Trends and new Technologies for Agricultural Machinery

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1. Situation, Challenges and Limits

Technology has played a crucial role in farming history to secure stable production of food, feed, fuel and fibre. Looking back in history, two prominent examples of technology and science progress have made the impact obvious: The mechanisation phase (transition from horse to tractor) and the green revolution (adoption of new high-yield varieties, chemical fertilizers, irrigation). As the focus has changed in many countries from pure food production to overcome hunger (in Europe after WW2) we see emerging prosperity triggering a next wave of demand in farming: changing diets, delivering renewable materials and producing feedstock for green energy out of our limited global farm land.

1.1. Situation

There are five major input factors shaping the overall land productivity: breeding, fertilizing, irrigation, plant protection, mechanization [1]. Not included here: the highly important downstream processes of post-harvest methods relevant for the overall delivery efficiency of agricultural products to consumers.

From the traditional engineering perspective, mechanization is the focus of equipment manufacturers. For decades and still today, mechanization as such and along with it the trend to increase performance and power of tractors, combines, implements and other machinery was a guaranteed success factor for more productivity, lower cost and commercial success. At the same time this development is fuelling structural change in agriculture to make best use of bigger machines on bigger fields. One could rephrase as follows:

Situation: larger equipment equals more productivity at lower cost.

1.2. Challenges

A broad set of challenges and risk factors drives the daily struggle of farmers: Extreme weathers and shorter time windows as results of climate change, market price volatility for agricultural goods, availability of skilled labour, erosion and soil compaction, weed control and pesticide resistances, traceability and reporting requirements of all kinds, maintenance of biodiversity, strong regulations in many aspects, food value chain management, financing, to only name a few and not mentioning tasks in the area of livestock and energy farming.

As we continue to deal with these on the demand and thus the productivity side of our farming practices in general, mechanization has changed its face and frame towards a much wider scope. Today we understand electrical and electronical systems, digital solutions, data driven features and sophisticated automation as part of the agricultural equipment engineering landscape. Looking at effectivity and efficiency from an ecological as well as economical perspective the balance between inputs (such as labour, seeds, chemicals, water, fuel, land etc.) and produced outputs as well as the impact of farming on the environmental and social systems it resides in has become more and more important. It all comes down to the excessively used term of sustainability.

To put sustainability into a tangible context, it is worth taking a look at the history of our farming practices and our species as such following the elaboration on the topic provided by Charles Merfield in the ASABE resource magazine: "Just a century old, industrial agriculture represents only 1 percent of the 10.000 year history of agriculture and only 0,05 percent of the 200.000 year history of Homo Sapiens. The average life of a species is a 1.000.000 years, which means that we need to plan for another 800.000 years." [2]. He concludes that our current farming practices are by no means sustainable to this scale. To be more realistic while at the same time not eroding the sustainability term his proposal is to take it in steps of 1000 years at a time. Balancing increasing global demand for food, feed, fuel, fibre with responsible execution in farming practice we can summarize into one statement:

Challenge: Sustainable productivity growth is the fundamental objective for farming.

1.3. Limits

Commercial benefit of increased equipment size was laid out based on reduced labour cost overcompensating for increasing capital cost while maintenance and fuel cost remain fairly stable across size and power level, **Figure 1** [3]. What does that mean for the future? Let us assume as a hypothesis, that this trend will continue in the decades to come. Looking back and correlating population growth to average relative machine weight and horsepower development delivers a surprisingly accurate alignment. Extrapolating this trend only for another one or two decades delivers eye opening consequences shown in **Figure 2.**

Based on this trend extrapolation it seems obvious, that there are very practical limitations of further equipment growth e.g. based on practical road transport, regulations on dimensions and weight but also increasing cost for e.g. mechanical design and structural adaption of further growth. We may run into a dinosaur problem. On top of that there are other aspects that require a critical assessment on the background of permanent machinery growth: There is a high financial burden and risk of huge single investments, key equipment up time risk as performance concentrates on single large machines, societal challenges on the subjective perception of large machines in our villages and on our fields, natural limits in precision and individual treatment possibilities for crops, little flexibility for varying applications, field and farm structures (especially for contractors), the impact on soil compaction, yield and required energy for tillage etc.

As the soil is the foundation for agriculture as we know it (and most likely will be for the foreseeable future, see chapter 3) it is worth looking briefly at the laws of growth in this context [4]. An example: The weight increase that comes along with a 10 % geometrical machine size growth adds up to a three dimensional growth of about 33 % (Length x Width x Height) and as such an over proportional growth need for tire sizes (Length x Width) to at least maintain the top soil contact pressure. As demonstrated by Söhne [5]. Even if we manage to keep the contact pressure constant, we still attack the soil in depth as the pressure bulbs expand over a wider cross-section area causing soil compaction and thus yield loss, degradation, water management issues and many more. Controlled traffic farming is seen as one answer, however it requires substantial efforts on machine side and for operations management to be successfully put into practice.

So while the public discussion is strongly focused on the challenges, opportunities and disruptions of digital systems, there is a very fundamental conflict looming on the horizon of the core machine hardware design:

Performance increase by growth of agricultural equipment is limited.

2. Paradigm Shift, Trends and enabling Technologies

2.1 Paradigm Shift

So what now? Are we curiously trapped in the success of technology optimization? To some extend this seems to be the fact. But technology becomes available just at the right time to enable new approaches and looking around in our industry and the farming community there are already fresh ideas to overcome current limitations. In principle it comes down to a change of perspective, to a paradigm shift in three aspects:

- Magnitude → Multitude

  Deliver further productivity and performance growth by sharing the workload across connected fleets of smaller machines and implements.

- Machinery → Agronomy

  Develop crop centric technology solutions instead of accepting compromises driven by conventional machinery design.

- Complexity → Simplicity

  Simplify design, machine architecture and platform variety. Reduce operator workload and interaction by moving lower level tasks to automation intelligence.

2.2. Trends and enabling Technologies

The big trends of technology in agriculture machinery are present in construction equipment, trucks and automotive industry as well – with some specific additional aspects but fairly stable overall for mobile off highway equipment and on highway vehicles: Connectivity (and all digital aspects), Automation (up to autonomy) and electrification (battery, fuel cells). As we see a broad agreement on the value and mid to long term benefits, there are opportunities and threats coming with it.

- Connectivity & Digitalisation

  Connecting items (machines, sensors, even plants and soil) to network infrastructure, collecting data streams, transforming data into valuable information and deriving informed decisions to support a given optimization goal is the generic approach of most digital features and services [6]. This is often combined with platform approaches that are characterized by creating more benefit the more participants connect (old world example: the telephone). Since development resources (invest, tools) are often lower and the innovation frequency is dramatically faster (IT cycles) this is a substantial chance for new players and business models coming along as competition to the traditional players. While disruption is often stated to be happening, so far there has not been a radical change in the way farming is done and some benefits have yet to be proven. Connectivity is the core technology to enable the paradigm shift from monolithic large machines to connected machine systems and fleets thus allowing collaborating teams of smaller units. Looking at risks there are two major aspects: creating standardized data and data exchange formats as well as assuring reliable and full network coverage.

- Automation & Autonomy

  There are four generic steps framing the logical development order as follows: 1: Creating **transparency** by installing sensor systems to machines and displaying information that was not accessible before to the operator (examples: a front camera system or an ultrasonic distance sensor). 2: **Assistance** systems by linking sensor information to expert knowledge and making optimization proposals that support the operator in the given task (examples: gear shift recommendation or light bar guidance). 3: **Automation** of processes where optimization proposals are linked to actuators of any kind thus are being executed without operator action other than strategic setting (examples: GNSS auto guidance, tractor-implement-management). 4: **Autonomy** to include strategic intelligence and complete perception to deliver driverless solutions. A high level of process automation and driverless operation is the prerequisite to allow smaller vehicles to become commercially viable since it takes labour cost for all units in a large fleet of connected machines out of the equation, **Figure 3**. Also the goal of plant specific treatments (goal: agronomy centric) can only be achieved at the required performance level with automated systems. However the commercial benefit of autonomy for traditional equipment is very dependent on the task and region (availability of human labour, major cost drivers of the specific farm or crop etc.). Societal impacts of autonomous systems on the other hand are being critically discussed. Copying arguments and technologies from automotive applications is not possible by large as use case and environment are very different, processes as such need to be automated (beyond driving and steering) as well and there is no possibility to back delegate as systems may come to critical situations (no driver present anymore). Finally again the removal of the operator cannot be the only goal – autonomy gives us the opportunity to enable better agronomic processes around the crop cycle on the long term and this potential needs to be addressed (e.g. reducing chemicals, water and seeds, protecting soils, developing cropping systems to more sustainable strategies etc.).

- Electrification & Fuels

  Electrification is widely seen as an obvious development trend, broad adoption being just a matter of time for diesel-electric architectures, electrified implements and smaller battery electric vehicles, **Figure 4** [7]. Benefits like reduced local (long term also global) emissions, machine noise, oil leakage and cost of energy are just the obvious benefits. Beyond that the controllability, durability with little maintenance, precise controllability, perfect integration into a world of connected, digitally controlled processes, support of decentralized renewable energy grids and not at least handling comfort (e.g. tractor implement connection) of electrified drive systems are clear arguments. However to fully embrace the potential it will be needed to rethink agricultural process opportunities and purpose design vehicle architectures beyond replacement of hydraulic or mechanic drives. Full electrification with batteries as an energy source is so far only viable for small agricultural machines due to cost and performance limitations. In the context of the claimed paradigm shifts, electrification supports simplification (driveline, maintenance, control, architectures) and in the best sense complements smaller equipment. One of the crucial challenges of electrification (besides cost of components) is and will be to solve the raw material supply chain (copper, cobalt, lithium, rare earths, …) and develop a sustainable circular economy. Future fuels (e.g. synfuels, gas, hydrogen) will play a role in the overall energy systems to achieve greenhouse gas reductions, mainly since they enable sector coupling (electric power grid, mobile energy, heat) while at the same time delivering more dense storage then battery systems for large machines in the foreseeable future.

3. Opportunities for the Future

So while we are still a long way from a broad market acceptance and commercial viability of fully electric, autonomous, connected and small machines, there is already more to come on the horizon and by a large extend the mentioned technologies will serve as enabling platforms for further steps or even disruptions:

- Controlled environment agriculture (CEA)

  The traditional form of a CEA system is a greenhouse but also plastic covers of row crops are simplified CEA systems. High tech CEA approaches include fully robotized indoor growing facilities of large scale e.g. as hydroponics or aeroponics. Sophisticated CEA concepts allow the permanent control and optimization of various growth parameters for the crop like light, nutrients, water, carbon dioxide concentration, temperatures etc. [8]. As of today not all crops are commercially viable for CEA and the facilities typically require a significant amount of energy input for heating, ventilation and lighting (LED). However, CEA has a high potential in producing fresh, local food with optimized water and nutrient supply, reduced pesticide use and multiple harvests a year. It is obvious that CEA at a relevant scale would have a significant impact on the traditional farm equipment market, since e.g. typical tractor-implement units or classic combine harvesters are not suitable nor needed in fully automated, hydroponic indoor crop production systems with installed robotic infrastructure for the whole crop cycle.

- Robot swarms

  Simplification and size reduction of conventional farm equipment while maintaining basic architectures (e.g. tractor-implement combination) and standards (e.g. interface design like PTO, hitch) have a high potential as detailed above. Looking further down the road, the future machinery generation for light duty and high precision tasks are autonomous, driverless, robotic platforms of small size (on the ground or in the air) collaborating as swarms with a centralized or decentralized intelligence [9]. The term "robotics" may have a certain flavour of science fiction, but looking at practical and even already commercial examples it comes down to rather simple and streamlined design: A chassis, an (electric) drive system, an application specific module and a sensor set, just enough to fulfil the required task. Today, robot companies are mostly targeting labour intensive, dull but tasks with a requirement for constant precision (e.g. mechanical weed control [10], spraying, seeding, vegetable harvest). The currently stable and successful business with conventional agricultural equipment limits the appetite for significant change of products and business models. However, looking at the potential of driverless robot systems impressively proves why ignoring this opportunity may be a high risk: little energy consumption, negligible soil compaction, precision and 24/7/365 operation to name a few.

- Artificial Intelligence and Machine Learning

  As of today, control design for machine modules and machine systems are mainly designed based on a priori expert knowledge (e.g. steering control for guidance, transmission control, …). This naturally comes with the inherent limitations defined by the available input knowledge in the design phase and ability to predict and sense relevant influence factors. Going forward, machine learning will enable system and process controls that improve (learn) as they sense varying inputs and outputs in different context situations while operating in the field over the lifetime of a machine and beyond. A natural challenge that comes with this human-like self-learning capabilities is the non-deterministic nature of this approach. The control algorithms can virtually learn any kind of behaviour and measures need to be taken to appropriately guide and limit this artificial intelligence according to safety needs and ethical agreements. The internet of everything (IoE) combined with powerful communication networks (5G) will allow to include more context information of given tasks and applications in the field (e.g. concerning weather, plant, soil, …), process data remotely (cloud) to actionable information and update machines over the air as better algorithms or new features become available.

4. Summary

Sustainable productivity growth is the fundamental objective for farming. Until today, the trend to larger equipment is driven by productivity increase at lower specific cost. However performance increase by growth of agricultural machinery will face limitations. A change of perspective (from magnitude to multitude, from machinery to agronomy, from complexity to simplicity) can open new opportunities and trigger fresh thinking for a next generation of equipment solutions.

Connectivity & digitalisation, electrification & future fuels as well as automation & autonomy are the major current technology focus areas in the industry. More radical approaches like e.g. controlled environment agriculture, robot swarms and artificial intelligence are on the watch list for future opportunities.

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FIGURES

Figure 1 - Tillage process cost for different machine/implement size combinations (non-autonomous). *Source: [3] modified.*

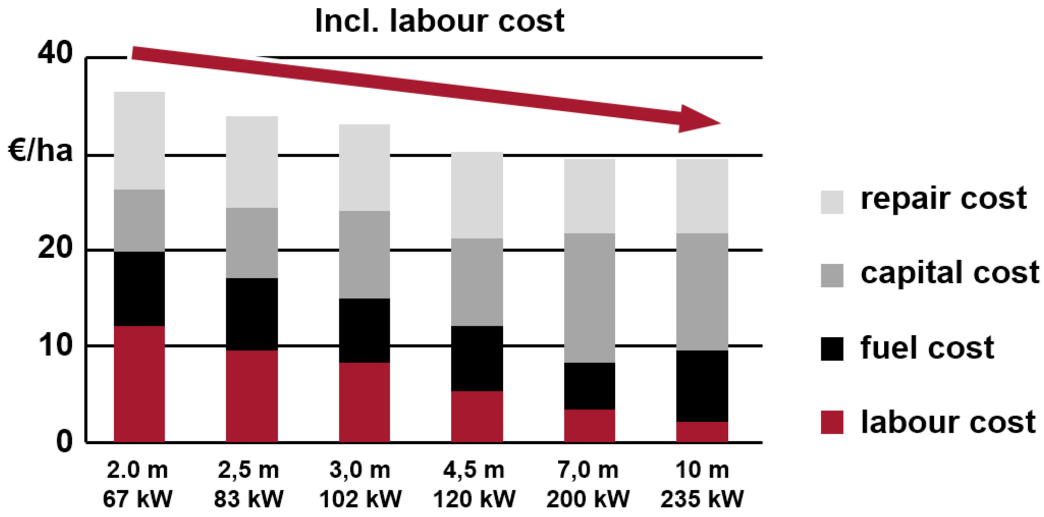

Figure 2 - Agricultural equipment in 2030? Extrapolation of a continued further machine weight and power growth. *Source: [11]*

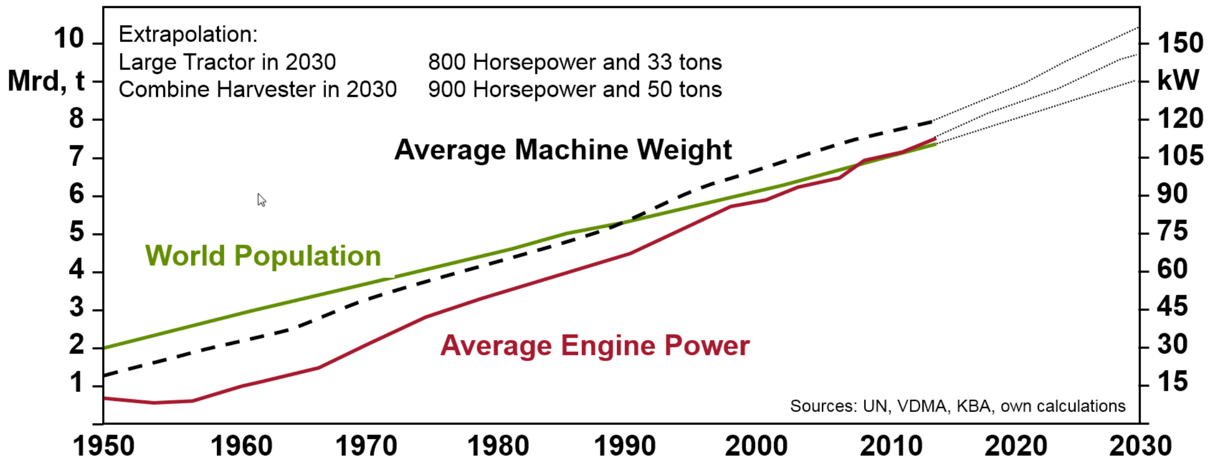

Figure 3 - Tillage process cost for different machine/implement size combinations (autonomous). *Source: [3] modified.*

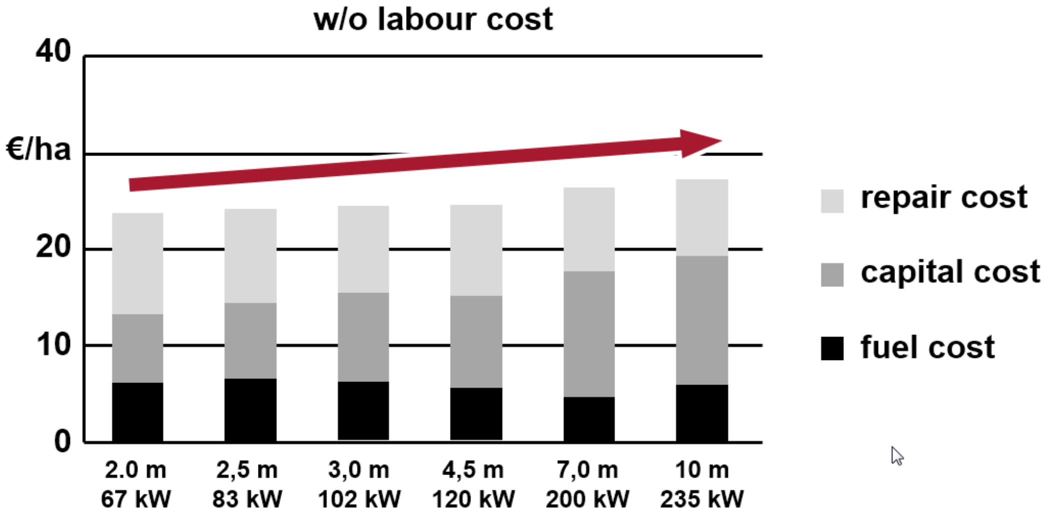

Figure 4 - The AGCO / Fendt e100 battery electric utility tractor with 50 kW rated power and a 100 kWh li-ion battery pack.