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Adaptive tillage systems

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Acstract. This paper addresses the perspective of developing autonomous tillage robots. The aim is to analyze the possible perspectives in site specific tillage performed by autonomous units, including the additional effects that can be achieved by self-propelled systems in contrast to the classic tractor-tool units.

In general, soil tillage can be defined with two different main purposes. One is the close-to-surface seed bed preparation for optimal conditions regarding seed germination. The deeper soil tillage normally involves other types of implements such as the chisel cultivator or the plough. For this operation, the aim is more complex, including mixing soil and organic residues, weed control and losing the soil structure.

Site specific tillage has great potential. The result of the tillage operation can be improved dramatically when the intensity of the operation is adapted to the local needs. The autonomic unit will by nature be a light weight and less intensitive design compared to the traditional tractor-tool unit. This means that soil tillage by autonomic implements is also the solution for reducing soil compaction. In fact, site specific tillage has great potential gains in addition to the optimized quality of the operation; substantial energy savings can be achieved, negative soil compaction and erosion risks can be reduced, and in general, the reduced and the less intensive soil tillage will support a naturally rich micro biology life, characterized by the occurrence of worms etc.

Key words: Adaptive soil tillage, agricultural engineering, implements, autonomous systems, adaptive systems, sensors.

INTRODUCTION

Overall, the purpose of the different tillage operations is to obtain the best possible conditions for seed germination, root development and crop growth. An important element in this is the weed control that which is closely linked to the tillage system; this also applies to biological life and soil structure. In the ideal situation, the tillage system helps to maintain good soil fertility. From a fundamental perspective, the aim is to ensure sufficient supply of oxygen to the roots and to the microbial life. In the ideal situation the tillage also contributes to stabilize a fertile soil structure including a pore structure that ensures the availability of water around plant roots, and allows the drainage of excess water (Andersen et al., 2013). In the process of optimizing the tillage tool system it is very important to keep in mind these side effects, which influence soil fertility. Good soil fertility leads to improved absorption of nutrients, better root development, and a faster and better turnover of biological residues. This again helps to maintain a good soil structure and fertility (Carter, 1992). For a given soil texture, the healthy fertility itself enables easier tillage operation to obtain the right conditions.

In an overall description, the porosity must be composed of small pores that, by capillary effect, can raise the water level to an area in which the plant roots can absorb this. Medium pores that enable the water drainage, and macro pores enable the oxygen availability in the soil (Andersen et al., 2013). Tillage operations disturb this structure, which must then regenerate after the operation. Due to this, light treatments are preferred. High compressive loads, primarily from wheels in the actual operation or other operations in the field, can cause the capillary pores to collapse (Alakukku, 1999) and to become so small in diameter that the roots cannot absorb the water, which will then be fixed in the soil (Glab, 2007). Furthermore, the access of the oxygen to the roots and the microbiological organisms is reduced by the collapse of the bigger pores. The top soil layer is also sensitive to tillage intensity. Too high intensity or a non-matching method causes soil aggregates in the soil layer to be broken into small particles (Atkinson, 2009). The effect is that soil particles become closely compressed, resulting in a dense surface with limited passage of oxygen and water sensitive to erosion caused by wind or water.

Different implement types each have their own positive or negative effect on soil tillage. Classic spring tines used for top soil tilling loosen and separate the aggregates by tension forces, adding a minimal glazing and crushing effect to the soil aggregates. Stiff tines or tines on rotor/ pendulum harrows have a more precise working depth, and their intensity can be controlled by the angle of operation in relation to the horizontal surface. However, the operation of these tines is more sensitive to the performance of negative effects such as the kneading and crushing of soil aggregates in the zones around the working implement in which compaction occurs. The sensitivity to these negative effects is highly controlled by the moisture content and the texture of the soil. The deeper tillage operations are traditionally performed by chisel plowing or mouldboard ploughing. These deeper operations are always effective in loosening the soil and mixing surface matters and organic residues into the soil. These operations always result in both positive and negative effects for the soil. However, a soil characterized by healthy fertility regenerates faster from these negative effects than a soil which is less healthy.

Today’s traditional tillage tools and systems are designed to perform an acceptable result over the entire area of a field. At a closer look, the soil conditions vary substantially across the field. Due to this, the intensity of the operation is designed to handle the most challenging parts of the field, which means that large areas are overworked. Consequently, much of the area is also overexposed to the negative effects of the tillage operation.

It seems that the potential for obtaining a better result is quite large, and much energy may be saved if the tillage intensity is locally adapted to the actual soil conditions. The concept of and potential for site specific farming has now been analyzed and developed over more than two decades. One might wonder why so little focus has been directed towards soil tillage operations.

Over the past decades, technical research in agricultural engineering has been focused on finding systems that could provide better results through considering synergies between the effect of tooling and natural biological effects. The major systems analyzed were ‘moldboard ploughing/ chisel ploughing’; ‘reduced tillage/

mulch tillage' and 'no tillage'. In the no-tillage system, the only operation in the soil is sowing. Moldboard ploughing is known as the classic way of operating the soil. Reduced tillage covers a wide range of technical systems in between these two extremes. Results generally show that there are big potential gains in reducing tillage intensity, such as energy savings, improvements in microbiological life, stabilization of soil aggregates and pore structure (Tebrugge & During, 1999). The main problem for the systems tested so far is the emergence of a compact zone of the soil under the depth of tillage. Reduced no turning tillage also causes another challenge in controlling weeds, as this is one of the main tasks of traditional tillage operations.

As evidenced in the above, a very complex relationship exists between tillage systems, soil microbial activity and soil structure. Introducing non-tractor-powered implements expands this complexity by a new dimension of possibilities. The following analysis is based on a design in which the primary tillage operations which are deeper than seeding depth are carried out with a tractor-powered system based on the use of a moldboard plow, and the seed bed preparation and seeding is performed by an integrated autonomous implement. This is to maintain an overview, and to analyze opportunities in both tractor-powered systems and new integrated autonomous systems. The hypothesis is that substantial potential exists in both types of systems, and that the development will gradually show the change from the classic systems as they appear today to the fully integrated autonomous systems (Atkinson, 2007; Jørgensen, 2012).

Potentials and results of locally adapted soil tillage

The idea and potentials of reduced tillage operations have been investigated by research. Results show big potentials for the saving of energy. One aspect of this is ensuring that the operation is adapted to local condition. The moldboard plough constitutes one example; results show that focus on the correct adjustment of the implement to local conditions implies assumed energy savings of app. 20% in compared to average consumption (Guul-Simonsen et al., 2002). Investigations on reduced tillage systems and no tillage systems show potentials energy savings of up to 50% measured by fuel consumption. In the systems tested a big variation in yield was observed, showing an average net effect close to zero. The main problems for these systems are soil compaction due to traffic, and weed problems. Challenging these related problems in the design of the new technical systems there might result in a realistic savings potential in the range of 30 to 40%. It is well documented that reduced tillage and no tillage systems adapted to the soil and field conditions caused by biological residues and weed pressure can cause improvements in soil structure and porosity, soil aggregates and stability and microbiological activity in the soil. However, it has been difficult to set up general systems or descriptions generating yield increases of more than 5–10%. The expectation is that systems adapting to the local soil tillage will lead to a net reduction in fuel consumption of 30 to 40%, and that the yield will increase by 10% or more; more importantly, this increase will be stable, due to existing systems without big Fluctuation

Design of the autonomous robotic implement

Modern tractors support systems of integrated implement control. The commercial systems are described as Tractor-Implement-Automation (TIA/TA), Tractor Implement Management (TIM) etc. Literature shows operative examples of controlling a wagon, a baler and a fertilizer machine. This demonstrates that the system is ready and could be developed to control a moldboard plough, for instance. A simple way of defining optimal adjustment could be to define a small load on the lifting arms and on the rear land wheel. If the bearing load on these components is becoming too heavy, a substantial amount of energy will be spent on rolling resistance. The correct adjustment can be implemented by using the existing adjustment options. The angle of the chisel (foreshare) may enhance efficiency so that the force to keep the plow into the ground is adjusted to perform a stable operation. To ensure a good quality when using this system, it is still important that the overall orientation of the plow is correct. A measure to be used could be the side oriented force measured on the landside in the furrow. The actuator could be the top link arm. In addition to this process control, the plowing depth could be controlled according to the local need. A possibility here could be to set the max depth at 20 cm and the minimum at 10 to12 cm. The restriction on the minimum depth of ploughing is defined to ensure that the ground strips worked by the individual plough shares are effectively reversed, so that crop and plant residuals are effectively mixed into the soil and covered by a top layer of soil. The need for a larger ploughing depth could be determined by the tracking resistance of the plough as an indicator of the need for loosening the soil. For this to take place, the operator must define some reference numbers, as the correlation between these data relies on soil moisture, soil texture and other elements. To make it even more effective, an adjustable soil loosening tine could be mounted immediately behind the main share, so that the soil-loosening below ploughing depth can take place without lifting the soil in the ploughing zone. The assumption is that the fuel consumption for ploughing can be reduced substantially by introducing this type of adaptive plow design. Also, the effect of the plowing operation will be optimized so as to ensure the best conditions for the subsequent seed bed preparation. If the goal is to investigate the possibilities and perspectives for smaller autonomic tooling units, it is important to also analyze the possibility for optimizing the comparable tractor powered operation.

The process of seed bed preparation and seeding seems to fit quite well into the development of a fully autonomous integrated system. One immediate benefit from such a system is to get rid of the tractor driving in front of the implement, making compacted tracks in the wheel track that have to be treated separately afterwards. In the integrated implement, the bearing and traction systems must be designed to work over the full working with to distribute the load and designed such that it if possible contributes to the tillage process. After a slight positive compaction of the loose top layer, the seed bed has to be prepared so as to obtain the best possible aggregate structure possible on the basis of the soil texture and the actual local conditions. The properties of the seed bed have been analyzed by more research studies, among these (Atkinson, 2007), who analyze the possibility of predicting the properties of the seedbed for the purpose of predicting crop establishment. Input to the model are selected physical soil properties, and the intensity of the prior preparing tillage operation. It is a hard challenge to find or develop sensors that are able to collect the data needed for an online setup. A first approach here could be to use image analysis to analyze the micro-scale roughness of the soil surface as a measure of the size and distribution of aggregates before and after the tillage operation. The driver must also supply some reference data to make the system operate. The final seeding operation can be designed by the use of classic components. The assumption is that such an implement for integrated seed bed preparation and seeding is an example of a new implement that performs better than the comparable tractor-powered unit. This is due to more reasons: reduced energy consumption, quality improvements due to seed germination and crop growth, and also to the environmental impact of erosion and the need for subsequent pesticides, mostly herbicides.

RESULTS AND DISCUSSION

It is believed that the systems described for plowing and sowing are realistic, both from a technological and an economic perspective. The TIM/TIA systems have been commercially available for the past five years. As the manufactures of the implements takes the opportunity to benefit from these new solutions and designs, many different implements will be introduced to the market. Among these, new tooling systems for tillage operations will also emerge. It is realistic to assume that the autonomic unit be developed due to navigation, tracking and sensor/tooling systems. Here the obstruction is the safety aspect. One might wonder why free moving autonomic robots are allowed in industrial surroundings, but not in outdoor solutions. The safety aspect has not been a part of this paper. Also on this topic much research is being carried out. State of the art in this is that sensors and control systems are available, so that the challenge is to design the standards for such systems to obtain acceptance from the authorities.

CONCLUSION

The systems described are intended as examples of a possible next generation of agricultural tools. However, it seems very likely that these types of sensor controlled systems will enter the market. As the technology for the tractor-based systems are already commercially available in the market, it seems obvious that these systems will be the first to be introduced.

In the same way as self-propelled sprayers and other similar types of implements are taking over in the market, it is believed that the autonomous systems will also enter the market in the next few years.

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