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New concepts of energy supply for sustainable agricultural systems

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The design of future agricultural production systems requires innovative approaches. For creating a more productive, resource-efficient and low-emission agriculture the systemic development of the agricultural processes, the operating conditions and the organizational processes is necessary. Fundamentally new approaches can be found by defining scenarios. Such a hypothetic concept does field operation without using internal combustion engines. Instead of this the power supply of performant machines can be done by electric direct supply systems or for small machines by battery systems with charging points. However, all this requires the electrical energy supply of agricultural fields. A direct electric energy supply utilizing the Center Pivot approach via rotating structures enables new production systems. Using innovative technologies new solutions with great potential for automation and a productive precision agriculture can be designed. This paper highlights an unconventional approach stimulating the discussion about future developments in agricultural engineering.

Key words
Sustainability, agricultural production, power supply, direct electric energy supply, Center Pivot, autonomous machinery, precision agriculture

A major part of the global food production is done on farmland, which is cultivated by high-performance agricultural machinery. The necessary energy demand is almost covered by the combustion of fossil fuels. As the availability of fossil resources is limited and because of the climate change greenhouse gases which are generated during the combustion process have to be reduced significantly. However, renewable and cleaner fuels seem not be available in a major amount during the next couple of years due to various sustainability reasons. A reduction of agricultural machinery use is no option either for the reduction of fuel consumption, which can be explained by the followed motives. Estimates indicate a world population of more than nine billion people by 2050. Associated with an increase of prosperity, the demand for food of high quality will lead to an increase of the demand of 70 to 100 % in 2050 compared to today. At the same time the available farmland cannot be increased significantly (DLG 2012). Especially in countries with a high population growth the production of basic food must be ensured and intensified. In addition transport distances have to be minimized and local agricultural businesses have to be strengthened. For a more productive as well as resource-efficient and low-emission agriculture new concepts of energy supply for mobile agricultural machinery have to be developed.

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Scope of research and development

In order to enhance the technology for agricultural production, especially agricultural processes, operating conditions and organisational processes have to be regarded. Thus, the majority of agricultural processes are largely based on historically developed process-chains. During the past decades the efficiency and performance of the machinery used have been increased, leading to great but only unilateral machine-related progress. Not only focussing on machinery, the spotlight has to be set on the flow of production systems while taking loans on strategies used in modern industrial production (eliminating waste in the production process). Scientists, agricultural consultants and farmers themselves have to develop appropriate methods adapted to agricultural conditions in order to realise efficient systems.

In order to disrupt existing process chains concept studies have been recently presented. Exemplarily can be referred to results presented by the TU Dresden concerning combine harvesting. The process steps mowing, threshing and loading were dissolved in order to compose them into new machine concepts based on autonomous machine swarms (Herlitzius et al. 2011). In addition suitable concept studies of robotic vehicles like the BoniRob (Bangert et al. 2013) or the Kongskilde Vibro Crop Robotti (Kongskilde Industries 2013) were presented as well as basic results on localisation and communication in autonomous systems (Schattenberg et al. 2013, Robert und Frerichs 2014). Principally known modular concepts like the "Gantry" are under further development too (CTF Europe 2013).

Operating conditions and their circumstances need to be considered. Major aspects like climate, topology or soil type cannot be influenced. However, the agricultural structure and the infrastructure are in limits modifiable variables which are also defined by the farmers, due to their agricultural area and machinery. The availability of services will affect the future production processes tremendously. It will be more important selling system solutions than selling agricultural machinery only. In addition this field of action has an internationally various but obviously political dimension. History and present show how political decisions set the orientation of the agricultural development.

The optimisation of organisational processes got an important lever in the agricultural production in recent years. This aspect is firmly connected to the holistic view on process chains and production systems. A significant increase in productivity and efficiency can be realised by management systems. However, service offerings and integrated software solutions using information and communication technology are strongly under discussion but in fact they only can be rudimentarily found in practice. This field of action including topics like precision farming and the exchange of information with upstream and downstream sectors of the agribusiness require the effort and openness of all participants.

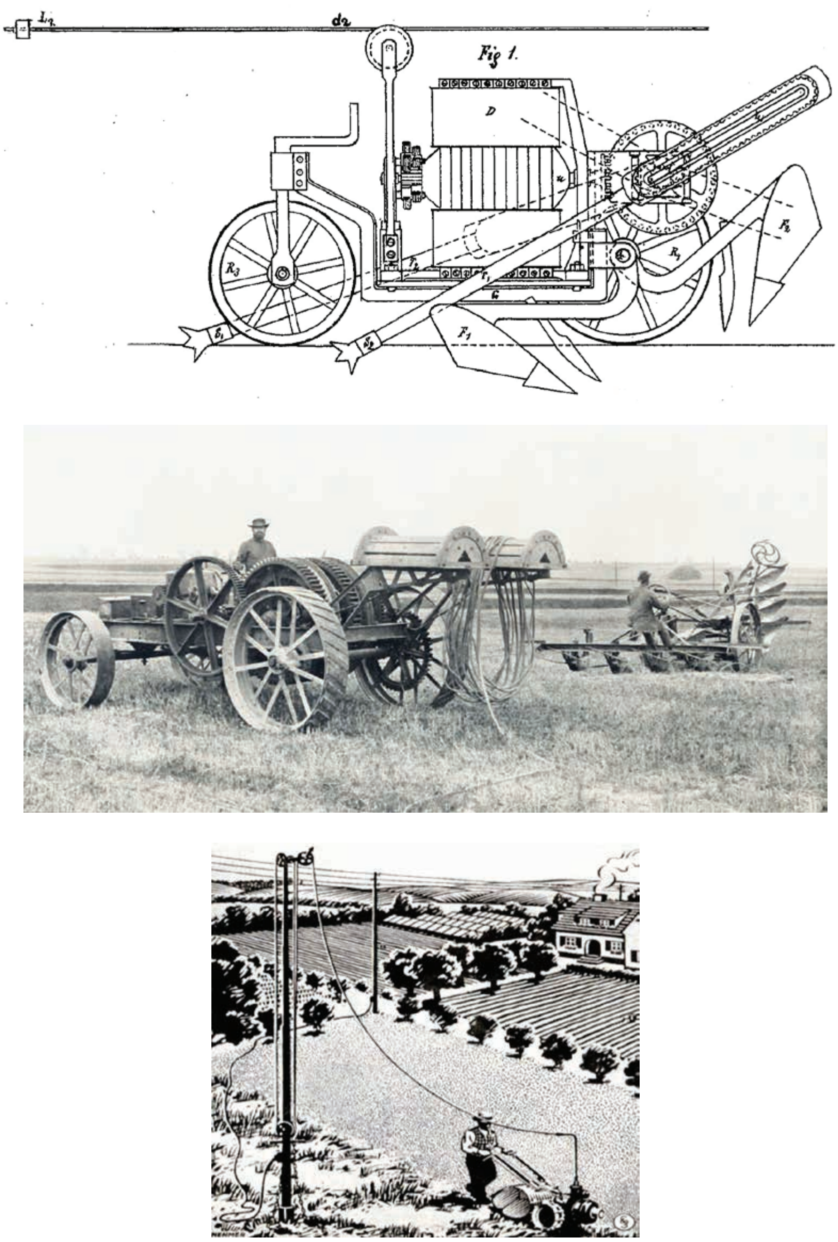
Energy supply for mobility on farmland

Providing energy for field work is the critical factor for solutions generated in all three described fields of action. Energy sources which are used today and in the near future are already known. Besides gaseous and liquid fuels (diesel, gasoline, LPG, CNG, LNG, BLT, ethanol, H_2 etc.) energy storages (batteries, capacitors, accumulators, flywheels etc.) are used in single but predominantly in hybrid mode. Globally, the forage for draft animals is an energy source too. In order to realise the required productivity and working conditions in agriculture, this should be of lower importance in the future. In addition to these energy sources which have to be loaded and stored, agricultural machines can directly be supplied with electrical energy, for instance via solar cells or systems which are directly connected via power lines.

In order to create fundamentally new approaches the methodology of forming scenarios can be used. Starting point for the following considerations is a scenario in which internal combustion engines can either not be used or can be used extremely limited. Due to reasons mentioned above the use of fossil fuels has to be reduced significantly. Alternatives like renewable fuels are known and they may have potentials but after full balancing, without discussing in detail here, they are judged quite critical. Against this background the scenario for an energy supply for agricultural machinery without internal combustion engines is focussed. For this scenario fuel cells are also not considered, but of course the authors are aware that this technology might be a long-term option.

Taking these restrictions into consideration energy storages and direct supply are the only remaining options. If evaluation criteria like performance potential, energy density, power density und greenhouse gas balance are utilised, it is quite clear that a direct electric supply – with renewable energy – of mobile machines is a considerably option. Realising this concept an electrical power supply of farmland must be ensured. This only brief statement is nevertheless of major importance because that means substantial infrastructure has to be created. But independently from the described scenario here various published future concepts of mobile machines are based on electric propulsion technology. Different prototypes of autonomous battery-powered vehicles (BoniRob, Prospero etc.) have been presented by research institutes (Bangert et al. 2013). Where do they get the energy from? The prerequisites for the use of those vehicles and also the consequences for agriculture have not been studied adequately yet. Supply and line concepts to and on the fields as well as charging concepts have to be developed. Beyond such solutions infield inductive energy transmission via power lines located in the tramlines are under discussion (Rauch 2012).

Concepts for an electric power supply on farmland have been already promoted at the end of the 19^{th} and the beginning of the 20^{th} century. Taking a look on this machinery is quite worthwhile because the developments were done more or less independently from the just started development of internal combustion engines. Exemplarily different systems are shown in Figure 1 a) to c). An electric plow was already patented by Siemens & Halske in 1880. The self-propelled plow is connected to an overhead power line. The propulsion is done by two lateral stakes (Kaiserliches Patentamt 1880). The well-known cable plow system (b) was re-invented by Maschinenfabrik Borsig using an electric motor unit and a movable anchor (not shown) (Brutschke 1894). Siemens & Halske presented a simple solution for hand-operated machinery (De Gruyter et al. 1927).



a)
b)
c)

Figure 1: Early solutions for a direct electrical supply of agricultural machinery; a) Electrical plow patented by Siemens & Halske (Kaiserliches Patentamt 1880) b) Cable plow equipped with an electric motor and movable anchor made by Maschinenfabrik Borsig, (Brutschke 1894) c) Solution for hand-operated machines made by Siemens & Halske (De Gruyter et al. 1927)

New concepts of energy supply of agricultural systems

In order to produce food without using fossil fuels in the future, connecting agricultural machinery to an overhead power line might be a possible solution. Starting point of the following presented thoughts is the so called "center pivot" well known from the half mile circular operating irrigation systems. This type of irrigation system as well as the rectangular operating "linear" or "lateral moves" are common in a lot of places of the world and already determine the structure und the organisational processes of the agricultural production there. In the United States more than 150,000 center pivots are installed irrigating each approximately 50 ha farmland. Currently the infrastructural costs are at about 1,300 $/ha (Cline 2009).

Following this approach, a centralised energy supply of farmland is imaginable. A segmental structure rotates slowly with a central supply unit providing electrical energy along the bar structure. Due to the rotation the energy can be provided area-wide. Agricultural machines can dock to the supply unit temporarily or permanently. This concept is not limited to circular systems, linear systems with lateral supply comparable with the irrigation systems can be realised as well.

Based on the outlined picture story shown in Figure 2 various aspects can be explained. The focus of this approach is set on a farm with large, circular fields. This solution relies on a large-scale farming as it is proven and seeming necessary in order to ensure the world's food supply. Obviously for a consistent sustainability mono-cultural crops have to be avoided. Hence the system-inherent parcelling is a good option. Another forward-looking aspect makes the scenario worthwhile to consider. Assuming that the production of basic food should be done next to regions of high population the presented concept is not only a possible solution for existing structures but also for new land cultivations (e.g. in Africa).

Exemplarily the production chain of corn for silage is shown in Figure 2. The target for a new system must be that it is at least as productive as it is state of the art. In addition it has to consider the latest technological trends. Tillage e.g. can be done conventionally using a cultivator which is drawn

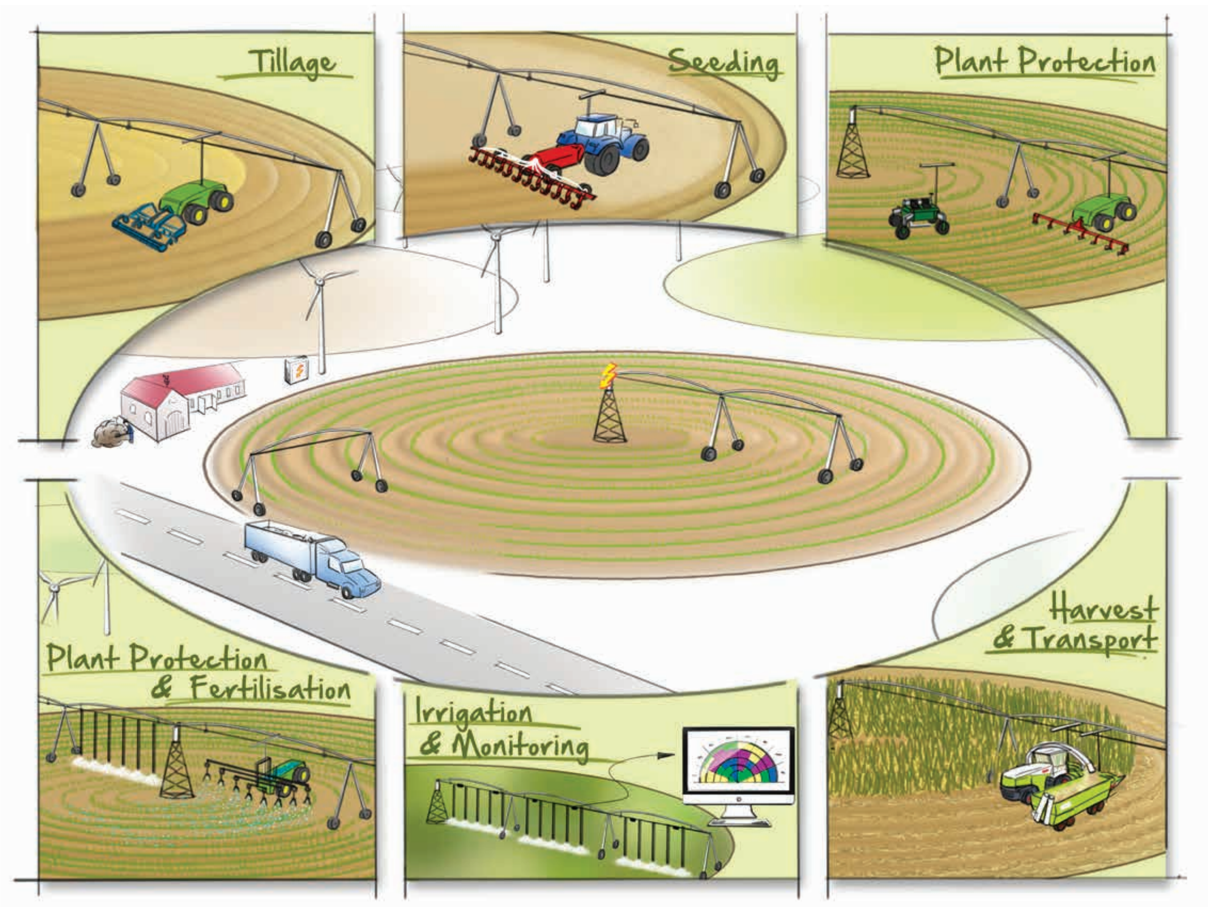


Figure 2: Electrical energy supply for agricultural field systems; Visualisation of the concept „Center Pivot“

by an autonomous unit. Due to the high energy demand of the towing vehicle during the tillage process a constant electrical supply is necessary. The seeding process is done by a conventional tractor implement combination using a precision seeder. An electrically driven standard tractor is used. For seeding an operator seems to be needed due to the sensitivity and significance of the seeding process.

Plant care can be done autonomously. A mechanical hoe with a large working width – probably sensor-controlled – can be towed by an autonomous operating vehicle. In addition, plants can be treated individually by autonomous small-sized vehicles in order to regulate weed (Bangert 2013). Such vehicles can be battery powered and connected to the electric power line from time to time for charging. For fertilisation and crop protection liquids can be spread using the sprinkling system of the Center Pivot. Granules can be spread locally by using autonomously towed pneumatic spreaders. Irrigation is the basis and the core discipline of the Center Pivot. By repeatedly passing the farmland a detailed plant monitoring can be realised. Not only precise applications can be done, with the available entire information all processes up to optimal harvest times can be predicted.

In the described scenario a forage harvester is used. For an optimal process control an operator is still needed. However the logistic process is done by autonomous driving and self-organising units. While driving parallel to the harvester trailers can be connected to the supply system for recharging their batteries. While driving to the edge of the field in order to load a truck the power supply is ensured by the batteries.

Necessary requirements

Due to the diversity of structures and regions a one-fits-all solution cannot be realised in agriculture. At least adaptations will be needed in order to use the described equipment. In regions with small plots such systems are hard to imagine unless land consolidation can be done. If not – for the scenario circumstances – an alternative power supply has to be chosen like charging points for battery-powered vehicles. But it becomes quite clear, if we want to be able to live without internal combustion engines in agriculture it seems to be essential to provide infrastructure for supplying field equipment and charging points with electric energy. In Figure 2 wind turbines are shown which only are representatives for a local sustainable energy supply including storage solutions (smart grid). Significant financial investments have to be made in order to install the required network. In addition the public acceptance has to be secured.

Furthermore a lot of technological prerequisites have to be fulfilled. In the described system the connection of each vehicle is realised by power lines. Whether the classic pantograph or a contactless inductive transmission is the best fitting solution has to be researched. The entire system requires certain flexibility. While working next to the central point of the Center Pivot outer sections have to be disconnected in order to prevent high circumferential speeds of the bar structure (compare with Figure 2). The draft design of a “Linear Move” system is shown in Figure 3. Even if, due to experiences gained by irrigation systems, Center Pivots might be the simpler solution, the integration of “Linear Moves” into existing predominantly rectangular structures might be easier. For such a system the energy supply can be realised inductively via power lines at the field edges. Safety issues of direct or inductive power supply have to be addressed but installed systems indicate technical controllability.

Agricultural machinery need to be transported between fields and farms. A possible solution is quite similar to the described process concerning field trailers. A suitable solution is the usage of electric storages that are not designed for the energy-intensive process but for transportation. However, further solutions like trailing have to be considered and evaluated as well. Using all possibilities offered by the concept a large variety of new process variants can be realised. Controlled traffic farming (driving always in the same tracks) is a very obvious inherent solution. In addition the question of appropriate machine concepts has to be answered. Previously developed solutions such as “gantry” concepts or multifunctional traction units have to be evaluated again.

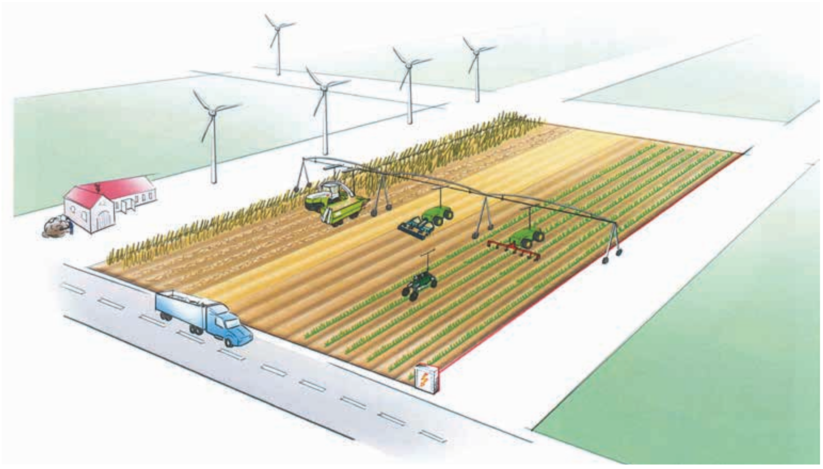


Figure 3: Electrical energy supply of agricultural field systems; Visualisation of the concept „Linear Move“

Potential for automation and precision agriculture

Due to the clearly defined field boundaries and possibilities of control, the proposed system has an enormous potential for safe automation. The amount of pesticides, fertilizers and the water demand can be reduced in order to realise more environment-friendly and resource-efficient processes. With a close to plant track of the sensors and the connection with field maps a never seen precise application can be realised, due to the exact location of each plant and detail. A plant-specific treatment of plant diseases or weeds using mechanical methods (e.g. hoeing) based on the knowledge of the exact location of each plant is possible. Agricultural machinery can be guided in the same way. As the conditions of the field and the crops are known at any place and at any time, an optimal process can be realised by predictive machine settings.

For sure, the presented concept has to be discussed critically. And like always for new concepts pretended arguments for a missing feasibility can be found easily. Diverse aspects like acceptance and safety issues have been addressed in the paper. It could be claimed economic calculations or greenhouse gas balances or life cycle analyses are missing. That can be done in future; the target of this paper is not to run through a certain system in detail. By the example of the direct power supply via Center Pivots shall be shown, with innovative solutions agricultural engineering is able to give answers in their field of responsibility regarding the immediate questions about productivity increase, climate change and resource scarcity. And it shall be shown by a systemic approach the various challenges as well as the wide range of chances of innovative solutions become obvious.

Conclusions

For a sustainable agriculture productive and efficient as well as low emission processes are needed. The holistic view on the scope of duties ("process chain", "operating conditions" and "organisational processes") is mandatory. Future challenges are that large, that the evolutionary development of agricultural technology is still necessary but no longer sufficient in the form as it is done today. The development of innovative and site-specific solutions is necessary. The described concept based on an electrical supply is an option for agricultural systems meeting a lot of aspects for sustainability. The installation of a near-field electric infrastructure is an essential requirement even for different electric solutions. The description of an unorthodox solution presented in this article intends to stimulate the discussion and development of future agricultural systems.

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