BOOK OF ABSTRACTS

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ORAL PRESENTATIONS

POSTER

HOW AUTOMATION INCREASES THE PRECISION AND EFFICIENCY OF THE FEEDING PROCESS

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Feed represents the largest cost when it comes to milk production. Good feed and controlling the feed costs are very important for the success of a farm. Dohme (2008) discovered in his research among 47 herds that milk production can vary by up to 13 litres of milk per cow per day. 56% of this difference is caused by factors that have nothing to do with the genetics of the cow or the composition of the ration. This means that 7.28 litres can be directly attributed to other factors such as feed frequency, feed pushing, the length of feed fence etc. Besides production, the feeding strategy has also a significant impact on animal health, fertility, production and the financial results of a farm. Therefore, farmers need to ensure that their cows utilise the feed in the best way possible.

The last decennia, milk production has more than doubled due to selective breeding, improved herd management and feeding cows easier fermentable feed. They get more than half of their energy requirements from fatty acids that remain after fermentation of carbohydrates. But cows can't digest the feed all by themselves. They need the help of thousands of different types of microbes to digest the sugar, starch, fibre, and protein in their feed. When cows eat a large quantity of rapidly fermentable feed, the rumen pH level can drop tremendously. This can cause sub clinical rumen acidosis, which damages the rumen wall. The forage passes through the rumen too quickly, as the bacteria that ferment the raw fibres are inactive if the pH level is too low, resulting in poor digestion of roughage.

A cow prefers to eat throughout the day. 10 to 14 meals per day are required for an optimal health and production. By eating more often, the pH level in the rumen remains stable, allowing the cow to make optimal use of nutrients in the feed.

Feeding more frequently and pushing the feed regularly, encourages cows to come more often to the feed fence to refill the rumen. By offering smaller portions, the possibility of selecting feed is reduced. This too has a positive effect on the stability of the pH value in the rumen. In addition, more frequent feeding results in fresher and tastier feed at the feed fence, which is also beneficial for the dry matter intake.

When feeding and milking are more spread out during the day there will be no large eating peaks. By automating the repetitive work of feeding and feed pushing, the frequency can be increased without adding labour. A milking robot ensures that cows can be milked any time a day. Therefore, automatic feeding is a perfect combination with robotic milking.

But a cow needs more than a higher feeding and feed pushing frequency. Sufficient space at the feed fence and comfortable cubicles for ruminating are, for example, of great importance for a healthy eating behaviour.

Precise feeding is also important for optimal cow health. Calculating the right rations requires time and attention from the farmer as well as their feed advisor. Each group of cows - depending on the lactation phase - has a different feed requirement. The ration must be adapted to the needs of each individual animal group because the energy requirement of high productive cows is not healthy for low productive cows. Dry cows and youngstock have also different nutrition needs.

Frequent feeding and feed pushing of a precise ration that fits the needs of a specific animal group has many benefits but is practically not feasible as it will mean a tremendous increase in labour requirements. That is why we at Lely developed the Vector automatic feeding system. This system is not developed to automate the current feeding process – this would only result in labour savings – it is developed around the feeding requirements of ruminants.

The Lely Vector pushes the feed for optimal accessibility. It measures the average feed height during feed pushing and distributes fresh feed when and where needed. By adjusting the feed supply to the eating speed, there is never too much or too little feed in front of the feed fence. Even when cows are allowed to graze outside.

Automation also brings more precision in the feeding process. With smart and exact software, the Vector system can compose a ration with an accuracy up to 98%. This means that the actual fed ration corresponds very well to the calculated ration. Because small portions are fed, the feed is fresh and tasty, the possibilities for selection are very small and the rest feed is almost nil. As a result, the rations that have been eaten are very similar to the fed ration.

Cows tell us if whether they are healthy or not and whether the food is right. It is important to have that insight to be able to act quickly when necessary. Planning, monitoring and adjusting should be a daily routine. Should a cow eat more often or eat differently? How can the ruminating behaviour be influenced? Each step should lead to an optimum in feed efficiency between 1.5 and 1.7. Everything above or below it is sub-optimal. By combing the data from our feeding system with the data provided by our milking robots, farmers can easily see the results of their feeding strategy.

Frequent pushing, feeding and an accurate ration ensure that animals utilise the feed as efficiently as possible. This is not new. In fact, many people are already aware of this but there are only a few who can realise this on farm level.

No matter how efficient we make the feeding process, the animals will produce manure. About 70 liters a day! This manure is applied to the field to give back the vital minerals that crops use to grow. The crops are turned into feed for the cows and, on their turn, cows turn the feed into milk, meat and manure.

This is a circular process but there is a problem; the manure also creates emissions, which is a loss of minerals. The minerals that leave the farm via the milk and meat also need to be compensated with feed import and artificial fertilizers. Therefore Lely started investigating the possibilities of an easy to manage and profitable solution for on farm circularity. A precise use of the minerals will increase the value of manure for the farm.

We believe that automatic feeding and a smarter reuse of the minerals in manure perfectly contributes to our vision; a sustainable, profitable and enjoyable future in farming.

SMART SENSORS AND SENSOR SYSTEMS FOR HIGHLY AUTOMATED AND AUTONOMOUS MACHINES

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Presentation Smart Sensors and Sensor Systems for highly automated and autonomous Mobile Machines.

- Focus of the presentation is the segment Mobile Automation (Agriculture-, Construction and Mining Machines, Special Vehicles).
- Transfer of the known automation levels from the automotive industry to the off-highway machine industry.
- The presentation will relate the automation steps of mobile machines with the requirements for sensors and systems. Demonstrated on practical examples. Derived from application requirements, the presentation will show sensor developments, specially in the field of environmental sensing (LiDAR, Radar, Vision Technologies).
- The developments up to the autonomous mobile machine are subdivided into subsegments:
  - Sensors for Motion Control,
  - Sensors for Environment Perception
  - Sensor Systems
  - Connectivity
  - Safety Sensor Systems

FUTURE FARMING

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My presentation serves at pointing out the rapid and oftentimes dramatic changes that we observe in our surroundings. I will shortly share with you examples of change in both a Danish and international context influencing agriculture and the food system.
The changes challenge farming practices with a pace we haven't seen before. Changes in customer market demands, regulation and technology leaps are both threatening in the short run and opens up for longer run opportunities for the farmer when it comes to producing new products demanding a higher value as well as new farming approaches and technologies.

Working for a farmer-owned innovation center it is in my opinion essential that we ensure knowledge sharing across the information value chain including universities, businesses, advisors and farmers.

Specifically, I'll show examples on how using high resolution cameras and sensor technique result in higher yields with less effort and at the same time contribute to farming practices for a more sustainable production.

In 2017 SEGES established a *Think Tank* for fueling business development called Future Farming. An initiative launched to continuously identify, qualify and leverage thinking and concepts reaching beyond five years plus. Future Farming is aimed at releasing long-term business potentials beneficial to the entire agro value chain.
An advisory board composed of leading company representatives, researchers and farmers and a group representing the millennial generation with people from within farming, academia, communication, digital and NGO's

Finally, I will point out actions representing the most promising market potentials according to the Think Tank Future Farming.

SEGES

SEGES is Latin for "Crops" and "value added". SEGES offers solutions for the agriculture and food sector.
Our prime objective is to identify the commercial potential in agriculture to provide Danish farmers and horticulture with the best tools for running their businesses more profitably and in a way, that takes into account the environment, the employment of resources and animal welfare.

SEGES covers all aspects of farming and farm management - from crop production, the environment, livestock farming and organic production to finance, tax legislation, IT architecture, accounting, HR, training and conservation. This is carried out in close partnerships with universities, government departments, businesses and trade associations.

Facts about SEGES:

- We perform more than 1,000 on-field trials every year. We strive to develop the best possible cultivation methods under different conditions.
- Our professional database, LandbrugsInfo, comprises of more than 120.000 articles for sharing on-field and live-stock trial results and analyses as well as clarification of regulations
- We carry out research and development projects on pig farms. As an example, SEGES also runs the Laboratory for Pig Diseases and the SPF Health Control. Another important business area is DanBred where SEGES - in close partnership with pig producers - work to ensure maximum breeding results and the application of the latest and best technologies.
- We develop and operate the popular and unique accounting program Ø90, which provides 37,000 farmers with an accurate overview of their financial situation. We develop, maintain and support many other IT tools used by farmers, including programs designed to manage cattle, pig, and crop production.
- We collaborate with the dairy and meat industry to develop and improve Danish food products. And we are involved with projects that identify competitive production methods and optimize on food quality.
- We employ around 650 people across Denmark. At Agro Food Park near Aarhus, at the Danish Agriculture & Food Council based at Axelborg in Copenhagen, and at laboratories and research farms in Jutland.
- SEGES turnover amounts to around DKK 1 billion per year (EUR 135 million).

STRAWBERRY HARVESTING AND TRANSPORTATION ASSISTANT ROBOT

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Keywords: mobile robot, harvesting efficiency, ergonomics, motorized wheelbarrow.

Strawberry automated harvesting task still very hardly goes for automation attempts. Existing solutions are complex, expensive and require additional investments in farm infrastructure, e.g. stable flooring, organisation of plant rows so that robot can navigate between them and reach the berries and precise position of plants themselves. Moreover capabilities of current AI progress in localization and evaluation of ripening level allows recognizing and collecting only up to 50 % of berries that should be harvested, whereas human worker can reach 90 % efficiency.

Besides finding and picking up the berries, there is a lot of room for improvement of the harvesting process. The strawberry harvesting performed by human workers can be decomposed into several stages including recognition and pickup of berries, heaping them in transport boxes, bringing the boxes out of plant rows when full. Carrying the boxes during harvesting takes time that could be used to search and pick-up berries thus decreasing efficiency of costly labour. Also additional carried weight especially when bended can result in severe problems with musculoskeletal system of human workers. In this study we propose mobile robotized system to target this issue.

The aim of the research is to improve strawberry harvesting process by using automated yield transfer from human workers out of the field. The concept can be summarized as follows. Mobile assistant robot is capable to follow human in strawberry plant rows keeping given distance from worker, carry crates and when necessary autonomously bring them back to beginning of row where it can be unloaded by another worker. Motorized wheelbarrows widely used in horticulture, construction, farms etc. served as inspiration for this design.

The mechanical construction is formed as a four-wheel base, divided into two drive modules each consisting of DC motors and gearing for two wheels. Each driving wheel has one 350 W brushed DC motor at nominal voltage 24 V. Motors have built-in spur gear transmission with ratio, motor axis and wheels are coupled by means of chain transmission resulting in the total gear ratio of 1:39, 40 Nm and 76 rpm on the axis of wheel. Maximums speed of robot is 10 km/h. To enable the robot to maneuver, different speed is set to wheels on each side. The drive modules are electrically independent and are mechanically connected with frame between them, this allows easy modification of robot base width to adapt various widths of plant rows. Space between the drive modules is dedicated to power source (battery unit), control system module and berry crate mountings. Power source is made using two 40 Ah lead-acid batteries connected in series for 24 V system. Using current battery set-up the robot can go on asphalt road at the maximum speed of approximately 0.5 h. Self-weight of the robot is 100 kg, payload is up to 200 kg.

At the current stage of development the robot acts as a remotely-controlled platform with work is in progress on image recognition subsystem allowing to follow strawberry rows autonomously and on human-following functionality. Plant row recognition and robot's relative position determination are performed using binary frame merge and Hough transform. This was possible because strawberry plants leaves have good contrast with fine grass or black protective film background. Complex AI algorithms were not involved as a result all image processing can be performed by a Raspberry PI class single board computer. Implementation of human-following subsystem consists of two parts: determination of angle to target user and keeping the given distance. Studies of related researches showed that it is hard to reliably determine the position of human user to be followed using only computer vision, especially in crowds and adverse weather conditions (direct sunlight, tusk). In this project we use radio beacon and signal strength measurement approach to solve this problem. User has radio beacon with omnidirectional antenna, but robot uses two receivers with directional antennas with narrow patterns. Angle to the user is determined by received signal strength difference. For both beacon and receivers a low cost solution based on nFR24L01 radio IC was used. This also allows to use radio channel for sending additional remote commands to the robot. Distance to the user is controlled by ultrasound sensor.

Performance of the developed platform allows to use it also in transportation tasks in other fields e.g. livestock farming, construction, forestry.

ROBOTIC ACTIVITIES AT NIBIO'S CENTER FOR PRECISION AGRICULTURE

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Keywords: Unmanned Ground Vehicles, visual steering, precision fertilizer

Precision Agriculture (PA) is about using new technology to adapt the treatment of soil and plant growth by demand, which often varies widely within the same field. This concept is thus an alternative to conventional farming, in which each field is treated uniformly. By means of PA, we may for example perform spraying (weed- and disease control) and apply fertilizers and lime at variable rates according to the site-specific requirements. These requirements are mapped by putting together information from many sources, in which detailed data from various sensor systems, spectrally enhanced cameras and global navigation satellite systems (GNSS) play a central role. Such equipment can be mounted on tractors, autonomous robots (unmanned ground vehicle, UGV), drones (unmanned aerial vehicle, UAV), helicopter and planes, and on satellites.

Our Center for Precision Agriculture (CPA) was established in August 2016 and is situated at NIBIO Apelsvoll in Kapp in Østre Toten community in Norway. The purpose of the CPA is to contribute to a resource-efficient and sustainable agriculture by shortening the time-span farmers need to adopt new agricultural technology.

We have utilized autonomous robots for increased efficiency in measuring campaigns in our field trials, related to several projects. This has been obtained by mounting multiple sensors on the robot platform, and utilizing RTK-GNSS based navigation for repeated measuring routines. In addition, we develop and adapt solutions for the automation of work-demanding manual farming tasks, in particular within the horticultural sector. In the past we have developed a prototype for robotized harvesting of snap-sugar-peas, and are now working on a harvester for raspberries. An area under expansion is the use of larger, more tractor-like robots for field operations with reduced soil compaction.

Another area were we use robots is precision fertilization. The basic hypothesis of precision fertilization is that the optimum rates of inputs vary situational and spatially within a field. We and other researchers have shown that site-specific nitrogen (N) input rates improve farmers' profits and reduce negative impacts on the environment at the same time. We have particularly focused the challenges, which are related to identify appropriate N demands when several stress factors affect the plants simultaneously. The stressors included in our work have been excessive or deficient water supply, weeds, and diseases. The fertilizer rates are adapted to the specific N-demand of the crops instead of applying the same amount over the entire field (conventional practice). Nevertheless, to apply predefined rates on specific locations, two prerequisites need to be met: an accurate application device, and a detailed application map, both harmonized in their spatial resolution. The application map gives an overview of the crops' N demands, they are obtained from the images acquired by a vertical take off and landing (VTOL) multirotor platform. After a scouting mission, the gathered images are radiometrically and geometrically calibrated, georeferenced, and processed to a 3D model and an overall orthoimage. Empirical models are applied on the orthoimage in order to create a complete map of the field. This map contains the above ground biomass and leaf nitrogen content information, which is fed into an agronomical model in order to calculate the nitrogen rate application map. The application map is then fed to our liquid fertilizer applicator where each nozzle can be controlled individually. The fertilizer application is carried by an autonomous electrical UGV, that uses GNSS based localisation for navigating inside the field.

The idea of using similar robots for precision fertilization is to reduce Greenhouse gases (GHG) emissions by using electrical vehicles, as well as soil packing by using multiple light weight robots or tractors instead of conventional heavy machinery. In order to have a fleet of vehicles, we present a navigation scheme that allow the UGV to follow autonomously another vehicle using a leader-follower formation.

GRASSROBOTICS – ROBOTIZATION OF FORAGE PRODUCTION

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Keywords: Energy consumption, soil compaction

Forage production from grassland and ruminant livestock production make the base of Norwegian agriculture (Steinshamn et al. 2016). The growth season in Norway will start earlier and last longer as the winter becomes milder. More extreme precipitation events, as well as increased overall precipitation are expected. (Hanssen-Bauer 2015, IPCC 2013).

When relying on heavy agricultural equipment to harvest grass, the equipment may cause soil compaction. This means that several consecutive days without precipitation are needed in order to avoid excessive soil compaction. The number of days with moist soil and wet conditions will increase with a wetter climate in the future. With increased soil moisture, the maximum permissible ground pressure of agricultural vehicles to get satisfactory crop yield decreases (Medvedev and Cybulko 1995). Use of lighter agricultural equipment is one possible adaptation to the increased precipitation.

One aim of the GrassRobotics project is to develop a less vulnerable harvesting regime for forage production that is more independent of weather conditions. In the grasslands, this will be achieved by equipping a lightweight robot with tools for mowing, collecting and transporting forage. There is currently no agricultural robot developed for this purpose. However, the robot used in this project, Thorvald, (Grimstad and From, 2017) can easily be rebuilt into such a system.

The first task to be addressed was the mowing of grass. For this purpose, Thorvald has been equipped with a 1.70 m wide cutter bar in front. As this is a relatively lightweight, battery driven system, the energy consumption of the cutter bar is of interest, as well as the system's ability to mow grass.

A small field test has been conducted. About 1,000 m^2 of grass was to be mowed by the robotic system. The weather was fair, with moist soil and wet grass after a rainfall the day before. A new GPS based path planner algorithm was tested, as well as a LIDAR based safety system that stops the robot if it senses a foreign object in its path.

The key findings of the field test was the following:
Mean power drawn of the knife bar was approximated with use of a voltage data logger, at three different velocities, 0.5 m/s, 1 m/s and 1,5 m/s. There was a quite moderate difference in power drawn dependent of velocity. The values varied from 1.2 kW at 0.5 m/s to 1.4 kW at 1.5 m/s. This indicates that higher velocities will result in lower energy consumption per area mowed. The robot is currently equipped with around 7 kWh of batteries, which should be enough to power the cutting bar for several hours. Note that these values do not include the energy drawn by the robot, only by the cutting bar alone. The bar is, however, assumed to draw considerably more power than propulsion.

The grass did for the most part get thoroughly mowed. A few exceptions were when chunks of cut grass got stuck on the cutting bar's gearbox, thereby pushing the grass in front of the robot down against the ground, making the knives miss. This happened a few times, usually at higher velocities.

The robot did not make substantial marks in the ground, despite the soil being moist. It was by visual inspection hard to determine where the tire tracks were.

The path planner made a path based on four coordinates that made up the corners of the test area. The path consisted of parallel, straight driving lines, with 180 degree turns just outside opposite sides of the mowing area.

The safety system was tested by standing in the robot's path. The robot consistently stopped when it saw an object about 2 meters in front of it. Each time the person moved out of the robot's path, the robot continued to go at given speed.

To summarize:
Grass mowing equipment has been fitted to the Thorvald platform. The system does cut grass, and battery power seems to be sufficient to drive the system for several hours.

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SIMULATION OF ELECTRIC AUTONOMOUS FIELD MACHINERY IN AGRICULTURE

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Keywords: DES, battery, tractor, self-driving, UGV

The research on electric agricultural field machines has been ongoing since the early 20th century and research on autonomous systems in agriculture since the early 1980's. These systems opens new possibilities for the management of agricultural fields and provides possible solutions for current and future agricultural challenges. The combination of these technologies is both rare and novel, and mitigates the drawbacks of each other while enhancing the advantages. Such technological systems combines the potential to reduce climate footprint by electric propulsion, with the increased production capacity and controllability of autonomous drive. Previous studies have shown that this kind of vehicles theoretically can reduce the total operating cost with 15 % and the global warming potential (GWP) with up to 92 % [1]. However, very few instances of working vehicles exist apart from prototypes, research platforms or small purpose-specific drones [2].

"Electric autonomous work machinery in agriculture – Effects of technology choices and system configuration" is a project managed by the Swedish University of Agricultural Sciences (SLU). The aim of the project is to study electric autonomous all-purpose field vehicles for agricultural use while analysing how different technologies, system structures and methods of operation affects the system. This is measured in total production capacity, costs, energy consumption and the resulting total climate impact calculated by LCA. The project is funded by the Swedish Energy Agency, and is currently on its first out of four years. It includes an ongoing PhD project and have so far resulted one bachelor and one master theses[3, 4].

The condition for a fictive 200 ha grain farm in the Uppsala region in Sweden was studied. It was assumed that the farm had at least one battery electric vehicle (BEV) autonomously performing agricultural field operations for a crop rotation with four different types of grain; barley, oats, winter wheat and spring wheat. Apart from field operations, soil workability, farm-field transport, repair/maintenance need and charging are considered in the model. At this stage of the study; 1-3 vehicles with 50 kW motor power were assumed and the effects of increasing battery size and charger power from their baseline values (70 kWh and 42 kW) were evaluated in the model.

Power demand of field operations is simulated using results from previous studies of agricultural machinery performance in similar conditions [5, 6]. These operations are stubble cultivation, harrowing, spreading of fertilisers and pesticides, sowing, roller packing and ploughing. Harvest is excluded due to the perceived difficulty in replacing the combine harvester. The system is simulated with site-specific weather and soil data to determine hourly soil workability. Battery electric drive and high power charging is simulated using results from previous studies or data from interchangeable equipment [1]. The model developed in the project is based on dynamic discrete event simulation using state-based decision making.

Weather, the number of vehicles, battery size and charger power are all influential on the timeliness and total number of days required for all operations. An important result in the theses [3, 4] was that when a higher charging power (over 43 kW) was available, increasing the battery size of the vehicle did not significantly reduce the time required to complete all operations. The same result was found in this study, which showed that increasing the charger power with 100% from the baseline gave a decrease in total time required by 9-36% (depending on the number of vehicles). A similar increase of 100% in battery size increased the time required with 2-26%. An increase of both these factors resulted in a total decrease of 9-26%, which is less than if the charger power alone was increased.

The results indicate that the number of vehicles, the battery size and the charging size have threshold values where a further increase leads to a diminishing rate of improvement or even a larger time requirement due to longer charging times without a similar increase in productivity. This implies that there are further optimization possibilities, and that it is possible to replace a large field tractor with a small electric autonomous tractor, if the thresholds are met. Especially, a smaller battery with higher charging power may be adequate where it previously was thought that a large battery was needed. Since investments in batteries are less cost efficient and have a higher environmental impact over time than investments in charging infrastructure, this indicates that a system with smaller batteries are both plausible and feasible.

Waiting for acceptable weather and soil conditions is unproductive time regardless of driveline or fuel, and such periods may be used for charging up the battery. This implies that the loss of productive time due to charging may be smaller when working in a real system than previously assumed, as waiting for good weather consisted of up to 35 % of the total active time.

Furthermore the study has shown that the system is sensitive to local and farm-specific parameters (distance to field, farm fuse size, weather, soil type, crop rotation) which makes a generalised solution difficult. The system configuration and technological set-up will be applicable to other farm types in other geographical areas, but the optimal solutions will look different. Future research in the project will include a deeper focus on energy consumption, cost, timeliness and climate impact of the vehicle.

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TRENDS AND CHALLENGES OF MODELLING AND SIMULATION IN AGRICULTURE

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Keywords: Discrete Element Method, Chrono, Functional Mock-up Interface, Granular Dynamics, Co-simulation

Modelling and simulations have become an important part of the product development in the agricultural research and industry. Modelling and simulations are present in several fields of research and engineering, from commercial Finite Element (FEM) codes for calculating stress and strain in structural mechanics to Computational Fluid Dynamics (CFD) for simulating air flow.

In this work, two methods of modelling and simulations in agricultural engineering are presented through two case studies. The first case concerns the development of an autonomous field robot using simulations on a systems level. The second case concerns the use of a numerical approach for simulating granular dynamics with application to the modelling and simulation of a soil-tool interaction process on a component level. The aim of the studies is the investigation and demonstration of the challenges and perspectives of conducting simulations on a systems level and the possibilities of applying models for estimating performance of a physical system on a component level.

The point of departure of the study in systems modelling relies on the co-simulation of an autonomous ground vehicle for conducting field operations within the agricultural domain, we refer to this as the Robot. The robot consists of multiple physical and cyber-physical systems, e.g. mechanical components and software components intertwined in order to realise autonomous field operations. By utilizing the standard, the Functional Mock-up Interface (FMI), we are able to co-simulate the resulting motion of the robot, which is a product of the interacting machine dynamics and the steering controller dynamics. The study is limited to include only Functional Mock-up Units (FMUs), i.e. model units, of these two systems. The co-simulation of the FMUs allows for investigating possible steering controller designs with a modelled input from the dynamics of the robot under various loads and designs in an early stage of the development.

Load case estimations are crucial to succeed in any design study. In agricultural engineering, a challenge is the estimation of the soil-tool interaction forces in the early stages of the development cycle. From a mechanical engineering perspective, a challenge is the variety of possible load cases due to different soil types and water content that can be excited to the tools and equipment during field operations. This, combined with the variety of available draught force capacity of the farmers, adds up to numerous load cases to be considered in the R&D process. The traditional method for estimating the different soil-tool loads are conducted by performing soil-bin test or field tests to measure loads and performance. This procedure is laborious and costly while providing only information in finite points of the designs space. Furthermore, the performance of a field test is conducted at a late stage of development.

In the second case study, the use of the Discrete Element Method (DEM) is proposed as the governing techniques for modelling and simulating the soil-structure interaction to evaluate the toolperformance under changing conditions on the component level. The open-source C++ multi-physics code Chrono is utilised to simulate the soil-tool interaction. In a preliminary study, the resulting effects of changing model parameters of a DEM soil model is investigated. The results are applied in the simulation of a soil-tool sweep.

Finally, pointers are given to future research in combining the systems approach of modelling including physics-based component level models.

EVALUATION OF RESIDUE INCORPORATION FOR DIFFERENT PLOWING DEPTHS AND RESIDUE AMOUNTS

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Keywords: site-specific; moldboard plowing; depth control; soil structure; aggregate size distribution; seedbed preparation.

Straw and plant residues play a key role in maintaining healthy soils, controlling soil erosion, minimizing risks of pests and diseases as well as increasing carbon sequestration. Although suitable combinations of plowing depths (PDs) and residue amounts (RAs) could be specified for a particular field, it still remains challenging to incorporate plant residues uniformly as the site-specific variations of soil properties, topography and/or residue distribution on the soil surface should be defined and considered. The aim of this research is to study the effects of varying PDs at different incorporated RAs for sandy loam soils.

A field experiment was conducted on sandy loam soils using a moldboard plow with slatted bodies in Central Jutland, Denmark, where RAs of 0, 4, 8, 12, 14 and 16 tons ha^{-1} were evenly distributed on the soil surface and PDs were set at 15, 20 and 25 cm. In total, fourteen combinations of PDs and surface RAs were evaluated. In order to define the effects of varying PDs for crop residue management, the spatial distribution of straw with depth and soil physical properties were determined. Soil water content, bulk density, soil aggregate size distribution, soil penetration resistance, and visual evaluation of soil structure (VESS) were analyzed with three repetitions per plot (n = 41).

The aggregate size distribution showed that the two most common fractions across PD and RA treatments, measured between 50.7 and 68.1% and between 7.9 and 13.7% were the fractions of less than 2 mm and of 8 mm, respectively. The results showed that the incorporation of large (14 and 16 tons ha^{-1}) RAs occurred at deeper than desired depths, though, these RAs were characterized by lower soil penetration resistance values within the plots PD15. Likewise, residue incorporation had a greater effect on penetration resistance in the 12.5-25 cm soil layer than in the 0-12.5 cm layer. However, the spatial distribution of incorporated plant materials had uneven and unequal distribution within soil profiles when incorporated RAs greater than 12 tons ha^{-1} were incorporated. PD was strongly positively (r_s = 0.80) correlated with the distance between the residue bands and the depth of straw incorporation.

Hence, the site-specific distribution of plant residue on the soil surface should be considered in order to obtain a desired PD. The approach of the inclusion of the spatial data would allow to achieve uniform supply of nutrients and minimize soil compaction, thus, allowing to obtain higher crop quality and yields as well as to mitigate negative environmental impacts in arable soils.

A NOVEL MOULDBOARD PLOUGH SYSTEM WITH SECTION CONTROL TO IMPROVE SOIL INVERSION AND REDUCE OVERLAPPING IN HEADLANDS

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Keywords: Soil inversion, seedbed preparation, residues, weeds, crop competiveness, precision agriculture.

In inversion tillage systems, mouldboard ploughing sets the stage for an desirable seedbed, thus, creating favourable conditions for seed germination, crop development and growth as well as minimizing the risk of pests and diseases and improving crop competitiveness against weeds. Optimal ploughing is inverting the topsoil homogenously across the entire field, however, undesired triangles are formed in the headlands when the plough is lowered and elevated. Therefore, special attention should be given to the intersection zone between the headlands and the mainland of a field as these triangles results in overlapping inversions when headlands are ploughed perpendicular to the mainland.

The overlapping operations causes uncontrolled mixing of the topsoil rather than the desired soil inversion, resulting in crop residues and weeds on top of soil surface after the final seedbed preparation. Weed propagules can also be just beneath the soil surface in this intersection zone, especially in grasslands. Although this issue is relevant in all areas of farming, organic agriculture could benefit the most as weeds cannot be controlled with the same efficiency as in conventional farming based on herbicides.

The aim of this research was to evaluate the agronomic effects of using a novel plough system with section control, which enables each furrow to be individually lowered and elevated, hence, eliminating the overlapping operations in the headlands. The system consists of a hydraulic double acting cylinder on each plough section that can be activated and deactivated when the plough is entering and leaving the mainland of the field, thus, potentially creating a nearly straight line in the headlands, perpendicular to the mainland.

Two field experiments were conducted in two different locations (sandy loam & loamy sand) in spring and autumn of 2018, respectively. The sandy loam field had crop residues (straw and stubbles) from a preceding wheat crop and the loamy sand grassland. The experiment was designed with six blocks, each with four repetitions of each treatment (without section control and with section control). The treatments were randomized between each block, with the systematic that there were different treatments at each end of each block.

The study showed that the plough was functionally in minimizing overlapping in the headlands as the undesired triangles were completely absent when utilizing the section control. In addition, the system showed other advantages such as improved ploughing quality in wedges operation, traction force reduction by elevating one furrow in e.g. hilly areas, and visually line marking, in the headlands, when initialising the field by partly lowering only one furrow to the required depth. The experimental results showed an improved incorporation of crop residues when utilizing the mouldboard plough system with section control.

DETECTION OF ODOUR FROM ANIMAL PRODUCTION IN FINLAND

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Keywords: Animal production, odour, annoyance, measurement

Agriculture is the most significant source of ammonia emissions that cause e.g. odour problems and acidification. Odour has become a local problem as a nuisance to the neighbourhood. Animal production farms have traditionally been situated in the rural areas well apart from densely populated areas. But as these urban areas grow, urban population comes nearer the farms. Problems arise when farms need to grow or change their production and neighbours oppose this due to expected odour annoyance. Odour annoyance has to be taken into account on environmental permissions for animal production units.

There are two different estimation methods used in Finland. The first simple one is a curve that is based on the number of livestock units in the production unit. The other one is a model that is based on animal and production dependent odour factors, prevailing wind directions and topography of the area. Both these methods have deficiencies. The prevailing odour can also be measured with an olfactometric method that is based on odour sensation of a panel of people with different sensitivities with annoyance of odour. Examples of the use of olfactometric method are presented.

ENVIRONMENTAL IMPACT ON USE OF PERENNIAL ENERGY CROPS FOR BIOGAS

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Keywords: bioenergy, life cycle assessment, anaerobic digestion, biomass

Anaerobic digestion of biomass is usually used for treatment of manure or other residues, but harvested crops may also be used as co-substrate which increases the profitability of the system. One of the main crops for biogas production still is maize, but it is expected that this monoculture could be replaced by perennial grasses. Perennial grasses are high yielding, do not require much management, their chemical composition is suitable for biogas production and they may increase the biodiversity as well as improve soil properties. The aim of the study was to analyse the greenhouse gas emissions and CO_2 savings in the process biomass – biogas – biomass. The LCA analysis was conducted using the SimaPro software where inputs were based on experimental investigation of perennial grass cocksfoot (Dactylis glomerate) yield and biogas produced at lab scale biogas digester at mesophilic conditions.

The results of the experiment present the productivity of cocksfoot varies due to the year of sward use, climate conditions and rate of fertilizers applied. The increase in biomass yield has significant influence on the biogas production boundary. The energy input is mainly influenced by the type of fertilization and biomass yield. When comparing global warming potential, the results found reveal that energy generation through biogas from perennial grass during its 6 years vegetation lead to significant reduction of emissions of CO_2 to atmosphere. Application of organic digestate for fertilisation strongly reduces CO_2 emissions by avoiding mineral oil-based energy input for mineral nitrogen fertilisers. Even additional digestate transportation to the fields does not overcome mineral fertilisation impact. Perennial grass processing into biogas has positive effect on the environment in terms of the GHG potential and creates sustainable closed cycle.

THE FUTURE OF DANISH BIOGAS AND ITS INTEGRATION INTO THE ENERGY SYSTEM

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Keywords: Biofuels, greenhouse gas emissions, energy supply

The biogas industry in Denmark has seen strong growth since changes were made to feed-in tariffs in 2012, with total biogas production increasing four-fold. Prior to 2012, the industry had to focus on electricity production on-site *via* combined heat and power (CHP). The produced electricity was generally fed into the grid and the heat, which constitutes more than half of the total CHP energy production, was utilised wherever possible. The 2012 changes made it economically feasible to upgrade biogas to natural gas quality and to inject it into the extensive Danish natural gas grid.
Gas, like electricity, is a flexible energy carrier and each has advantages and disadvantages over the other. With many countries investing in renewable electricity production (mainly wind and solar), one major obstacle is the matching of supply and demand. For this reason there are many research directions focussing on storage of electricity. The natural gas grid in Denmark (and indeed many other countries) has a flexible storage capacity of several months due to the scale of the network. The gas can be utilised in several ways; in large scale power stations, smaller decentralised CHP, households or as a vehicle fuel.

This work describes the recent changes and potential future utilisation of biogas with reference to recent studies of a variety of possible future scenarios where sources of biomass are considered and their integration with other renewable energy sources.
Current biogas production in Denmark has reached more than 10% of the country's natural gas demand, with room for further expansion following better utilisation of waste products from agriculture, municipalities and industry as well as plant biomass. However, Denmark has strong regulations regarding the use of plant biomass for energy production, with ongoing reductions in the proportion of energy crops permitted to be used in a biogas plant. Therefore, the focus has been on plant biomass that is not in competition with food/feed production.

The cost of a fossil-independent energy supply in Denmark has been estimated at up to 159 billion DKK (21.3 billion euros). Future projections suggest a strong move towards light electric vehicles is necessary to achieve political goals for reduced fossil fuel consumption and greenhouse gas emissions. Biogas can play a role in production of electricity for vehicles but current limitations in battery capacity mean that heavy electric vehicles are not yet feasible. However, biogas upgraded to natural gas quality can be used as a fuel for heavy vehicles. Gas powered vehicles need a pressurised storage tank that can be difficult to mount in the limited space inside modern light vehicles, yet heavy vehicles have much greater potential in this regard. A recent study has shown that Danish biogas production could substitute up to 56 PJ of transport fuel, with an estimated 42 PJ required to supply 100% of heavy vehicles (trucks and buses) and 50% of light commercial vehicles (vans). Conversion of vehicles and infrastructure are required to achieve this, and it is estimated that this cannot occur completely until 2035.

OIL-CONTAMINATED SOIL TREATMENT BY HERBACEOUS PLANTS AND THEIR SUBSEQUENT USE FOR BIOGAS

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Keywords: anaerobic digestion, biomass, soil cleaning, naphta pollution

Renewable energy sources are needed to reduce fossil fuel demand, price fluctuation, depletion of resources and climate change. Using phytoremedial methods in biomass engineering, there is a possibility to create a sustainable method of biomass growth in mid-low contaminated sites soil system. The aim of the research was to assess the oil-contaminated soil treatment by herbaceous plants and their subsequent use for biogas production in order to create a closed cleaning and plant biomass utilization cycle.

Results show that the proper selection of herbaceous energy plants can reach high level of oil contaminated sites treatment from 223 to 594 mg/kg of oil hydrocarbons concentration in soil. By using 3 selected plants soil pollution with oil products declined by 3,2; 2,2 and 1,6 times respectively. In all cases, the test showed that the soil pollution of oil products was lower or slightly higher than threshold value of permissible maximum (200 mg/kg) soil pollution after one cycle of treating by plants. Plants endurance limit has not been reached, visual oil hydrocarbons toxicity effects were not observed.

After the evaluation of the biogas yield and energy conversion efficiency performance it was found that all selected herbaceous plant biomass is suitable as raw material for the production of biogas. The biogas potential of selected plants ranged from 377.2 to 822.9 l/kg dry organic matter with an energy value ranging from 7.1 MJ/kg to 17.1 MJ/kg.

ELECTRIFICATION OF NON-ROAD MOBILE MACHINERY

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Keywords: powertrain electrification, non-road mobile machinery, hybrid powertrain, technology assessment, agricultural machinery

Aim of research

Electric powertrains have been successfully used in passenger and heavy vehicles, and some heavy machinery applications. In recent years, electric powertrains have been studied increasingly also in mobile machinery to increase energy efficiency, improve controllability, and reduce emissions. Electric powertrains have numerous advantages over traditional mechanical and hydraulic powertrains but there are still important challenges to overcome for long-term commercial success. This research presents a technological assessment of powertrain electrification in non-road mobile machinery (NRMM). The research focuses on analysing technology enablers and challenges for electric powertrains. A special focus is given for the electrification of agricultural machinery by analyzing the benefits of using electrified powertrains in agricultural tractors and electric power in implements.

Research method and background

A thorough literature analysis and assessment of the technology development was carried out. Because NRMM does not form a generic, uniform group of applications nor they have a clearly distinct customer base, a systematic evaluation was necessary to understand complex technological transitions and changes such as powertrain electrification at industrial level. This research work was done as a part of a national research project called Electric Commercial Vehicles (ECV). The research work is now focusing more on electrification of agricultural machinery at the University of Helsinki.

Research findings

Electrical energy storages are key components in the success of powertrain electrification of mobile machinery. The technological development of lithium-ion batteries has been very beneficial but the progress has not been as fast as expected. The battery specific power and energy, lifetime and costs are important characteristics for NRMM. Thermal management of lithium-ion batteries is a specific practical challenge because operation in hot and cold temperatures accelerates aging and battery performance is decreased in cold conditions. Even though batteries are often in the spotlight, ultracapacitors have been developed to the level that their usability, feasibility and applicability is approaching that of batteries. However, as long as ultracapacitors have low energy density, they are most suitable for short-term energy buffering in high power applications. Besides energy storages, electric motors can be considered as key components for mobile machines that require good torque capacity over a wide operating range. It is often more suitable to use electric motor with integrated gearbox for higher torque capacity. In comparison to common industrial applications, the NRMM power electronics is required to have robust protection against vibration, shock and corrosion.

The high cost of electric components is challenging for economically successful electrification or hybridization of NRMM. Cost reductions of individual components are important but because NRMM are so diverse, the system development and integration costs can be considered even more important. For example, the future cost estimates for lithium-ion batteries in the cell level do not represent well a battery system cost in which the system integration, battery management and thermal management system can play a major role.

As hybridization will probably be the first major step for mass electrification of mobile machinery, there is and will be a crucial need for specific integrated subsystems such as dieselgenerators and motor-transmissions. Nowadays, diesel-generators are mostly manufactured for stationary use and they do not correspond to the needs in NRMM. Another integrated system is the combination of the electric motor and gearbox. Because many machines operate only at low driving speeds and require a substantial amount of torque at the wheels, gear reductions have to be used from the electric motor to the wheels. Traditional gearboxes used with diesel engines can be used but these are far from an optimal solution and therefore specific gearboxes are often utilized with electric motors.

Mechanical and hydraulic power transmission systems have been dominating in agricultural machines. In general, the energy efficiency of mechanical power transfer is typically quite high but it suffers from the limited controllability in terms of continuous speed control. On the contrary, hydraulic power transfer can be controlled quite accurately but its energy efficiency is much lower. It has been challenging to improve the weaknesses of these two types of power transfer, which has increased the interest towards electric powertrains. Electric systems typically have high energy efficiency and can be controlled accurately. With higher level of accuracy in system control, work processes can be optimized and thus increase productivity. Other benefits are better operating comfort, less noise pollution and additional freedoms of power transfer design. Without mechanical or hydraulic connections the component positioning in machines is easier and allows new layout possibilities. Even high voltage power cables are quite flexible and do not require a lot of space. In addition, most of the electrical components are easy to maintain which results in less use of brakes and lower maintenance costs.

The actual benefits of electrification of agricultural machines and heavy machinery depend heavily on the given application. In certain applications, such as small size reach trucks and large size mining machines, electric powertrains are already widely used because of their inherent advantages. The smooth control and low noise of electric motors is advantageous when operating in confined and enclosed places. In very high power applications (traction power higher than 500 kW), mechanical transmissions are challenging but electric motors can easily handle high torque and power without weakening controllability and energy efficiency. Among agricultural machinery, there are not many commercial applications available in the market but research has been carried out increasingly. In recent years, the market leading agricultural tractor manufacturers have introduced powertrains having full electric powertrains. Electric systems are assumed to be the next major technological change in the development of agricultural machines. It will be partly integrated with automated systems because electric powertrains offers benefits in implementing autonomous operation in agricultural vehicles.

Summary

The key findings of this research indicate that the electrification of NRMM is slowly started and the progress is demonstrated by hybridization of some specific, successful mobile machines. In short-term, high component and technology development costs remain the main barrier for higher adoption of electric and hybrid powertrains. In the long-term scenario, many NRMM can operate autonomously and powertrain electrification has become mainstream technology.

Successful demonstration machines already act as references and they increase the confidence on powertrain electrification. There are already machinery applications with electric powertrains that have economic market success. However, large-scale adoption of electric and hybrid machinery needs more push from the manufacturers and active participation from the end users.

GRASS CLOVER MAPPING AND TARGETED NITROGEN FERTILIZATION STRATEGIES USING IMAGE PROCESSING

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Keywords: Deep Learning, Remote Sensing, Plant Classification, Semantic Segmentation

Plot trials of targeted nitrogen fertilization on grass clover mixtures show promising potentials. Nitrogen fertilization, based on the local distribution of the grass and clover, can increase the yield, improve the yield quality, and reduce nitrate leaching. While the true grass and clover distribution can be determined in small plots by hand, this approach is not feasible to upscale. In this work, we map and provide a targeted fertilization strategy for 150 hectares of grass clover based on image recognition in color images collected in October 2018.

Mounting a 5 megapixel high-speed down-facing camera and a GPS on an ATV, the fields were systematically traversed to capture spatially distributed and geolocated images. This provided an average of 114 canopy images per hectare. Using deep learning techniques, all pixels in the images were automatically analyzed to accurately locate grasses, clovers and weeds, and their corresponding canopy area. Based on inverse distance weighting, the plant distributions of each image location were extended to cover all intermediate areas.

The mixed crop distribution maps revealed a clover content ranging from almost one percent to more than sixty percent, with a large variation both within and between the fields. Applying the current danish guidelines for targeted fertilization of grass clover mixtures, the distribution map is translated into a map optimized for targeted fertilization.

The high-speed ATV-based data acquisition platform and corresponding image processing pipeline is demonstrated on 150 hectares, where it estimates the grass and clover distributions. Subsequently, fertilization maps, based on the distributions, are developed to show the potential of targeted fertilisation.

AUTONOMOUS WEED MAPPING IN CEREAL FIELDS

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Keywords: Deep Learning, Plant Classification

Information about the presence of weeds in fields is important to decide on a weed control strategy. This is especially crucial in precision weed management, where knowing the position of each plant is essential for conducting mechanical weed control or patch spraying.

Already, modern sprayers are able to mix herbicides on-the-fly to ensure that no more chemicals than needed are used. However, these sprayers are not fully utilized as they are not sensing the presence of weeds.

Here, we present an automated data chain, where top-down images are collected by a high-capacity camera, which uploads the images to a server that firstly detects where in the images weeds are present, then determines their species. As the images are georefered, the detections in each image can be combined into weed distribution maps for each detected weed species. These maps, when used by the sprayer, eliminates the use of herbicide where it is not needed, and optimize the dosages elsewhere.

The weed detector consists of two serialized convolutional neural networks: The first part is optimized towards size-independent detection of weeds in cereal fields. This part of the detector is able to detect weeds even in highly occluded fields where big parts of the weeds are hidden under leaves from other plants. The second part of the detector is optimized to classify the species of the detected weeds and handles 19 Danish weed species. This two-step detection and classification has two advantages: Firstly, it allows for training the detector on weeds, where humans cannot determine their species. Secondly, hard-identifiable weeds are not influencing the detectors ability to detect the presence of weeds. The detector and classifier have been train on a total of more than 55 000 weeds, collected in more than 170 cereal fields during four growth-seasons.

CROPMANAGER - A PLATFORM FOR PRECISION FARMING

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Keywords: Precision farming, Holistic information system

CropManager is a new web platform aiming at making precision farming practically applicable for professional farmers. Most of the machinery owned and used by professional Danish farmers contain variable rate technology. Even though the machinery can perform these operations, farmers do not use the full potential by utilizing these technologies. Many have presented problems and implications as cause for the missing utilization, but for the scope of CropManager the focus is only on the farm management information system (FMIS) and communication with the tractor terminal or manufacture cloud solution.

Our hypothesis based on that farmers do not use precision farming because it has become too complicated and time-consuming. To make it simpler and less time-consuming five problems have been addressed. These five problems are:

1) Creation of prescription maps – Creating prescription maps can be performed in different ways. Currently, satellite images are the most used data sources. However, many systems ask the farmer to input their own mathematical model to transform satellite data into a specific amount of e.g. nitrogen.

2) File transfer between an information system and a tractor terminal – Transferring files between an information system and a tractor terminal is both time consuming and requires dedication. Many systems require farmers to download a file to a USB key and move this to the tractor terminal.

3) Documentation – Even though it is very important to transfer the application file from the information system to the tractor terminal , getting data back into the information system as "as applied" data is almost equally as important. This documentation allows for learning and future documentation to officials. However, systems available today do not offer this functionality, but instead requires manual data entry.

4) Data cleaning – Information from the machinery (e.g. yield data) is often raw data and contains lots of error-filled data that needs to be cleaned before they can be used within other models.

5) Fragmented information systems
Different FMIS have tried to individually solve these four previously mentioned problems. This means that farmers must work with different solutions, adding another layer of complexity and time usage when transferring files between information systems.

To solve these five problems, the holistic FMIS, CropManager has been developed. The development has been performed in collaboration with Danish farmers to ensure alignment with their requirements. The CropManager platform makes precision farming easier and less complicated by guiding farmers in creating prescription maps and transfer prescription maps to the tractor terminal through the cloud. When the farmer has completed the job in the field, CropManager receives an "as applied" map form in the terminal, which is then automatically cleaned and saved as documentation.

SPRAYING APPLICATION IN FUTURE FARMING

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Keywords: digitalization, sensors, GNSS, GIS.

Equipment for spraying application have gone through a huge development during the last 20 years, especially considering operator safety, drift reduction, adaption of spray volume and spray quality as well as being an important tool in precision farming. Some examples are parallel tracking combined with GNSS adjusted section control, automatic boom control and GIS based site-specific dosage of pesticides.

The most common understanding of precision farming of today is the use of a temporal and spatial treatment of areas in the field due to their specific needs regarding growth conditions, yield optimization and environmental aspects. Spraying application plays an important role in Agriculture 4.0 due to increased digitalization and use of sensors, IoT and treatment of single plants or even single leaves.

In the future the crop may be scanned 24/7 by the use of sensors and imaging all over the field with improved resolution. The use of VR and 4D imaging technology will further increase the use and quality. We have only seen the beginning of this process in agriculture. More exactly and increased number of sensors, big data, data cloud storage and networking and interaction from different farms linked to proper software and analysis will make it possibly to detect pest attack at an initiating stage before visually seen and only in the first, early small locations. This makes it possibly to keep the amount of pests on a low level. The use of satellites, drones and robots will be able to scout the crop more frequently. New application concepts e.g. special nozzles attached to robots may apply only affected leaves. Compared with a conventional broadcast application of today, the amount by this method may be reduced up to 99% and still obtain the similar biological efficacy. Simultaneously, the environmental risk will be reduced in the same range. The use of agricultural field robots equipped with imaging systems and adapted hoes may also make mechanical weeding more precisely and powerful in an IP system than by conventional methods. Spraying application even in near future should be able to significantly lower the amount of pesticides due to several and better sensors, improved imaging systems and more adapted equipment for spatial and temporal application in the field. Examples of different applications and solutions will be shown in the presentation.

ECONOMIC PERSPECTIVES OF PRECISION AGRICULTURE IN DENMARK

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Keywords: Precision Agriculture, autosteering, cost, benefits.

Precision agriculture (PA) and auto-steering systems have a wide potential to improve agricultural performance, ranging from improved use of crop nutrients, higher yields, crop quality as well as reduced overlap and better production economy. At the same time the technology can provide fuel savings as well as reduced inputs to reduce negative environmental impact. In particular targeted technologies such as section control on sprayers, less costly biomass and vegetation index measures from satellite images as well as precise RTK-GPS systems have been develop within the last decades to support this development.

Dispite the promises the cost of implementing these single technologies are often quite high compared with the benefits.

Aim of research
The objective of this study is to provide an overall and integrated methodology approach to assess the net-benefits of commercial available precision agriculture technologies in Denmark - and further to provide an overview of the overall economic potential og implementing PA in the Danish agricultural sector.

Experimental design and methods used
In this study we will present a methodology approach to provide an overview of costs, and benefits and net-benefits of the most feasible pathways for farmers to implement PA on their farms. It is based on a system approach with an assessment of both single technologies and a combined use of different technologies. Focus is on a traditional arable crop rotation based on Danish conditions. Key figures and estimates are mainly based on different Danish sources (companies and farm advisors) and studies on different precision agriculture practices. It is expected that all technologies are either commercial available or will become available within the next 2-3 years.In the financial analysis is made an estimation of different cash flows from introducing these technologies with an assessment of life time, input costs and expected net-benefits in relation to in-field variability scenarious and field size.

Major findings
Findings from this study indicate that several PA technologies are beneficial when implemented on large scale farms as well a combined and integrated application of different tools. To obtain an economic benefit from implementing variable rate application it requires that some spatial variability occur within the field. Variable application provide little economic net-benefits if the field consists of homogeneous fields without variation. In those cases the GPS-systems might only provide minor net-benefits if any at all. However autosteering and section control on sprayers and fertilizer spreaders appear to be viable solutions for many large farms. In addition, the socio-economic benefits from implementing variable rate pesticide and possibly nitrogen application combined with section control appears to provide an overall benefit to arable farmers. In general, the net-benefits are modest for many single technologies but it seems possible to obtain a benefit from a combined use of

technologies. A full implementation of technologies will provide a benefit between 30-40 EUR per hectare. However the cost of investments implies that only the large farms will gain a net benefit (benefit – costs) due to significant scale advantages. Danish farm holdings with an arable farm area below 100-150 hectares will probably not gain from investing in PA-technologies at the current cost level and development stage.

Summary and perspectives

To summarise, it can be concluded that several precision farming technologies are likely to provide net-benefits on Danish farms. Several of these technologies are mainly beneficial for large farm holdings and the economic viability depends on site-specific yield variation.

To improve the development of PA technologies it is important to focus on an improved and better integrated decision support systems for fertilizer application that are based on both soil texture, yield, NDVI measurements, soil drainage conditions as well as climatic forecasts. Better technical solutions for weed and fungi detection are also needed to provide additional value added to the farming sector.

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HOW TO SPEED UP INNOVATION IN AGRICULTURE?

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Keywords: Innovation, Agriculture, User-Centered Design, Multi-Actor Approach

Innovation in agriculture often stops at the adoption phase. According to recent research, new products or services are not adopted because of their poor usability or the users mistrust in new technology. Usability issues arise when designers have inadequate understanding of the use-context. Mistrust originates from bad experiences using the new technologies.

How to overcome these obstacles of swift innovation? The presentation concludes results from two research projects on agricultural innovations: the OECD Joint Research Program research ´Speeding up innovation in agriculture´ (2011-2012) and EU HORIZON2020 project ´AgriSpin´ (2015-2017). Based on these, recommendations on how to speed up the innovation process are given.

The OECD-funded research ´Speeding up innovations in agriculture´ was done as a web-based questionnaire and personal interviews of selected experts. The results pointed out the most important hinders. Poor adoption includes mainly problems in acceptability. Farmers also face problems in integrating the new technologies in the existing systems at the farm level. They tend to have mistrust on new technology as a whole. A recommendation was made that the education of engineers, designers, marketers and end-users of new technologies need to include more user-centered elements. They also need to interact better during the RDI process. User-Centered Design (UCD) was promoted.

´AgriSpin´ was a forerunner of Multi-Actor Approach in HORIZON2020. The Cross Visit Methodology including thorough analysis of 50 innovation cases in Europe was applied and improved during the project. The Spiral of Innovation was used to illustrate the cases and to communicate them to wider audience. Pearls, Puzzlings and Proposals were reported for each case in Final Symposiums where relevant stakeholders were informed about the findings and challenged for developing the local innovation environment of agriculture. Conclusions include that agricultural innovations, although technological in nature, are developed, realized, disseminated and embedded through a social process. This process should be understood better to be able to support it correctly. A recommendation was made that the Multi-Actor Approach should be used since the application environment is complex.

POSTER

GREENHOUSE GAS EMISSIONS OF CARROT TREATMENT TECHNOLOGY

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More than half of the world's agricultural products are lost and do not reach their consumers. Food production is rather energy-susceptible. To solve this problem, solutions focused on reducing this loss are being developed. This article examines how to preserve product quality while, at the same time, reducing the environmental impact incurred during the preparation of fresh carrots. It also explores the extent of the effectiveness this would have on the current loss of fresh carrots throughout the supply chain. When carrots are treated with ozonated water, it is not only reduces food loss, but also increases productivity. Ozonated water is introduced during the preparation of carrots for sale at farms where fresh carrots are made ready for trade, and at the final stage of processing, the products are sprayed with ozonated water, which allows the surface of the products to be disinfected. The assessment was carried out with SimaPro 8 software, where two scenarios were compared using a standard carrot treatment line, and another using product spray stage with ozonated water. Based on the research of the environmental impact of carrot preparation technology for trade it was found that by using the spray technology of ozonized water, total CO_2 emissions decreased by 45.2 % and the total amount CO_2 emissions is 32.91 kg $CO_{2\ eq}$/t. The data suggest that there is a clear potential for increasing the level of meeting consumer requirements while reducing the environmental impact that may occur during product preparation for trade.