Concept Study of a Modular and Scalable Self - Propelled Implement System

Limitations of current Tillage and Seeding Tractor – Implement Systems and Vision of future Technologies

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Abstract

Besides minor exceptions, the processes of tillage and seeding have not moved towards self propelled concepts, as it has happened for grain harvest and partly for forage harvest operation. High performance machine tractor – implement systems today establish productivity by growing increasing working width and higher operational speed supported by larger storage volumes and increased tractor power availability causing weight and dimension start to be a major limitation. In conjunction with the continuously increasing size of farm machinery, the problem of soil compaction is aggravated causing increased power and energy requirements and increased CO_2 emissions. Regarding function and information processing technologies, tractor and implement are continuing changing in regards of function and information processing technologies into integrated processing systems, which will make future tasks of biomass production, farm internal and external process documentation and strongly improved resource sustainability economically manageable. The idea of a modular and scalable self-propelled implement system tries to address the above mentioned challenges with the goal to deliver configuration capability regarding actual task, field conditions and farm infrastructure providing greatly increased scalability of peak performance, productivity and economy. Two major and very different approaches in defining future technology are discussed: The implement focused approach where the tool sections, drives and frames are segmented and the tractor focused approach where the tractor becomes modular in regards of power and traction capability.

Current Situation

Agricultural mechanization is characterized by an enormous growth rate in productivity, which is probably unprecedented compared to other areas of industrialization during the last century. This growth has been triggered from the availability of combustion engines in the beginning and always benefited from incorporation of technological advances primarily developed for other industries. Introduction of synthesized fertilizers gave another boost to the growing output per area, which drove the implementation of self propelled specialized machines breaking with the traditional tractor – implement configuration supported by growing power density of engines and higher strength materials. With minor exceptions the processes of tillage and seeding have not moved towards self propelled concepts yet (Figure 1).

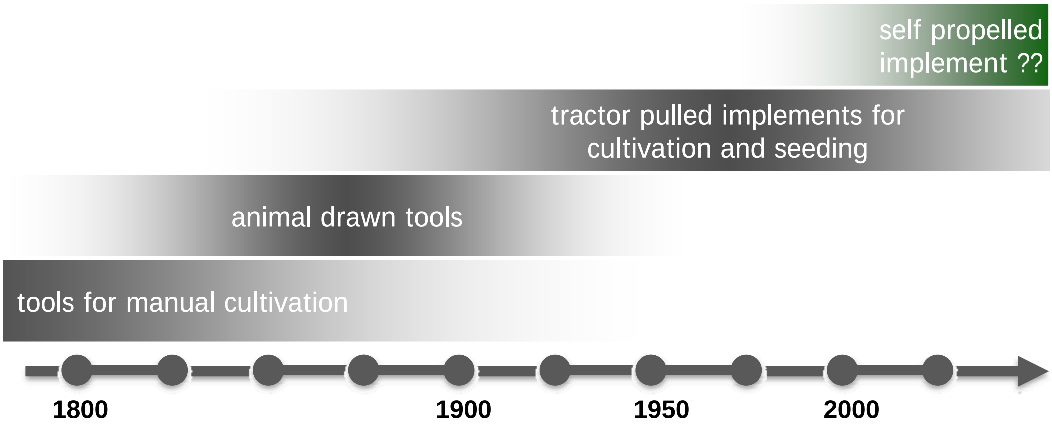

Figure 1 Evolution of tillage and seeding tools and technologies.

Today genetic engineering and automation of machinery systems have started the next level of productivity growth leading to different variations of precision agriculture and smart farming. Awareness of limited resources and reduction of greenhouse gas relevant emissions is starting to put pressure on farm business and machine manufacturers to re-organize the total system towards sustainable low-input and high-efficiency agriculture. The trends affecting future agricultural development can be summarized as follows [1]:

- increased risks of soil degradation and competing uses of soil,
- movement to commercialization and existence of global markets,
- focus on ecosystem services and application of genetic engineering,
- increase in farm size and changes in social structure.

High performance machine systems today establish productivity by growing working width and higher operational speed supported by larger storage volumes and increased engine power (Figure 2). Therefore weight and dimension have become a major limitation specifically in the highly developed farm operations in the European Union and North America. Negative effects of increased machinery size are partly compensated by using larger tires, additional axles or even track undercarriages.

Reduced field travel due to reduced number of field operations doing conservation tillage and increased working width of the machines have also rather positive effects. New operational concepts like no-till / strip-till or controlled traffic are being successfully tried, however they are not universal enough to provide a general solution [2]. One of the main specific challenges in today's industrialized and highly productive environment is to sustain the soil as the growth medium for biomass. Soil compaction is one factor that deteriorates soil quality as a

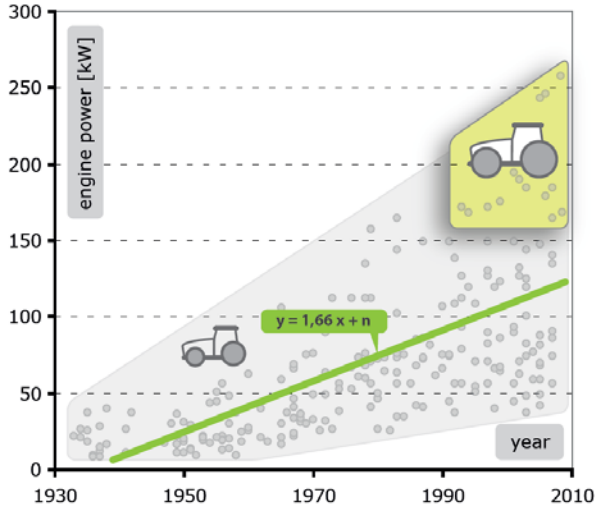

Figure 2 Evolution of tractor installed engine power

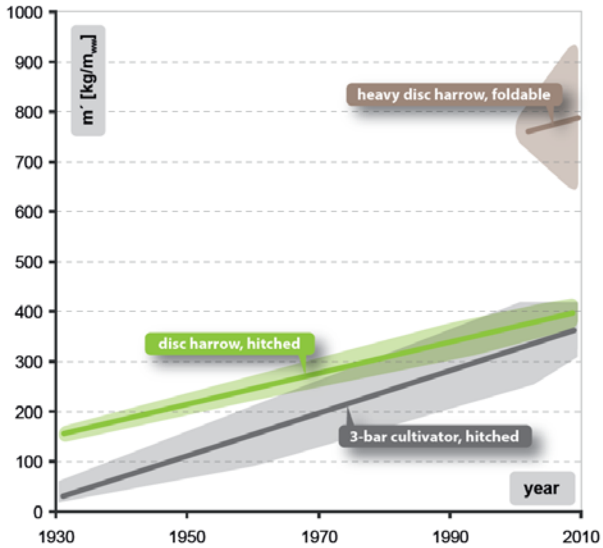

Figure 3 Weight per width of tillage implements

growth medium [3]. With the continued increase of size of farm machinery (Figure 3), the problem of soil compaction is aggravated causing increased power and energy requirements, increased CO_2 emissions, difficulties in seedbed preparation, plant emergence and growth during the growing season, and eventually reduced yields [4]. Topsoil compaction is more influenced by the peak contact stress and without any cultivation, topsoil compaction effects can be measured up to 5 years [5]. Subsoil compaction is mostly related to total axle load. In the upper subsoil (~35 cm), the natural recovery from compaction is very slow if it occurs, the compaction below 40 cm is even considered persistent [6] and leads to the risk of yield depression over a longer period [7].

Limits of current technology

The continuous weight increase of all machines and implements (Figure 3) and the tendency to use machinery in critical soil conditions to increase usage hours have raised the risk of soil compaction. Higher implement weight is an unavoidable consequence of wider machines at higher structural loads due to higher operating and transport speeds and additional efforts of folding mechanisms. Not only did the weight of tractors increase, but they also need additional ballast to be capable to transfer their available engine power into draw bar force [8]. Cultivation and seeding tractor - implement systems have to find solutions for the following challenges:

- Speed equals productivity: Typical speed in operation has doubled in the last 50 years, which is energetically unfavourable, creates respectively more wear and utilizes tools beyond their optimal range. The effects are shown in Figure 4. Coefficient ***e*** is considered constant in the model, but is to be expected that it grows for higher operating speeds beyond the 10 km/h, which makes the parabola even steeper.
- Operating width equals productivity: The growth in width lowers specific power consumption and is favourable for the quality of seeding and seedbed preparation but it adds weight and compromises manoeuvrability. Even bigger problems are all the additional efforts to maintain transport width.
- Draw bar force requirement: The three point hitch has been enlarged to category four by now and seems to be at its final limit. Heavy implements cannot work without their own supporting wheels and use the adjustable drawbar. Tractors are getting more and more front ballast weight to balance axle loads in operation, which increases soil loads in general and rolling resistance if not in operation.

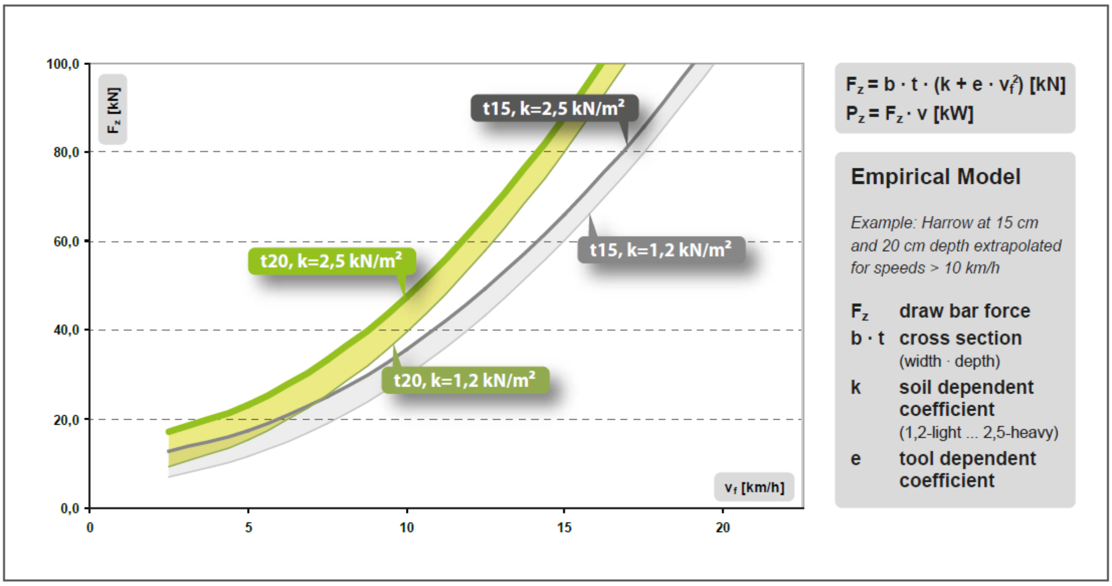

Figure 4 Operating speed and draw bar requirements

Development history of tillage and seeding tools & technologies

Usage of ploughs has been known since the beginning of civilization as the primary cultivation process, featuring the ability to turn around and mix topsoil to control weeds, prepare a suitable seed bed and bury surface crop residues. As tractor power became available in the 1930s, implements started to grow in width and operating speed – a tendency which still characterizes implement development today. Starting in the 1970s, combination of tillage and seeding without ploughs evolved into conservation tillage where mechanical cultivation has been partly substituted by herbicides. In certain conditions, some cropping systems even manage direct seeding with no-tillage, which delivers a maximum decrease of investment cost, fuel consumption and the amount of required labour. At the same time, no-tillage increases the campaign performance, resulting in a very powerful cultivation system [9]. The 1990s brought increased power density of electronically controlled tractor engines, power shift gearboxes and CVT technology, which allowed new growth rates of implement operating speed and width. As a result, foldable implement concepts were created with the result that greater structural loads required higher strength material in combination with a much better understanding of load cases, which drove sophisticated solutions for structural components.

Definition of concept objectives

Constraints in physical dimensions are reached today and legal restrictions as well as additional guidelines to be expected keep driving system cost up. The growth in installed capacity in a machine or a given combination of machines is counterproductive in regards of flexibility of the system and scalability of capacity. The idea of a modular and scalable self propelled implement system tries to solve above mentioned challenges with the goal to deliver

- configuration capability regarding actual task, field properties / conditions and farm infrastructure by providing the ability to configure width and / or depth of combination of implement functionality as well as the power supply related to the actual task,
- scalability of peak performance, productivity and economy.

Technology enablers like multi axle navigation control, electrification of drive trains, composite and function integrated materials, plant and soil sensing with its respective mapping technologies or cloud computing based process management and processing of big data have affected and will change the nature of field operations towards more automation with the objective of better utilization of all given resources. Specifically with electrification, it becomes possible to completely rethink the tractor – implement domain to

- reduce the required traction force of tractors by using distributed drives on implements allowing speed variable active tools or single driven wheels up to a level where an implement does not create any force requirements at its connection points for traction and navigation anymore and becomes virtually self propelled, relying only on an external power source and communication with the fleet,
- have modular power sources based on tractor power and auxiliary power modules,
- significantly increase the degree of automation of implements with the ambition that the resulting increase in productivity and resource protection fully amortizes the additional system cost for such modular systems.

Concept Vision

Not only engineers started to think about alternatives besides the obvious trends of STRONGER, FASTER, WIDER or BIGGER. The evolution process, which agricultural technology will face, has profound implications on the future design and functionality of tractor – implement systems and their ability to interact with soil and plants environmentally sustainable and economically efficient. The next decades will see known agricultural concepts shifting towards highly automated, flexible operating machine systems with hybrid power sources and distributed drive architectures. In the long perspective, research shows that a paradigm shift from large machines to smaller and more intelligent multi-robot systems is expected, which can establish and nurse plants even at an individual level [10]. Figure 5 visualizes the relationship of customer value / productivity and general system cost.

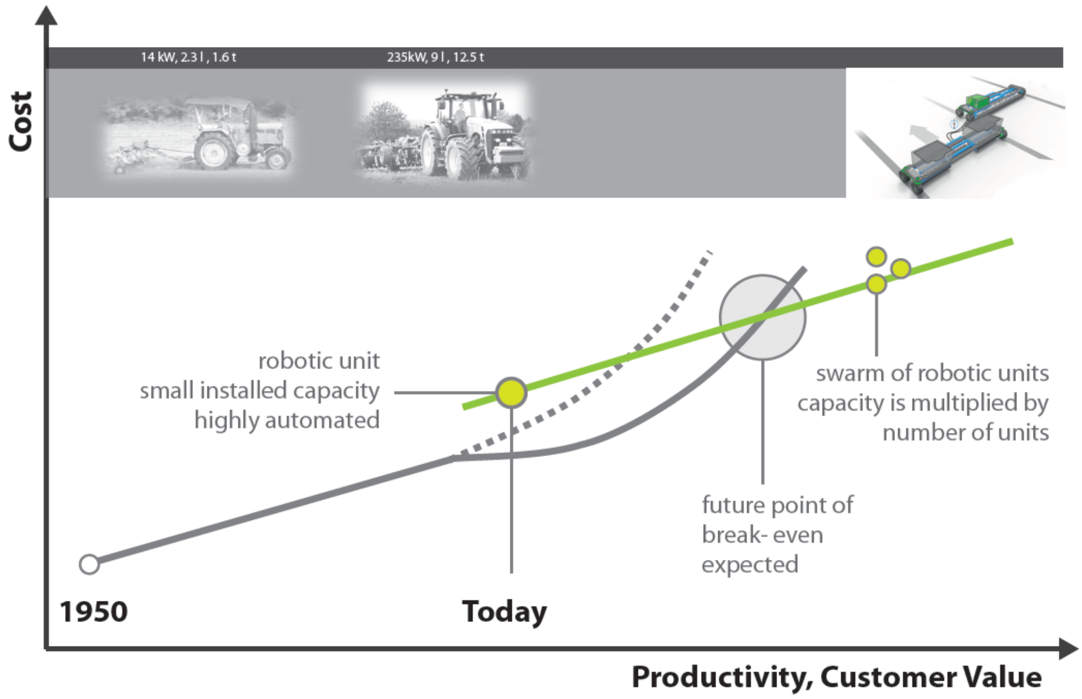

Figure 5 Evolution of tractor-implement systems towards robotic swarms

The additional efforts to cope with the reached constraints in physical dimensions and legal restrictions while still delivering value growth drives system cost of known concepts faster than they used to be in the past (dashed line). This trend is currently balanced by increasing system efficiency and new features both mainly driven through automation. Machine systems utilizing robotic concepts are not economically viable today, however, a future point of break even is expected where the value increase is delivered by system flexibility and adjustable capacity delivered by a number of modular units (swarm).

Modular Implement Versus Modular Tractor

Focusing on future challenges and technology trends in agricultural industry, an engineering group from the Institute of Processing Machines and Mobile Machinery met for a brainstorming together with the Center for Industrial Design Engineering at the TU Dresden and the Fraunhofer Institute for Transportation and Infrastructure Systems IVI in order to search for possible answers. A very specific and creative potential was established by merging engineering experience in agricultural technology development and the holistic approach of the industrial designers, who emphasize the connection and interactivity of design, ergonomics and functionality. As intended, the brainstorming lead to two major and very different approaches in defining future technology:

- The implement-focused approach where the tool sections, drives and frames are segmented and deliver defined, standardized interfaces where they connect to each other and to the supporting components like storage and distribution of fertilizer and seeds and the automation components comprising sensors, controllers and actuators.
- The tractor- focused approach where the tractor becomes modular in regards of power and traction capability.

Approach Modular Implement

Figure 6 shows the modularized implement in field and transport mode in its Controlled Traffic Setup featuring 9 m units.

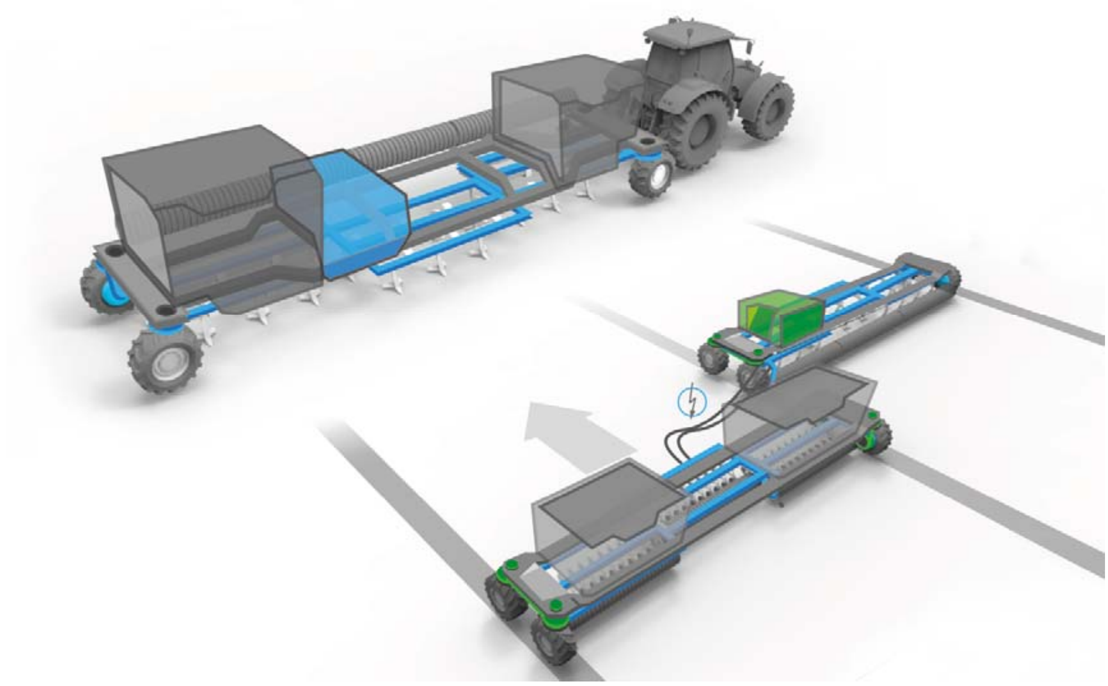

Figure 6 Concept study modular implement

Active and passive segments of tools are exchangeable. The wheels are used for transport, depth control and traction support. In combination with active rotating tools, traction and navigation can be executed mechanically separated from the tractor, which stays the centre for the operator and supply of energy. Additional power needed for wider tillage or combination of several stages of tillage and seeding operations in one pass is available through power modules generating electrical power using fuel cells or converted from combustion engines.

Approach Modular Tractor

Figure 7 shows the modularized tractor, which is segmented into operator station and the power / traction modules that can be connected with the cab module and deliver different levels of power and traction capabilities from the single wheel axle up to a tracked tractor.

Figure 7 Concept study modular tractor [11]

The cab module has electrical single wheel drives that are also capable to work in a "Segway"- mode to mobilize the module.

Next Steps

The manifest contradiction of the two approaches shows that such fundamental changes in machine system concepts cannot be executed without a valid proof of the idea regarding all objectives and requirements of future farms. It is an iterative process to establish concept ideas and determine their ability to respond to all challenges including the profitability of farm operations. In order to characterize concepts in their strength and weaknesses, it is necessary to

- develop a simulation methodology of tractor - implement systems, which is sufficiently able to describe the farm operation regarding business management, resource impacts and functional criteria including a description of logistical tasks and their impact on cost,
- create a design methodology for description of alternative system concepts,
- assess sustainability factors and responding values (ecological, economical, social),
- investigate the need, scope and complexity of automation supported by drive technology and navigation,
- investigate the need of alternative materials for lightweight structural design.

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