production areas that can be used to implement a Spot farming. The challenge will be to develop methods for data preparation and planning. The results of it will represent a sensible compromise between optimizing the fulfillment of basic requirements of individual crops and the natural and eco-design of the entire system at the different scale levels of the area as well as at the multiplicity of possible restrictions. This includes, among others, a close cooperation between crop production, agroecosystem research and landscape planning. Moreover, modern methods offer the possibility to further network data, knowledge and tools. This is necessary to develop expert systems which can both increase productivity as well as reduce the negative impacts of plant cultivation on the environment by providing targeted support (Scheiber et al. 2014).

Optimum growing space

For the technical implementation of the maximization of light and stand space for the individual plant by a cross compound sowing, an improvement in the deposition accuracy of the sowing device technology is necessary. In this context, sowing machines are required which should be able to place any type of crop in the required placement accuracy. First approaches are achieved in this context with the help of a precision sowing machine. However, the required positioning accuracy cannot be maintained especially at higher driving speeds (Köller and Gall 2013). Also precise site-specific sowing depth is a challenge to give the plant an optimal growth. Technical solution for it may also include an improved seed treatment of crops, which are not yet modified (for example, cereal seed treatment). A georeferenced seed placement would also generate further technical advantages in the cultivation of the crop over the entire growing season. This applies e. g. to mechanical weed control, whose tools can be controlled more precisely if the locations of cultivated plants are known in order to control weed even in the vicinity of the plant. Also the targeted application of root-available fertilizers in the soil could be realized if the plant location is known.

Breeding research

Spot farming also offers new opportunities for breeding research. In the current cropping systems, consisted of densely populated monocultures, breeding needs to invest considerably more genetic resources into the tolerance and resistance properties. Although this improves the health of the plant population, it generally has a negative impact on the yield (Huth 2002). The cropping system design allows a reduction of the crop phytosanitary pressure as well as strengths the natural plant defense mechanisms. In this way, genetic resources in breeding can be shifted in favor of yield.

Site-specific management

The targeted small-scale, site-specific management must be carried out with other machine concepts. The current device technology is especially optimized for power and space efficiency, in order to achieve the highest possible productivity in the short processing windows available. A basic option for further increasing the power lies in the use of autonomous systems. They can in the future e. g. use electronic drawbars which multiply the power of conventional technology with the same personal use (Jahnke et al. 2013). However, this would essentially be an update of the current development path.

Autonomous machines

Another option is the smaller autonomous machines, which work in swarms, perform different processes and coordinate themselves independently. The lack of clout observed in this type of machines could be compensated by the number, the almost permanent availability, the larger editing window for light machines and by the small-scale site-optimized management way of a Spot Farming. This approach requires a complete review of process engineering from soil cultivation to harvesting. This will determine where the use of such autonomous machines in the context of new cropping systems,

e. g. Spot Farming, appears to be meaningful and feasible. Moreover, such systems can also perform alternative plant protection procedures (e. g. hoeing, stamping, flaming, hot foam treatment, etc.) and thus reduce the use of chemical plant protection products to the minimum required (Sellmann et al. 2014, Gude 2012, Bosch 2015). However, many research questions remain to be clarified (energy supply, logistics, security, right, necessary sensor technology, new management systems, network infrastructure in the country, etc.) until new cropping systems and appropriate process engineering become marketable. Nevertheless, the current technical development paths offer the opportunity to focus on a landscape and yield-oriented crop production, which could meet various requirements in the context of sustainable intensification.

Conclusions

The aspects of a new production system presented here show a direction at the beginning of the conceptualization of the future sustainable intensification of crop production. In principle, the approach is to first focus on the crop and on the restrictions confronting cultivation and only then think about possible technological solutions. First technical approaches are partly in the development phase, whereby it will take several years to reach the market maturity. A simple continuation of the current developmental path in crop production, which can still be a little further advanced by means of autonomous technology and digital networking, appears however to have reached its limits.

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Authors

Dr. Jens Karl Wegener is head of the institute, **Lisa-Marie Urso** and **Dr. Dieter von Hörsten** are members of the scientific staff at the Institute for Application Techniques in Plant Protection, Julius Kühn-Institute, Federal Research Centre for Cultivated Plant, Messeweg 11/12, 38104 Braunschweig, e-mail: jens-karl.wegener@julius-kuehn.de.

Till-Fabian Minßen is member of the scientific staff at the Institute of mobile Machines and Commercial Vehicles, University Braunschweig, Langer Kamp 19a, 38106 Braunschweig

Cord-Christian Gaus is member of the scientific staff at the Institute of Farm Economics, Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, Bundesallee 50, 38116 Braunschweig

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