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CROPS Evaluation of economic viability, social aspects and sustainability of agricultural robotic systems

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Abstract

In the EU-funded project CROPS a work package was dedicated to economic viability, social aspects sustainability and exploitation of robotic systems. Tools, studies and action plans were delivered to the project to support and guide technical research in the direction that should lead to further implementation that is socially responsible and economically accepted after the CROPS research program.
A simulation tool for each CROPS application, to determine the economic viability of: sweet pepper harvesting, harvesting systems in orchards (grapes and apples) and precision spraying are developed. A study on social aspects, standard requirements and other requirements for sustainability, describes the social aspects, economics and sustainable requirements for: sweet pepper harvesting, harvesting systems in orchards (grapes and apples) and precision spraying. The method used is influenced by thinking about CSR (Corporate Social Responsibility) and the ambition is to provide an understanding of the dynamic relationships between the triple bottom line, people, planet and profit, and to measure and weight the effects of efforts to raise performance levels in all three of these domains. The evaluation on all the aspects within People Planet Profit led to new system requirements which are implemented by the involved work package leaders of the robotic systems.
For the sweet pepper harvester the evaluation is positive in general. Specific advantages for robotising the sweet pepper harvesting task are workforce development: employment, education, working conditions, absenteeism. When robots replace human workforce there are no limitations to climate conditions. The climate can be adjusted to the plant needs. Plants grow very well under high CO2 levels, high humidity and high temperatures, under which people cannot work. By keeping windows closed in summer, such high levels with higher yield can be reached. A sweet pepper robot will be profitable when it is introduced rentable into the market. In the long term workforce costs are increasing, but robot costs are still decreasing. A sweet pepper robot will save workforce costs and improve product quality and safety. A negative condition is that robots are expensive. In the beginning the pay-back time might be up to five years and more. Therefore, more initial capital is needed to invest in robots to harvest sweet pepper.
For the harvesting system in orchards (grapes and apples) the opportunities are almost the same as for sweet pepper harvesting and are looking positive. However, there are no advantages expected in energy saving due to closing windows in greenhouses. The energy consumption will increase a bit. There will be also initial capital needed which might be difficult to find.

For robotized precision spraying, opportunities are looking positive as well. It will give social support using less pesticide by applying pesticides more accurate. Workers don't have to work under bad/protected conditions. There will be also more initial capital needed which might be difficult to find. However, in the end, using less spraying fluids, robots will save money and become profitable.

Keywords: automation, robotics, economics, social requirements, CSR

1 Introduction

This paper describes the method and results to evaluate robotic concepts with respect to requirements for social aspects, economics and sustainability in the work packages 5 -7 of the CROPS research program. It is expected that this evaluation will lead to new functional and technical requirements. This analysis of the social aspects, economics and sustainability is necessary to feed the design of the applications. In this paper requirements are described for: harvesting system for sweet pepper ; harvesting system for apples and precision spraying.

2 Materials and methods

To evaluate social aspects, economics and sustainability, a short version of the method "Duurzaamheidsscan voor de agrofood sector (Sustainable scan for the agro food chain)" is used. The method has been developed by Boone (Boone et al., 2005). The scan was developed in order of the Dutch Ministry of Economic affairs to evaluate innovations and companies in the agro food chain.
The method is influenced by thinking about CSR (Corporate Social Responsibility) and the ambition is to provide an understanding of the dynamic relationships between the triple bottom line, people, planet, and profit, and to measure and weight the effects of efforts to raise performance levels in all three of these domains.
In this research a short checklist of the "Duurzaamheidsscan" has been used and discussed with the leading participants who are responsible for the design of the applications in work packages 5-7. The checklist score and an explanation are described in this paper.
A simulation tool has been developed to evaluate the economic viability for robotic harvesting and precision spraying (**Fout! Verwijzingsbron niet gevonden.**). The simulation tool has been developed with the program Excel (Microsoft, Office 2010) and contains three main parts: conventional method, automated method and investment space (

Table 1). The tool should assist researchers and developers in a convenient way with the design of the application. By changing settings, such as cycle time or missed fruits or quality losses, the simulation tool should directly provide answers about the economic viability including investment space, capacity, required number of robots and payback time.

Table 1 Structure simulation tool economic viability

Conventional method	Automized method	Investment space and ROI
Basic information	Basic information (robot idea)	Investmentsapce
Labour costs	Labour costs if robot misses	Return on Investment
Investments and materials	Labour (operator) costs	
Quality losses	Investments	
	Quality losses	

3 Results

The results of the sustainability analysis have been summarized in Table 2.

Table 2 Sustainability analysis

Sustainability analysis for robotic systems	Sweet pepper harvest	Harvest grapes & apples	Precision spraying
People			
Landscape quality (concentration, smell)	O/+	O/+	+
Social Support (appreciation by citizens)	++	++	++
Labor (employment, education, working conditions, absenteeism)	+++	+++	+
Food safety (MRL)	+	+	+
Animal welfare and animal health (Failure, antibiotics, illness prevention, animal feeding)	+	O	O
Planet			
Energy (consumption)	+	-	O
Climate (Greenhouse gases)	+	+	O
Nutrients (surplus en emission)	+/o	+	O
Water(use)	+/o	+	O /+
Crop protection (inputs en emissions)	o	+	+++
Biodiversity (area en number)	o	O	O/+
Soil (Quality)	o	O	+
Plant health (Q-organism)	+	+	O
Particulates (emission)	o	O	O
Profit			
Income (yield, costs)	++	++	+
Capital (Investments)	-	-	-
innovation (power)	+++	+++	++
competitiveness (import/export)	+++	+++	++

3.1 Explanation sweet pepper harvesting

Less traffic movements of workers, during the day to the production site (+). Traffic is more spread due to workforce shifts during 24/7 production time (+). Also evening and night traffic to the production site (-). Robotic systems perform on maximum level in a clean environment and organized production site. Therefore, production sites need to be very well organized (+). In old greenhouses it is difficult (not impossible) to adjust the growing system and infrastructure to the robot. When robots are feasible it will also enhance the replacement from old to new modern production sites (+).

In the Netherlands 60% of the harvesting work is done by people from Eastern Europe (2010, Arbeidsmarktbeeld – Glastuinbouw). The other part of the work is done by people from other countries and students and pupils from the Netherlands. Less than 25% is done by native Dutch people. When robot systems get implemented there will be more Dutch workforce involved in building, selling, operating and maintaining the robot systems. This is good for the Dutch employment. It is the “foreign” group of people who often have to work under bad working conditions and high work pressure. In some cases foreign workers also suffer from bad transportation and housing conditions after working hours (+++).The new generation grows up with a lot of technology. Robots are fancy and hot and can be associated to a modern work environment. The work of harvesting sweet pepper is repetitive work during the whole day. It is monotonous work which is not very attractive and mostly done by foreign people (+++).

The work is repetitive, with much tension on body parts. It can cause injuries, such as RSI, back pain and other stress syndromes. Robot systems can avoid these injuries (+++). The work conditions are getting worse in greenhouse horticulture. Due to energy saving and improved climate control for maximum production yield, greenhouses are kept more and more closed. Due to closing greenhouses more and more CO2 levels are kept very high, summer temperature can rise above 30 °C and humidity can rise to 100%. In winter the temperature can be kept low and it can even be too cold to work in, with high humidity and increasing artificial lighting. Also, the new LED-light developments in greenhouses can cause strain on eyes and infect the day-night rhythm of people. The new light systems (LED) are not friendly to work under. Finally, due to new re-entry legislation, it is not allowed due to bring people into the greenhouse when chemical crop protection is used. Optimal climate conditions for people are diverging more and more from optimal climate conditions for the crop. In the future it is almost impossible to work full-time in a modern greenhouse. Robotizing the production site is the answer (+++).

People can spread plant diseases easily from plant to plant, and also from one production area to another. Sometimes measures of disinfection are taken, but are not always enough. Robotic systems do not move from outside to inside, disinfection is easier and can be done automatically. Robots contain quality sensors and obtain knowledge about place and time of harvested peppers (tracking and tracing). Problems with plant health or product quality can be more easily located and, as a result, measures can be taken. Food safety will improve (+).

A biological approach is used in sweet pepper to improve food safety by using less chemical crop protection. Insects and mites are often used to prevent pests and diseases. With robotic systems less chemical protection is needed, due to a better hygiene performance and consistent harvest cycles, so animal welfare of insects and mites will increase (+).

When robots replace human workforce there are no limitations to climate conditions. The climate can be adjusted to the plant needs. Plants grow very well under high CO2 levels, high humidity and high temperatures, under which people cannot work. By keeping windows closed in summer, such high levels can be reached. As a result, additional energy tools become more rentable. An example is energy storage in aquifers during summer for re-use in winter (++).

Robots need electric power to operate, but this is just a fraction of the energy saving that can be obtained by keeping more extreme climate conditions (-).

When windows can be closed more often, less CO2 will be emitted. Hence, environment pollution reduces (+).

Robots contain quality sensors and obtain knowledge about crop conditions. Problems with nutrient deficiency, diseases, or low product quality can be more easily detected and quick measures can be taken. The information will improve control of nutrient emissions (+).

Robots contain quality sensors and obtain knowledge about crop conditions. Problems with drought stress or water stress can be more easily detected and quick measures can be taken. The information will improve control of water use (+). By keeping greenhouse windows closed less water will be used by the plant (+).

People can spread plant diseases easily from plant to plant, but also from one production area to another. Measures are taken but are not always enough. Robotic systems do not

move from outside to inside, disinfection is easier and can be done automatically. Robots contain quality sensors and obtain knowledge about crop conditions. Problems with plant health or product quality can be more easily detected and quick measures can be taken. Pests and diseases can be located earlier and chemical measures are not always needed. Inputs will be reduced and because of this also emissions reduce (+). By keeping windows of the greenhouse closed, emissions of chemical crop protection additives to the outside air will be less (+).
It is not to be expected that a robotic system for sweet pepper harvesting significantly influences biodiversity (o).
Sweet peppers do not grow in the soil but in stonewool, perlite or cocopeat substrate. It is not expected that a robotic system for sweet pepper harvesting influences soil quality significant (o).
By using less chemical crop protection additives, plant health will increase. (+).
It is not expected that a robotic system for sweet pepper harvesting influences emission of particulates significantly (o).
A sweet pepper robot will be successful if the return on investment is three to five years and the robots meets the required functionality. In the long term labour costs are increasing, but robot costs are still decreasing. A sweet pepper robot will save labour costs and improve product quality and safety (++). In greenhouse horticulture many management care is put into human resource management. Much time is spent to recruit people, instruct people, improving quality of the work of every individual employee, and to adjust performance with costs. When robots are introduced in horticultural practice, management will change. More time is available for strategic market decisions and quality improvement of the system rather than spending a lot of time on individual employees (++).Robots are expensive. In the beginning the pay-back time might be up to five years and more. More initial capital is needed to invest in robots to harvest sweet pepper. In the beginning the economic life cycle might be even shorter than 5 years, due to weak components. In most greenhouse production areas, capital is generated from investors and banks. Investors and banks want to take limited risks, with short pay back cycles (-).
When sweet peppers can be harvested by robots other tasks in the greenhouse will follow. The way of producing the high value crops will change dramatically. Also the way to manage a sweet pepper production site will change and lead to new innovations to improve quality, tracking and tracing of products in the greenhouse, improve logistics, occupancy, maintenance and planning. (+++).
The information which is generated by the robotic system can be used for logistics in the greenhouse and at the place where sweet peppers are sorted and packed (+++). It is much easier to set up a production site or to grow to a larger scale. There is no need to educate people to a certain level of skills before you can start produce. This is also a risk because increasing the scale can become too easy and a surplus in production is easily generated. With the height of capital investments needed managing directors should be careful (-).
Western countries can compete again against countries with lower wages. Costs of logistics will increase by time and sweet peppers are produced in large volumes. Therefore it is desirable that production sites of sweet pepper are close to consumer. Robotized production sites have less problems with available workforce, housing of employees, parking and logistics of workforce, legislation of work (++).

Summary of sustainable system requirements for the sweet pepper harvester

1. Robotized production sites need to be located in areas where 24/7 economy is accepted and not a problem for nature, culture and social environment.
2. Production sites need to be clean and organized
3. Robotized production sites need to be located in areas where an educated workforce is available to sell, build, operate and to maintain robots.
4. Modern greenhouse production sites are in the future more difficult to work in due to extreme climate conditions. Before introducing robots it is important to make a risk analysis of the work conditions in the greenhouse. Possibly precautions need to be made for workers who operate and maintain the robots. Precautions could be special clothing, limited work time in extreme climate conditions, and health indicators. An-

other possibility is to move automatically robots to a climate controlled zone to maintain and repair the robotic system.

5. It is important to make an estimation of the use of electric power compared to energy savings due to robotic systems.
6. Only feasible payback times with a reasonable risk make it possible to acquire funding from investors and banks.

3.2 Explanation harvesting systems in orchards: grapes and apples

The sustainability analysis of harvesting systems in orchards: grapes and apples harvesting are similar to sweet pepper harvesting. This means that in general the use of robots for harvesting fruits and vegetables is very positive from a sustainability point of view. Only the main differences will be discussed here.

The working conditions in grape an apple harvesting can be very harsh for people in agriculture due to the outdoor condition, and high work pressure. Robotizing the production site could provide a very interesting answer to this problem.

A biological approach is used in apples and grapes orchard to improve food safety by using less chemical crop protection. Insects and mites are often used to prevent pests and diseases. With robot systems less chemical protection will be needed so animal welfare of insects and mites will increase (+).

Robots are expensive. In the beginning, the pay-back time might be up to five years and more. So, more initial capital would be needed to invest in robots to harvest apples and grapes. Moreover, in the beginning the economic life cycle might be even shorter than 5 years, due to new developments. In most orchard production areas, capital is generated from investors and banks. Investors and banks want to take limited risks, with short pay back cycles (-). Due to the seasonal harvesting periods for apples and grapes pay back times are expected to be longer compared to greenhouse horticulture where the harvesting season is much longer.

The sustainable system requirements for harvesting systems in orchards are the same as for sweet pepper harvesting, except for Sustainable system requirement number 4 (section 3.1) which is not applicable. Outside climate conditions will not change when using robots instead of human workers.

3.3 Explanation precision spraying

A detailed sustainable analysis is carried out for precision spraying (CROPS public deliverable 12.1). In general the introduction of precision spraying is positive to almost all sustainable aspects. Small sustainable risks are detected analyzing the profit of these systems and the people that are working with these complex systems.

Spraying with canopy optimised sprayers and close range precision sprayers require well educated and skilled personnel. This may possess some risk in the beginning, as farmers will be faced with the requirement of education. Required education may drive some farmers away from using precision spraying devices. On the other hand, orchards are usually located in remote areas, which face the problem of migration of educated people to more urban areas. Precision spraying offers the possibility that educated and skilled personnel stays in remote areas, offering interesting work, well-paid jobs and social security.

Current fans of orchard sprayers have power consumptions up to 25 kW, and consumption can be reduced by a substantial amount. The amount of increase of energy consumption will be in our opinion approximately offset by the reduction of power, required to drive a fan of the sprayer. For the close range precision spraying the required energy consumption may reduce in comparison with state of the art methods. Canopy optimised sprayer should be designed such that with less pesticides delivered also reduced energy consumption will be achieved. This may require improvements to the air delivery systems of state of the art sprayers.

Agriculture is not among the cash rich economic sectors. In addition, farmers must spend more and more money every year for seeds, seedlings, nutrients, plant protection chemicals

etc. This reduces availability of cash for buying new types of machines. In most orchard production areas, capital is only available from investors and banks. Investors and banks want to take limited risks, they require short pay back cycles, often limited to up to five years. The canopy optimised sprayer should be designed with cost of production in mind. If possible we should during the design use less expensive sensing devices and omit very expensive sensing devices like thermal or time of flight cameras.
During transportation of droplets from the spraying to the targeted area large droplets fall down before reach the target or slip down from leaves because of great weight. Such kind of losses is estimated to be about 10 – 20 % for current state of the art processes.
Pollution of soil leads to pollution of ground water, as rain washes the pesticides in the soil to the lower layers of the ground.
Soil compacting with spraying machinery will not be altered by using canopy optimised spraying, while using close range precision spraying for selected varieties and diseases/pests this may be improved. To reduce environment pollution and save the chemicals, only targeting of the sprayer is not enough. The sprayer must be able to produce the two phase pesticide flow of suitable properties, such that droplets will not fall to the ground before they reach the target or slip down from leaves.

Summary of sustainable system requirements for precision spraying

1. Canopy optimised spraying and close range precision spraying will require well educated and skilled operators
2. Canopy optimised sprayer should be designed such that with less pesticides delivered also reduced energy consumption will be achieved. This may require improvements to the air delivery systems of state of the art sprayers.
3. Canopy optimised sprayer and close range precision sprayer shall not require very expensive equipment like time of flight or thermal cameras, if possible.
4. To reduce environment pollution and save the chemicals, only targeting of the sprayer is not enough. The sprayer must be able to produce the two phase pesti-cide flow of suitable properties, such that droplets will not fall to the ground before they reach the target or slip down from leaves. This is especially important for close range precision spraying, because this process is much different from cur-rent state of the art pesticide application techniques. Flow properties like air and pesticide flow rate, air velocity, turbulence level, average droplet size etc. must be considered.

3.4 Simulation of economic viability

The simulation tool for the economic viability for sweet pepper and apple harvesting and precision spraying is public available from the project website (CROPS, 2012). One can request for the tool by sending an e-mail to the coordinator: jan.bontsema@wur.nl. The simulation has been developed with the program Excel.

With the tool it is possible to change functional and economical parameters and analyse the effect on cycle-time, required robots per ha, investment space and return on investment.
In the case of sweet peppers it is also possible to analyse the situation when a robot does not harvest close to 100% and extra human capacity is required to harvest the rest.
To exploit the potential of this option an additional small survey has been carried out. Conventional harvest data has been analysed during the season with different product densities in the greenhouse at peak time and at the beginning of the production season. Simulating this effect showed that a robot which only harvests 50% of the peppers could still provide an interesting business case.

4 Conclusions

In general, it can be concluded from this study that the use of robots for harvesting and precision praying in agriculture would have a positive effect on sustainability aspects. However, with expected payback times of 3-5 years, the lack of investment capability of the agricultural sector has been identified as the main risk for successful introduction of robots for precision spraying, and harvesting of sweet peppers and apples.

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