D 3.1.
Current and future agricultural practices and technologies which affect fuel efficiency

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Abstract

The report investigated how fuel efficiency could be improved in agriculture, providing signposts for future research and development, with the objective of informing agricultural equipment manufacturers, dealers and agricultural support organisations. The farming practices of precision agriculture, controlled traffic farming (CTF), direct drilling and minimum tillage, energy independent farms (EIF), hydroponics and vertical farming were established as priority topics for research and development. As were the technologies of hydrogen fuel cells, electric vehicles, automatic boom and variable rate application. Fuel efficiency improvement in the priority topics was high, ranging from a 20% fuel efficiency improvement in automatic boom technology and variable rate application, to an improvement in fuel efficiency of over 100% in hydroponics and vertical farming when compared to current arable farming. The priority topics ranged from being commercially normal practices from the present with direct drilling and min-till, to fifteen years or more in the case of hydrogen fuel cells, CTF and EIF.

Certain topics outside the top eight should be investigated further, due to their ability to provide a fuel efficiency improvement of over 20%. These topics were alternative methods of woodchip drying in the forestry sector, hybrid and contour mapping. The first could provide fuel efficiency improvements of up to 100%. Contour mapping could be straightforwardly integrated into the agriculture sector. These topics are recommended for further research and development.

1. Introduction

Background

The European Union (EU) has set a 20% energy reduction target for countries to comply with by 2020. The agriculture sector is a large consumer of energy and is being encouraged to assist in meeting this target. This target, in combination with rising fossil fuel prices, has resulted in many different developments in agricultural practices to reduce energy consumption. Efficient 20, a European project aimed at encouraging the agriculture sector to assist in reaching this target, commissioned this report to highlight the different practices and technologies that could result in improved fuel efficiency.

Confusion can arise when using different energy related terms, such as energy efficiency, fuel efficiency, life cycle assessment and fuel consumption. Further confusion can arise when the two agricultural variables of yield and chemical use are brought into the situation. To avoid such confusion, the terms, and their definition in respect to the report, are stated as:

Energy Efficiency – The percentage of energy outputs of a process in comparison to the total energy inputs. Yield is classed as an output, and chemical use an input, due to the energy use to create fertilisers, herbicides and pesticides. Thus, an increase in energy efficiency can be achieved through an increase in yield or decrease in chemical use.

Fuel Efficiency - The percentage of energy outputs of a process in comparison to the total fossil fuel energy input. Due to the use of fossil fuels to create chemicals, a decrease in chemical use will increase fuel efficiency. Likewise, as yield is normally the result of using fossil fuels used as inputs, an improvement in yield will increase fuel efficiency. Furthermore, replacing the fossils fuels used with alternative sustainable fuels will be classified as improving fuel efficiency.

Life Cycle Assessment – An assessment of energy used by a product from ‘cradle to grave’, i.e. from design and manufacturing, through its life and its final disposal.

Fuel Consumption – The total fossil fuel used by a product or process over a given period of time or distance.

Distinguishing the difference between energy and fuel efficiency was important when looking at alternative fuels and the technologies which use them. Establishing the effect of yield improvements and chemical use reductions was also important. Some of the technologies will have reductions in chemical use as the main benefit. Manufacturing the chemicals is energy intensive and uses fossil fuels, thus it is important to convert the reduction in chemical usage to an improvement in fuel efficiency.

Objectives

The objectives set for the report are stated. However, the report structure will not be based around these objectives as it would result in an unstructured report due to the quantity of technologies and practices investigated.

i. Establish how farming practice is changing to improve efficiency, identifying the latest research and emerging technologies which are likely to reach the market in 3, 5 or 10 years’ time.

ii. Determine how the machine manufacturers are adapting to, or driving these changing practices.

iii. Investigate what the companies producing diesel engines for agricultural vehicles are doing to improve efficiency.

iv. Explore what farmers are doing to improve efficiency. This should identify new techniques and methods that farmers are starting to adopt.

v. Signpost future research and developments.
Constraints

There were constraints set when the report was commissioned, and further constraints became apparent as the report was undertaken. The constraints are stated.

i. Agriculture is to be defined as both farming and forestry sectors.
ii. The report is to be aimed at informing agricultural equipment manufacturers, dealers and agricultural support organisations.
iii. A maximum of ten researchers to be approached.
iv. Any farming technologies and practices should only be targeted towards arable and fresh produce production. Thus, the research excludes livestock production.

Acronyms

AMS – Agricultural Management System
CDA – Controlled Droplet Application
CNH – Case New Holland
CPPS – Closed Plant Production System
CR – Common Rail
CTF – Controlled Traffic Farming
EGR – Exhaust Gas Recirculation
EIF – Energy Independent Farm
EPM – Engine Power Management
EU – European Union
EV – Electric Vehicle
GIS – Geographic Information System
GPS – Global Positioning System
ICE – Internal Combustion Engine
ICEV – Internal Combustion Engine Vehicle
JD – John Deere
LCA – Life Cycle Assessment
LED – Light-emitting Diode
NDVI – Normalised Difference Vegetation Index
NH – New Holland
PA – Precision Agriculture
SCR – Selective Catalyst Reduction
SRC – Short Rotation Coppice
SSNM – Site Specific Nutrient Mapping
UGV – Unmanned Ground Vehicle
VRA – Variable Rate Application

2. Material and Methods

A literature review was conducted investigating the practices and technologies effecting agriculture. This involved the use of journals, books, online and magazine articles, manufacturer pamphlets and opinions from unbiased people within the sector. This literature review specifically targeted fuel efficiency, and the changing practices and technologies that were not affecting this were removed from the process. The literature review formed the basis for the assessment of agricultural practices and technologies listed through Section 3 to 8. For each practice or technology reviewed, the effect on fuel efficiency was discussed and if possible quantified.

Following this process, a research priority table was produced, with each technology or practice rated in terms of improvement in fuel efficiency according to a set scale. They were also rated by what other benefits they could give to agriculture according to a set scale. These two numbers were added together, and the eight highest scoring became the priority topics for improving fuel efficiency in agriculture. This table is available in Appendix A.

The eight priority topics became the basis for a survey process. A prominent researcher for each of the topics was approached and surveys were tailor made for each of the topics, ensuring that relevant information was gathered. The important information was extracted and summarised in Section 10, the full survey results are listed as appendices.

The results of the literature review and survey process were discussed. Following this conclusions were made, giving strong signposts for future research and development.

3. Diesel Engines

Diesel engines have traditionally been the main focus in improving fuel efficiency in agriculture. Billions of pounds of investment have been made by the automotive sector into improving the diesel engine.

A major consideration when objectively looking at diesel engines is that the thermal efficiency of an internal combustion engine (ICE) is poor, with the most advanced diesel engines in the world only being about 50% efficient [48]. Currently most production steel diesel engines have a limit of 37% thermal efficiency and an overall energy efficiency of about 20% [50], thus the efficiency of the diesel engine is not anticipated to vastly improve and fuel efficiency enhancements will be limited. Therefore is it time to prioritise alternative methods for improving fuel efficiency in agriculture?

Diesel engine manufacturers argue that further improvements can be made to improve fuel efficiency. Some of the technologies that could or are currently achieving a fuel efficiency improvement in agriculture are detailed.

3.1 Emission Control

John Deere and New Holland and the other main machine manufacturers have adopted emission control products to meet European emissions regulations for their diesel engines. John Deere has opted to develop exhaust gas recirculation (EGR), whilst New Holland have decided against this for tractors over 100bhp and have instead
opted for selective catalytic reduction (SCR) also known as AdBlue.

EGR circulates the waste exhaust gases back into the engine cylinders, lowering the combustion temperature, which reduces the amount nitrogen oxide, a harmful emission produced by the engine [27]. However, in reducing the combustion temperature, the power, torque and fuel economy of the engine are reduced as the engine is less efficient. Thus EGR is reducing fuel efficiency, but does reduce emissions.

SCR uses a catalyst, AdBlue, to treat the nitrogen oxide in the exhaust gases, converting it into water and Nitrogen [40]. This is a post combustion process and has no effect on the engine performance. New Holland’s promotional material suggests otherwise, claiming the new engine ‘breathes clean fresh air’, but this is due to other design modifications. Furthermore, in the promotional material the effect of SCR is being combined with Engine Power Management (EPM) technology, which improves fuel economy, torque and power. Therefore, SCR does not improve fuel efficiency, but does reduce emissions.

3.2 Engine Power Management

New Holland use engine power management (EPM) alongside SCR in their EcoBlue engines. EPM tailors the engine power delivery to the operation that is being completed by the tractor [40]. Thus, a boost in power is automatically made available to the operator when the machine requires it. For example a 125hp rated tractor such as the New Holland T6050, runs at 125hp but has a reserve power increase available of around 36hp, raising the machine to 161hp for high power applications. Therefore because the engine is not running at full capacity all of the time, fuel consumption is reduced, improving fuel efficiency. New Holland states their EcoBlue engines improve fuel consumption by up to 10% and that power and torque are increased by 7% and 13% respectively [40].

3.3 Stop Start Technology

Stop-start technology has been introduced into the automotive industry, with the main companies such as BMW, Volkswagen, PSA Peugeot Citroen, Mazda and recently Ford all adopting the technology for their ICEs. The technology automatically shuts down the ICE as the vehicle stops; reducing the time the engine is spent idling. In the automotive industry stop-start technology typically reduces fuel consumption by 5-10% [53]. This technology could be transferred to agricultural machines, where depending on the operation being completed, machines can be idling for periods of time.

3.4 Piezoelectric Injectors & Common Rail

The third generation common rail (CR) diesel engine with piezoelectric injectors was launched in 2003 and was first used by Audi in automotive vehicles. The injectors consist of several hundred piezoelectric wafers, which expand rapidly when an electric current is run through them [45]. Using this method of injection increases injection speed, accuracy and fuel atomization.

It has been stated [47] that using a third generation CR with piezoelectric injectors in a turbo boosted diesel engine reduces fuel consumption and emissions. Robert Bosch GmbH [45] quantifies these reductions as 3% and 20% respectively. DENSO [16] have further developed the third generation CR diesel engine so that it now operates at a pressure of over 200MPa compared to 160MPa when it was first introduced, improving power and efficiency. This advancement has further increased fuel efficiency.

3.5 Petroleum Diesel Catalyst

Research has been conducted [56] establishing the effect of a ferrous picrate based homogeneous combustion catalyst on the combustion and fuel consumption characteristics of a diesel engine. The results indicated that the fuel consumption decreased and the thermal efficiency increased when using the catalyst. Fuel consumption was reduced by 2.0-4.2% depending on the load applied to the engine. Pending further testing it is something that can be introduced as an additive to diesel to improve fuel efficiency.

4. Alternative Fuels

4.1 Biodiesel

Biodiesel is a fuel that has been increasing in popularity due to it being cheaper than equivalent fuels. Research [49] states that there is little difference in fuel efficiency between a production diesel engine using the biodiesel and standard petroleum diesel. It was also stated that the efficiency of the engine depends on whether it has been set up for each type of fuel, with the right setup producing similar results between diesel and biodiesel. However, it has been stated [12] that there are good results in reducing most emissions using biodiesel with up to 50% reduction in carbon emissions using a 100% biodiesel fuel. Furthermore, because it is from a sustainable resource and is an alternative to fossil fuels, it can be stated that machines using 100% biodiesel fuel improve their fuel efficiency by 100%. However, most diesel engines will only run a 20% biodiesel to 80% petroleum diesel mix without any modifications, thus the fuel efficiency improvement is currently 20%.

4.2 Fuel from Pyrolysis

Another form of biofuel, currently at an experimental stage, is pyrolysis oil and synthesis gas (syngas) obtained from the pyrolysis of organic materials. A pyroformer
converts organic material into charcoal, oil and gas through heating the material. The ratio of each product is dependent on the running temperature, heating rate, heating duration, operating pressure and the type of organic material utilised [52]. Pyrolysis oil can be converted to syngas which can be used to create biodiesel. Research [52] yielded impressive results when establishing whether unconverted pyrolysis oil obtained between the 400-480 degrees range with added catalysts, could be used as a petroleum diesel substitute. The research used fish as the organic matter for the pyrolysis. Pyrolysis oil and petroleum diesel have similar efficiency and combustion characteristics. However, pyrolysis oil gives a significant reduction in most emissions. Establishing the fuel efficiency improvement pyrolysis fuel can give is difficult due to it being at an experimental stage.

Pyrolysis is a future technology that could be used in the form of a pyroformer on farms to convert waste organic matter into a fuel that can be used by machines. Sufficient charcoal is produced from the pyroformer to continuously heat the process to gain useful oil and gas. The technology lends itself to the ideal of an energy self-sufficient farm.

4.3 Hybrid Vehicles

Hybrid vehicles have become more popular and widespread within the automotive sector. Hybrid vehicles are split into two driveline configurations; series and parallel [26]. A series configuration has one energy converter providing power, and a separate energy source or sources providing the energy. An example of a series configuration would be a diesel engine generator charging batteries, powering an electric motor providing the vehicle drive.

A parallel configuration has multiple energy converters coupled together to provide a combined drive. An example of a parallel configuration would be the Toyota Prius driveline; electric motors and an ICE combine through a planetary gearbox, resulting in one combined drive. Typical series systems are generally less fuel efficient than parallel systems, due to the combined efficiency of requiring three propulsion systems; ICE, generator and electric motor [26]. However, the Caterpillar D7E hybrid tracked bulldozer shows that it can be an efficient configuration. The D7E has a 25% gain in overall efficiency and a 20% reduction in fuel consumption over the standard D7R model [9]. This technology could be transferred to the agriculture sector.

Research investigating the life cycle assessment (LCA) of a solar assist plug-in hybrid electric tractor [39] showed that during the complete product lifecycle the hybrid’s energy emissions were approximately 17% of a comparative diesel engine tractor. Energy consumption in this example was generated from renewable sources, exaggerating the emission savings as this change from fossil fuels was also used as part of the calculation.

4.4 Electric Vehicles

Electric vehicles (EVs) can be more fuel efficient than those powered by an ICE. The primary reason for this is due to the high efficiency of the electric motor, which can be over 80% efficient [26] indicating a gain of 60% over an ICE. However, Table 4.1 shows that when taking into account the electricity generation method from crude oil and other system inefficiencies, difference in energy efficiency and therefore fuel efficiency is minimal. Should the electricity come directly from renewable energy sources, for example an on-site wind turbine, then the inefficiency of using a generator is removed. If this was the case, an EV system would be approximately 55% efficient. This would represent a 35% improvement in energy efficiency and a 100% improvement in fuel efficiency as no fossil fuels would be required.

Unfortunately EV development has been hindered due to an insufficient international copper supply to mass manufacture electric motors. This will change as the aluminium electric motor is developed as an alternative. It is estimated aluminium electric motors are approximately 5 years away from commercial introduction.

Another issue with the electric motor specific to agriculture is that although it has a large quantity of torque available at low speeds, large EVs struggle with starting to move in high resistance situations; for example on hill starts. As a result there is a lot of work being conducted by electric motor companies such as ZF [55] looking at new transmissions to get around this situation. These transmissions should allow high torque from zero mph through the low speeds.

Table 4.1 - EV and ICEV Efficiencies (Source: Husain, 2003)

<table>
<thead>
<tr>
<th>ICEV</th>
<th>Efficiency (%)</th>
<th>Max.</th>
<th>Min.</th>
<th>EV</th>
<th>Efficiency (%)</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil</td>
<td></td>
<td></td>
<td></td>
<td>Crude oil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery (petroleum)</td>
<td>90</td>
<td>85</td>
<td>97</td>
<td>Refinery (fuel oil)</td>
<td>95</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>Distribution to fuel tank</td>
<td>99</td>
<td>99</td>
<td>40</td>
<td>Electricity generation</td>
<td>33</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Engine</td>
<td>22</td>
<td>20</td>
<td>92</td>
<td>Transmission to wall outlet</td>
<td>90</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Transmission/axle</td>
<td>98</td>
<td>95</td>
<td>90</td>
<td>Battery charger</td>
<td>85</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Wheels</td>
<td>98</td>
<td>95</td>
<td>98</td>
<td>Battery (lead-acid)</td>
<td>75</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Overall efficiency (crude oil to wheels)</td>
<td>19</td>
<td>15</td>
<td>20</td>
<td>Overall efficiency (crude oil to wheels)</td>
<td>14</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

4.5 Hydrogen Fuel Cells

The hydrogen fuel cell is similar to a battery; the difference is that as long as fuel in the form of hydrogen and oxygen is supplied to the fuel cell it will keep producing energy, whereas batteries produce electricity from stored chemical energy and need recharging [26]. The only emission from a hydrogen fuel cell in operation is water, although energy is required to produce the hydrogen required. New Holland
5. Changing Farming Practices

5.1 Direct Drilling & Minimum Tillage

Direct drilling and minimum tillage (min-till) are farming practices that have increased in popularity over the last twenty years. Both systems replace the plough as methods of establishing a crop. Direct drilling is pretty self-explanatory and drills the seed into uncultivated land, reducing the energy input considerably, but also reducing yield. The min-till technique uses tines and discs to cultivate, which both use substantially less energy than a plough, and has been shown to increase yields. It works on the concept that by turning over the stubble from the previous crop, this will decompose and produce the nutrients required for the following crop.

It has been stated [23] that direct drilling decreased yield by approximately 7% on average compared to ploughing over a three year period, and that min-till increased yield by approximately 2.5% on average. These figures vary depending on the quantity of passes. Amazone [3] states that the fuel consumption saving between min-till and ploughing is 41-46% during cultivation and tillage operations dependant on soil type. Bayhan et al. [4] states the fuel consumption saving during tillage operations is slightly higher at 49%, and estimates the fuel consumption saving between direct drilling and ploughing during tillage operations is approximately 89%.

These are impressive statistics, but must be taken with caution. Many farmers have stated that certain soils are not suitable for direct drilling, as they become hard without cultivation and lead to poor yields. This has resulted in the halfway stage of min-till becoming more popular, as it does not suffer from this issue as much.

5.2 Field & Tractor Course Design

Field design can have a strong bearing on the fuel efficiency of agricultural operations. Shape, contours and obstacles can all cause fuel inefficiencies due to increased manoeuvring or through reduced yield via nutrient loss. It has been stated [1] that efficiency of farm machinery operation can be affected by three factors: the travel speed, the effective swath width, and the field traffic pattern. Field design can impact all three, thus is an important consideration when trying to improve fuel efficiency. Long thin fields are often used abroad to improve fuel efficiency due to reduced machine turning. However, research in Spain [46] showed that machine efficiency improved very little above a threshold of one to two hectares. In large parts of Europe, increasing field size is unlikely due to the public’s value of biodiversity and smaller aesthetic fields.

The coordinates of tractors during spraying operations were recorded [42] using precise GPS coordinates, to establish the effect of tractor course on the consumption of fuel, time and chemicals. Using a predetermined optimum tractor course for each field resulted in up to a 16% reduction in distance travelled and a reduction of 10% on inputs due to reduced overlap and misses. Thus 16% of tractor fuel would be saved and reduction of chemicals would save fossil fuels in production. It can be estimated that in this case fuel efficiency could be improved by up to 20% with the use of a predetermined course in fields that are extremely irregularly shaped; this would drop significantly for regularly shaped fields. This is something that could be done now to improve fuel efficiency.

5.3 Precision Agriculture

“Precision agriculture offers the possibility of growing better quality crops, while optimising the use of inputs and minimising environmental impacts. It is a revolution in agriculture brought about by the application of information technology.” [13]. Thus any form of agriculture that uses some form of new technology is labelled precision agriculture. Precision agriculture is a change in farming practice to using technology to improve accuracy, yields and efficiency. As technology drives change through improvement, most changes to farming practice and new
agricultural technologies are linked to precision agriculture.

When looking collectively at the new and current precision agriculture technologies such as global positioning systems (GPS), aerial and satellite imagery, geographic information system (GIS) mapping, yield monitoring, site specific nutrient mapping (SSNM), contour mapping, normalised difference vegetation index (NDVI) mapping, the N-Sensor, automatic steering (autosteer) and automatic boom (auto-boom) systems, the technologies can provide an accumulative fuel efficiency improvement of approximately 80%. These technologies and the benefits associated with them are detailed in Section 6, dedicated specifically to precision agriculture.

5.4 Controlled Traffic Farming

Controlled traffic farming (CTF) is the practice of using one set of permanent tracks for all the machinery operations on the field. This reduces soil compaction across the rest of the field, which improves yield, reduces fuel consumption of machines with implements, and allows wider use of minimum tillage and direct drilling.

The use of CTF in Australia was estimated in 2005 as over one million ha [10]. One consideration to take into account is that in Australia the standard track width for the majority of agricultural vehicles is now three metres [10], ideally sized as the Australians have wider roads to transfer machinery about; this is not the case in the large parts of Europe. Furthermore, it was stated [10] that the main barriers of entry to European farmers are; incompatibility of existing machinery, cost of conversion, poor attitude from farmers to CTF and change in general, and contractors are unlikely to have compatibly sized equipment.

Due to the soil compaction benefits of CTF [15], uncompacted soils result in energy savings for operations such as tillage. Trials implementing complete CTF showed that “Energy demands for seedbed preparation fell by up to 87%, while power requirements for primary and secondary tillage were reduced by 45% and 47% respectively.” [10]; this represents an improvement in fuel efficiency of at least 45%.

Soil compaction also impacts yield through the loss of nutrients. “There is a considerable body of evidence to suggest that wheel loads in excess of 5000kg will cause a permanent 2.5% reduction in yield due to subsoil damage” [10], although the same source also states there was no clear relationship between soil type, yield and compaction. Furthermore, avoiding soil compaction can increase nutrient recovery by up to 20%.

5.5 Hydroponics & Vertical Farming

It was asserted [5] that plant growth in a rooting media, including soil, is technically hydroponic, as soils are water based solutions. However, hydroponics is often associated with suspending plants roots into a container based nutrient solution, replacing the need for soil. It can also be achieved by using an inert medium such as sand, gravel or perlite with a nutrient solution flowing between. The advantages of hydroponics are: complete nutrient management, increased yields and easier harvesting [44]. The main disadvantages are: no soil barrier to hinder the rapid spread of diseases and the high initial capital cost.

It has been stated [44] that hydroponics can increase yields per acre of cereals and fresh produce, from 38% in cabbage, to 3000% in tomato production as shown in Table 5.1. Where the produce is grown in artificial conditions and the yields are increased, it is presumed that the method uses more fuel per acre compared to traditional soil production. However, due to substantially increased yields, hydroponics could significantly increase fuel efficiency; in many cases by over 100%. A life cycle analysis of using hydroponics for each crop needs to be conducted to accurately establish changes in energy consumption.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield Per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soiled</td>
</tr>
<tr>
<td>Soya</td>
<td>600 lb</td>
</tr>
<tr>
<td>Beans</td>
<td>5 tons</td>
</tr>
<tr>
<td>Peas</td>
<td>1 ton</td>
</tr>
<tr>
<td>Wheat</td>
<td>600 lb</td>
</tr>
<tr>
<td>Rice</td>
<td>1,000 lb</td>
</tr>
<tr>
<td>Oats</td>
<td>1,000 lb</td>
</tr>
<tr>
<td>Beets</td>
<td>4 tons</td>
</tr>
<tr>
<td>Potatoes</td>
<td>8 tons</td>
</tr>
<tr>
<td>Cabbage</td>
<td>13,000 lb</td>
</tr>
<tr>
<td>Lettuce</td>
<td>9000 lb</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>5-10 tons</td>
</tr>
<tr>
<td>Cucumbers</td>
<td>7,000 lb</td>
</tr>
</tbody>
</table>

Vertical farming is the current and future research of hydroponics in urban high rise buildings, with hydroponic tanks on each floor resulting in a building for food produce. With the continuing exponential growth in world population, more efficient use of land will have to be implemented to satisfy the demand for food; vertical farming fits well into this ideal.

A similar technology in principal to hydroponics and vertical farming is the closed plant production system (CPPS). CPPS is like an artificial greenhouse, with on average ten layers of plants being grown indoors using artificial light. However, unlike hydroponics, the plants are grown in soil. Compared to a similarly sized standard commercial greenhouse, CPPS with ten layers can increase productivity by fifty to sixty times [32]. This is due to the use of artificial lighting, as it allows for more harvests, increased quality of plants, closer spacing of plants and multiple layers.

Currently, CPPS is at a fully commercial state, utilising autonomous irrigators [32]. The main benefit is for
greenhouse grown fresh produce, such as lettuce and for plants that are initially grown in greenhouses and then replanted in the field. In theory, artificial lighting could be used for growing any crop, but with larger crops, depending on the height of the building, layers would decrease, and harvesting becomes an issue.

5.6 Energy Independent Farms

The idea of farms that are completely self-sufficient in energy use and production is an attractive proposition. Research was conducted by the Swedish University of Agricultural Sciences looking at this idea [31]. The research investigated using ley or straw; a residue left over from arable production. The residue was put through an anaerobic digester to produce biogas; this was either refined to make biofuel or used in a gas turbine generator to satisfy the electricity requirements of the farm. The report states that all the energy requirements of the farm could be met from the straw and ley residues of 24% and 13% of the farm area respectively.

The same concept could be used with other renewable energy technologies such as solar panels, wind turbines, hydrogen fuel cells, biomass boilers, heat sink pumps and pyroformers. These could all be used to produce electricity or forms of biofuel, which could be used to fulfil the energy requirements of the farm. A realistic commercial model could involve several farms in a local area joining together for energy production, sharing the high initial capital investment in one or more of the technologies.

New Holland are trialling their new hydrogen 135hp fuel cell tractor at an energy independent farm near Turin, Italy [17]. The farm, La Bellotta, takes the idea of producing all the energy required on site and puts it into practice. The site has its own 1MW anaerobic digester (AD) on site and an 180kW photovoltaic panel plant installed to the roofs of the farm buildings [33]. This covers the energy requirements of the farm, and produces an additional income of excess energy sold to the local community. The mainstay of the farm is egg production, although it does have organic crops and forestry, most of which are used for biomass.

Both the examples show that energy independent farms are a realistic proposition, providing the technology chosen is correct for the resources and local environment. In a truly energy independent farm, fuel efficiency is improved by 100% due to the complete replacement of fossil fuels.

6. Precision Agriculture

6.1 Global Positioning System

The use of global positioning systems (GPS) to give precise location coordinates is a current technology being implemented in agriculture. Having knowledge of a machines position enables other technologies and farming practices such as CTF, yield monitoring, auto-steering, auto-boom technology and GIS mapping. GPS doesn’t improve fuel efficiency, but enables other technologies and farming practices that do improve fuel efficiency.

The Galileo navigation system is a GPS system being installed for exclusive European use. Whereas before GPS relied predominantly on US and Russian satellites which are susceptible to offline periods of time in times of war. Galileo offers free use up to a precision of one metre, but has a commercial option for one centimetre accuracy. This is an important development ensuring the technology can be reliably used uninterrupted all year round. The full array of 30 satellites is expected to be completed and launched by 2019 [18].

6.2 Geographic Information System Mapping

Geographic information system (GIS) mapping is an enabler to other precision agriculture technologies and forms the basis for which most of them operate. Data from different sensors and GPS coordinates provide the information input to be plotted on mapping from satellite or aerial imagery; this information is often shaded in different colours according to a pre-set scale. This allows for mapping of different variables across a field. For example, if yield was mapped from data taken from a yield monitor during harvesting, poor yielding areas of a field could be identified. The definition of a system is dependent on the image resolution used to create the map and the GPS and sensor sampling rates; the higher the resolution and sampling, the more accurate the mapping. GIS mapping does not improve fuel efficiency, but does enable other technologies which do improve fuel efficiency.

6.3 Yield Monitoring

Yield monitors are a commercially available product that records the moisture content and yield levels of grain as it is harvested, allowing management decisions about future trading and storage of the grain to be made. Yield GIS maps can be produced, showing variances in yield across a field and over harvests in different years. One way it can improve fuel efficiency is in parts of a field where the yield is not worth the energy put into growing the product. These areas can be identified and not planted, thus in doing so saving fuel and other inputs. This fuel efficiency saving is estimated at under 5%.

6.4 Site Specific Nutrient Mapping

Site specific nutrient mapping (SSNM) is best described as a halfway stage between standard spraying and variable rate application. SSNM uses GIS mapping to assess the field as a whole and fertilizer quantities are determined from this data. The amount of fertilizer required by a rice crop to achieve a profitable yield target is determined by the calculated crop response to the fertilizer [8]. The
timing of applications is decided upon according to critical growth stages of the crop. Each field therefore has a different level of fertiliser application. Research [22] conducted on rice in the Mekong Delta, Vietnam, showed an increase in yield of between 6-10% with the application of the SSNM technique. However it has been stated [11] that the energy use for an SSNM system can be up to a 10% increase in comparison to a standard un-specific spraying technique. Thus, the improvement in fuel efficiency is negligible.

6.5 Contour Mapping

The contours of a field can have a significant effect on energy efficiency, with corn grown on the summit or shoulder positions of a field being 30-40% less efficient [43]. This reduction in energy efficiency and therefore fuel efficiency was predominately due to reduced yields, caused by nutrient loss from slope run-off. Through GIS mapping of these contours, areas of the field that require increased or decreased fertiliser application can be identified to the farmer, improving yield and subsequently fuel efficiency. Implementing this into the practice of precision agriculture is anticipated to be a development in the near future.

6.6 Normalised Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) is a measure of plant growth, typically from satellite imaging. NDVI involves looking at the greenness of plants, mapping it and using this information for fertilizer application through auto-boom technology [11]. The greenness of the plant is matched to that of previous yields recorded for different crops, identifying whether a plant needs more or less nutrients to produce optimum yield.

It has been stated [11] that using NDVI mapping in accordance with variable rate application can reduce fertilizer use by 40%. Meisterling [37] states that fertilizer production accounts for approximately 25% of energy use in producing wheat crops using an LCA approach. Thus, using NDVI mapping can reduce energy use by 10%, improving fuel efficiency. NDVI and VRA combined will also increase yield by a similar amount using auto-boom technology.

6.7 N-Sensor

Yara, a UK based company has produced a product called the N-Sensor. The N Sensor measures the light reflectance of crops and relays this information back to its controller in real time. The information is instantly processed by the program and a suitable fertilizer application rate is selected for that part of the field. This allows for real time variable rate application of fertilizer without the need for a GPS system or nitrogen application maps. However, there is the option to add a GPS system for retrospective nitrogen mapping of fields for future planning. Currently software has been developed for winter wheat, winter barley, spring wheat and spring barley, winter oilseed rape and potatoes [54]. Software has also been developed for protein application in cereals. N Sensors are available with their own light source for operation at night.

N Sensor technology improves crop yields by up to 8% [54] and reduces fertilizer use; both improve fuel efficiency. Yield increase was confirmed by a case study on a 440 ha arable farm in Oxfordshire [25], where yield increased on average by 3% and the quality of the crop also increased. The additional power required to run the sensor has not been discussed in the company literature; using the sensor will increase fuel consumption due to the power required to run it. However, when balancing the increased fuel consumption with the increased yield and fertilizer use, it is estimated that the maximum fuel efficiency increase from the system is 10%.

6.8 Automatic Boom & Variable Rate Application

Automatic boom (auto-boom) technology uses GIS mapping produced from GPS data in the tractor to vary the rate of fertiliser, pesticide and herbicide application across independent sprayer nozzles across the sprayer. If the sprayer has already sprayed an area, it is detected in the mapping, and the nozzles covering that area are closed, reducing overlap. In irregularly shaped small fields, auto-boom technology can reduce fertiliser, herbicide and pesticide use by 15.2-17.5% [34]. NDVI, nutrient and contour GIS maps can also be used, with the areas requiring additional or reduced fertilizer identified, and spraying changed accordingly. This practice is also known as variable rate application (VRA). The technology does not affect fuel consumption, but when combined with autosteer reduces overlap, resulting in improved fuel consumption. VRA also improves yield, and therefore improves fuel efficiency. Furthermore, VRA reduces the amount of chemicals required, which is a high energy product.

N-tech Industries, California, is a company that specialises in auto-boom technology and VRA. They have two main products; Weedseeker and Greenseeker. Weedseeker is an automated spot sprayer that uses optical sensors on the machine to identify weeds and spray them. The same sensors are used on Greenseeker, but record the NDVI values and identify the amount of fertiliser required to achieve optimum yield for any particular spot in the crop. Weedseeker and Greenseeker make substantial savings on the use of weed killer and fertiliser respectively, and the latter actively improves yields. By combining the benefits of reduced chemical use, improved fuel consumption through reduced overlap, and an increase in yield, an estimate in fuel efficiency improvement is given at approximately 20-25%.

An alternative technique for reducing pesticide usage during spraying operations is controlled droplet application (CDA). This technique was first introduced by the spraying
company Micron in the 80s. CDA works by providing a gravity supply of chemicals to the sprayer nozzle, which creates identically sized spray droplets by spinning the nozzle through the use of a battery powered motor [38]. By having the correct sized droplets, substantial savings on pesticide use can be made. This technology has become widely used in handheld fertiliser applications, but could be used more in automotive applications as an alternative to pressure nozzle spraying. Concerns have been raised about vortexes being created behind tractors when fine droplets are used. If CDA and VRA could be combined, substantial reductions in chemical use could be achieved, resulting in increased fuel efficiency.

6.9 Automatic Steering Systems

Automatic steering (autosteer) systems use a GPS in the machine to plot a path for the vehicle to follow. This enables the operator to concentrate on the implement and the operation it is conducting, improving accuracy, saving time, reducing overlap on spraying, and improving machine efficiency. When combined with turning algorithms for the ends of the field [6], efficiency is improved further as the operator only has to manage speed settings and the implement.

John Deere AMS (Agricultural Management Systems) offer a full range of auto-steer systems, from minimal auto-steer to fully automated systems where no driver input is required for steering [28]. These automated systems reduce driver error and pass overlap, resulting in improved fuel efficiency. Other companies such as Trimble, Case New Holland (CNH) and Ag Leader also offer similar systems. These systems are currently on the market and ready to use, but uptake is slow due to cost, reluctance to change, and the reliability of GPS systems.

Autosteer is also an enabler for future fully autonomous unmanned ground vehicles (UGVs). These vehicles are already used in the military sector, an example is the Israeli Guardium UGV [20], which is set a patrol route to follow using GPS, but also has additional sensors which allow it to react to obstacles or unforeseen circumstances. These sensors are a combination of imaging, laser and radar. This technology could be transferred to the agricultural sector to enable an autosteer tractor to avoid obstacles such as electricity pylons or mid-field ditches.

In a case example from a 1050ha arable farm in Essex, UK, it was stated that over three cultivation passes and three drilling passes of the land, a total of 200ha of overlapping was eliminated [24]. This represents approximately a 3% improvement in fuel efficiency. This was a large farm; with smaller or irregularly shaped fields the amount of overlap will be higher. Combining this with the potential benefit from turning algorithms and the increased accuracy in which the driver can conduct operations, leads to a prediction in fuel efficiency improvement of between 5-15%.

7. Other

7.1 Varying Machine Size

The current tractor design trend has seen an increase in tractor size to improve operation efficiency. However, larger, heavier tractors use proportionally more fuel and cause unwanted side-effects such as soil compaction. It is anticipated by agricultural companies and researchers [21, 51] that the future of agriculture will involve smaller, fully autonomous unmanned tractors. These tractors have the benefit of reducing soil compaction, and use less fuel. Scientific principles show that the force required to move a tractor, is equal to mass multiplied by acceleration, with implements and rolling resistance acting as proportional resisting forces against the tractor. With a smaller tractor, the forces required are reduced due to reduced mass, rolling resistance, and smaller implements. Furthermore, smaller more efficient engines could be utilised.

The drawback is that more passes have to be completed by the tractor to cover the same field area. Research is required to establish whether smaller tractors with more passes are proportionally more fuel efficient than larger tractors with fewer passes. It is anticipated that the future design of autonomous tractors will be dependent on the operation, resulting in a variety of different size autonomous vehicles. Currently it is unable to quantify the impact size has on fuel efficiency.

7.2 Machine Maintenance

Machine maintenance can have an impact on fuel efficiency; a well maintained machine will be more efficient. By carrying out regular maintenance such as maintaining the correct machine settings and replacing filters the engine will run cleaner and will require less fuel to achieve the same power. It is a benefit that has been importantly advertised to agriculture for a long time now. This awareness drive should continue to ensure the importance of maintenance is recognised. It has been stated that correct machine maintenance can reduce fuel consumption by 5-15% compared with a badly maintained machine [2].

7.3 Implement Travel Speed

Selecting the wrong implement travel speed is another preventable cause for poor fuel efficiency. Each implement will be designed a different way, therefore will have different optimum operating speeds. Kichler [30] researched operating speed for two different tillage implements. The results showed that operating speed had a large effect on fuel consumption, in one case a 115% increase in fuel consumption. The results also showed that a slower or faster speed did not necessarily result in higher or lower fuel consumption; but rather it depended on how the implement was designed. Thus, if looking to reduce
fuel consumption and increase fuel efficiency, an optimum speed should be chosen for the implement according to the manufacturer’s specifications. However the trade-off between productivity and fuel consumption must be taken into account. The improvement in fuel efficiency depends on the implement and cannot be quantified for the report.

7.4 Lightweight Materials

Lightweight materials, similar to those used in the automotive sector, are beginning to be introduced to the agriculture sector. It has been stated [35] that lightweight aluminium alloys are being used for machine components where weight reduction is critical. An example given was the KRONE row independent maize header for the Big X forage harvester; cast aluminium gear housings are used for the different header drives. This saved about 120kg, enabling a larger header, in this case fourteen rows; without this modification the weight transfer of the rear axle would be too large.

Another set of lightweight materials that will have a large impact is the use of composites such as carbon and glass fibres. The body panels of many agricultural machines are made using glass fibre [35]. Other materials, such as metal-ceramic composites, will slowly be introduced into the agriculture sector as their use increases in the automotive sector. Lighter machines that are the same size as existing machines, retaining similar performance, will improve fuel efficiency. Quantifying the effect lightweight materials could not be achieved for the report, as it would involve investigating every machine component.

8. Forestry Specific

8.1 Shift Towards Energy Production

Due to the increasing cost of fossil fuels, there has been an increase in demand for wood to be used as biofuel across Europe. As an example of this increase in demand for biofuel, it is anticipated that by 2017 the demand for wood fibre in Britain will be fifty million tonnes [14]. However, Britain currently only has the capacity to produce twenty-three million tonnes. This leaves two options to make up the shortfall in supply; importing wood from other countries such as Canada, or increasing the supply.

This move towards energy production has benefits for trying to improve fuel efficiency, but does have a negative impact on the timber sector. Energy produced from woodfuel is considered to be almost carbon neutral, as trees use the carbon in the atmosphere to grow. Thus, replacing fossil fuels with woodfuel will result in an improvement in fuel efficiency in sectors outside of forestry. However, the timber sector still needs a supply of wood for construction, which is being threatened by this move to energy production. This improvement in fuel efficiency in the energy production sector is countered by the argument that importing wood from abroad is not fuel efficient.

The alternative of increasing wood fibre supply has led to substantial research into the use of energy crops such as miscanthus, trees with accelerated growth such as eucalyptus, the use of crop residues and looking again at short rotation coppice (SRC). Each option has a major disadvantage; energy crops challenge food security, trees with accelerated growth are killed by harsh frosts, using crop residues stops nutrients in the residue going back to the soil and SRC isn’t financially feasible.

Establishing the effect this change in forestry practice has on fuel efficiency is difficult, and the time was not available to calculate this for the report. However, it is definitely having an effect in the energy production sector.

8.2 Harvesting Methods

Varying harvesting methods can have an impact on fuel efficiency. A study [36] showed that by using a midfield operation in thinning and using wider spaced skid roads, productivity could be improved. Figure 8.1 compares the midfield method and the standard method typically used for harvesting operations. By felling trees towards the skid roads, using a harvester for trees within reach of the skid road and following up with a forwarder to collect the trees, productivity was improved by 11-27% for the forwarder
and 30-33% for the harvester. Thus fuel efficiency improved by the same amount. The machinery became more productive with this method as the age of the trees was increased. Furthermore, by using a chainsaw instead of a harvester for the felling of about half of the trees, fuel efficiency was increased further. Using this midfield method of harvesting could improve fuel efficiency by approximately 10-40%.

John Deere Forestry has produced a system called Timberlink for their harvesters and forwarders. The system measures productivity and fuel economy, showing the operator how to optimise the two whilst they are harvesting [29]. The information is recorded for management purposes, and operators who are efficient and productive are rewarded, whilst those that aren’t can be retrained using the techniques of the efficient operators. This is similar to a yield monitor on farming machines, and increases yield through management of technique. To quantify this fuel efficiency improvement is difficult due to variation between operators and management practices.

### 8.3 Woodchip Drying

Actively drying woodchips is an area within the forestry sector that would benefit from structure. From previous conversations with members of the Technical Development department of the UK Forestry Commission’s research arm, it was stated that there is no recommended or proven optimum method for actively drying woodchips. Currently it is done as seen fit by woodchip producers, with little regard or knowledge for fuel efficiency. Woodchips are dried to improve their calorific value for combustion by reducing moisture content.

A report commissioned into woodchip drying [19] stated that a fuel efficient method of woodchip drying had been introduced to a biomass power station in Sweden. The plant used the heat lost through thermal inefficiencies in the biomass generator to actively dry the woodchip supply for the generator. In this example fuel efficiency would be improved by 100% as no fossil fuels are used during the drying process. Furthermore, by drying the wood the calorific value of the chips was also increased. Similar improvements in the rest of Europe should be a priority in this sector.

### 9. Survey Results

#### 9.1 Priority & Recipient Selection

Each of the topics reviewed in the report were prioritised by their potential to improve fuel efficiency and the other benefits they could give to agriculture. This priority table and when the author anticipates that the topics will be commercially introduced and become commercially normal is available as Appendix A. The eight highest priority topics were identified, and an expert or researcher for each of the topics was approached. A survey was sent to each of these recipients, and the results of which are summarised in this section. Results for the topic of direct drilling and minimum tillage were not obtained due to the topic having been extensively covered in agriculture. Results for the topics of electric vehicles and hydrogen fuel cells were unavailable due to research conducted in these areas being commercially sensitive; the majority of research in these topics is conducted at a commercial level. To compensate for this loss of survey topics, a general survey on fuel efficiency in agriculture was sent to an expert in the topic. The full survey results are available as Appendices C - H.

#### 9.2 Precision Agriculture

Professor Khosla, President of the International Society of Precision Agriculture was approached for his opinion on a set of questions regarding the agricultural practice of precision agriculture (PA). Professor Khosla gave very detailed responses to the questions asked of him, thus this is merely a summary of what he said.

When asked about the affect PA can have on fuel efficiency Prof. Khosla states that fuel efficiency has been improved by farmers reducing the quantity of operations they have to conduct in the field through the aid of PA. However, he states individual technologies and practices have not been evaluated by the group regarding fuel efficiency. He also states that the time period for which PA becomes a normal agricultural practice varies upon the extent to which it is practiced; in the US approximately >75% of farmers use some form of GPS during operations, whereas very few are practicing variable rate application in comparison. Prof. Khosla believes PA will become more widespread sooner than most people anticipate due to the falling cost of technology combined with the rising cost of produce.

Prof. Khosla states that determining the most important tool for PA is very difficult due to the variability between different farms, with no ‘one size fits all’ option available. However he does state that the ability to predict water and nutritional needs for different crops is important, but is currently restricted by available sensing technology. At the end of the survey he states that this technology and robotic automation are two of the most important areas requiring development and research.

When asked what barriers are hindering the introduction of PA to agriculture, Prof. Khosla detailed the three areas of education and extension, compatibility and portability, and expectation and realisation. The first two areas have been issues in other technologies and practices. A detailed explanation of each is available in Question 5 of the full survey, available as Appendix C.

Regarding the period of time it would take for a farmer to repay the investment in PA from the results achieved, Prof. Khosla indicates that this is variable on the technology being utilised. Some technologies, such as variable rate application, will pay for themselves in the
first year, whilst others may take longer. The size and physical properties of the farm will also affect the impact of PA practices and technologies.

Regarding the opinion that PA is too complex, Prof. Khosla completely agrees with this and is sympathetic to frustrations farmers have regarding new complicated technology. He states that this is due to PA still being in its infancy and that this will improve over time.

Finally Prof. Khosla states that the big uptake in PA in the US has been a result of consolidation of farms. Farm sizes have grown significantly with the average farm size in Colorado currently over one thousand acres. These large farms are well suited to PA and find it easier to swallow up the initial outlay on PA technology through a scale up of the benefits. In many parts of Europe, with the exception of parts of Eastern Europe this is not the case, with smaller farms still prevalent. This issue can be negated by sharing equipment between farms, reducing the cost of investment. The full survey results are available as Appendix C.

9.3 Hydroponics & Vertical Farming

Dr. Dickson Dispommier from Columbia State University, New York, was approached as a one of the leading international experts in vertical farming. It was his belief that vertical farming would become a commercially normal practice and produce a large proportion of cities food requirements within ten years. He goes on to state that there are already commercial vertical farms in existence and that there are no barriers hindering the introduction of vertical farms. Taking this information into account, and the potential yield improvements stated in Section 5.5, it is the author’s opinion that this practice will become widespread within the ten years stated. The area which Dr. Dispommier indicates needs further development to aid the introduction of vertical farming is in the field of light-emitting diode (LED) efficiency.

Furthermore, four commercial examples of vertical farming were stated or mentioned in the survey, with Dr. Dispommier being involved as a consultant for the latter three. These were; the Plantagon seventeen story vertical farm in the Swedish city of Linkoping, a three story building in the South Korean city of Suwon, the four story Nuvege building in the Japanese city of Kyoto and the PlantLab Company in the Netherlands. The Plantagon seventeen story building in Sweden is set to become the international flagship building for vertical farming. The full survey is available as Appendix D.

9.4 Energy Independent Farms

Mr Luca Remmert, owner and farm manager of La Bellotta, Turin, Italy, was approached due to La Bellotta being one of very few farms that are completely energy independent. There were some language issues, but the information provided by Mr Remmert was very insightful into how these farms can become a reality. He states that in Italy, as with many countries in Europe, the farms are not big enough to merit each producing their own energy. This problem could be solved by the introduction of a sharing system between several farms, similar to how farms currently share machinery.

Mr Remmert also states that the farm has broken even on the initial investment it made into the energy production systems it acquired. The photovoltaic panels were introduced in 2008, and the anaerobic digester in 2010. The next technology planned to be introduced on the farm is a hydroelectric power generator to make use of the river flowing through the farm. It is important to note that the ideal energy generating technology for a farm is dependent on the local environment and the produce of the farm. Having detailed research to what technology is best for the situation is something that Mr Remmert specified as important.

In a separate email with Mr Remmert, he explained how the farm maintains its organic status, even though the faecal waste from the hens on the farm is fed into the anaerobic digester as opposed to being spread across the fields. The digestate, the waste product from anaerobic digestion, has very good fertiliser properties, thus is used instead. This is a mixture of digested crop residues and faecal waste from the hens. The full survey is available as Appendix E.

9.5 Controlled Traffic Farming

Mr Tim Chamen, Director of CTF Europe Ltd. was approached due to his high level of expertise and experience in the area of controlled traffic farming. Mr Chamen stated that a fuel saving of 35-40% can be made when switching to CTF with a minimum tillage or direct drilling approach, and that CTF will become common practice in 15-20 years. Mr Chamen goes on further to state that the main barriers to the uptake of CTF is an intransigent mind set by many farmers, incompatibility of current machinery and the perceived high cost of conversion. In relation to this he states that a fundamental change in machine design is currently under development and is likely to be exhibited at Agritechnica 2013.

Furthermore, Mr Chamen states that the period for full repayment in the conversion investment varies between twelve months and ten years dependent on the level of investment required in new machinery and the size of the farm. Regarding the perception that CTF is too complex, it was stated that this problem can be overcome through the demonstration of farms that have converted to farmers who are interested in conversion. Proof of improvement will be the main driver for increased CTF popularity in Europe.

Finally Mr Chamen states six priorities for future research for the topic of CTF, these were: management of the traffic lanes, management of non-trafficked beds and the possibility of designer soils, the extent of which CTF reduces nitrous oxide emissions, effective control of slugs and snails in low input systems, whether converting to
CTF simultaneously with direct drilling removes the issues of direct drilling, and the benefits and extent to which CTF could reduce tillage in root vegetable production. The full survey is available as Appendix F.

9.6 Automatic Boom & Variable Rate Application

Mr Tom Bals, Chairman of the Micron Group, a UK spraying company was approached for his views on variable rate application (VRA) and additionally for further information about the company’s controlled droplet application (CDA) technology. Mr Bals states that VRA is not as new a technology advance as it would seem, with Micron developing a VRA system in the middle of the 1990s. Due to the continued innovation in their own CDA technology, the VRA development was stopped due to research and development costs. Mr Bals also states that it is anticipated that VRA will become a standard practice in some form by 2025 on the majority of large arable farms in the UK. It is the author’s opinion that a similar estimation could be given for the rest of Europe.

Mr Bals continues by estimating that VRA can save between 0-70% in chemical use during spraying operations. Furthermore, CDA could save between 0-95% in chemicals in herbicide and pesticide use. Using the table given in Appendix B, VRA therefore could improve fuel efficiency by 0-17.5%, and due to fertilisers not being applied using CDA, the CDA technology could improve fuel efficiency by approximately 0-16%. Further improvement in fuel efficiency will be obtained from VRA technology due to a reduction in the number of passes a machine has to make. Mr Bals went on to make reassurances of how Micron is developing shielding to overcome the issue of vortexes behind sprayers when fine droplet sizes are used. Finally he stated that to improve the popularity of VRA, simple and cheap mapping needs to be researched and developed to make the technology more accessible. The full survey is available as Appendix G.

9.7 Fuel Efficiency In Agriculture

Mr Andres Annuk from the Department of Energy Engineering, Estonian University of Life Sciences, was approached for a general opinion on fuel efficiency in Agriculture. He is primarily involved in research for the sustainable energy sector which has strong links to many of the technologies and practices investigated by the report. Mr Annuk gave a conservative estimate for fuel efficiency improvement in agriculture of 2%, 3% and 5% for the next three, five and ten years respectively. This falls short of the European target of 20% reduction in energy use by 2020.

Mr Annuk also stated that in his opinion the key to improving fuel efficiency in agriculture is to improve ground treatment, by reducing the use of fertilisers and ensuring nitrogen is not lost from the ground. He also stated that optimising the distance travelled by machinery and the logistics system of moving produce is important. Furthermore Mr Annuk stated that cooperation from local producers was an issue stopping the improvement of fuel efficiency. To solve the problems hindering the improvement of fuel efficiency he stated that more resources are required to inform producers about energy, fiscal policies require change and new technologies need to be developed.

When asked what technologies or practices will be prominent in the future of agriculture in Europe, Mr Annuk stated that energy production will be more decentralized, with energy produced being utilised nearby. Also he stated that a smaller proportion of energy will be used with the use of different tillage systems. Furthermore he anticipated that logistics would be developed, so that the movement of produce will be designed around the most energy efficient solutions. Finally, Mr Annuk was asked what should be the research priorities for improving fuel efficiency in agriculture. He responded with the following priorities; development of new technologies and materials, integration of different technologies together, development of smart electricity grid systems to cater for local energy production, energy storage, and new technologies for obtaining liquid biofuels from local resources. The full survey is available as Appendix H.

10. Discussion

From the information gained from the literature review, it is the author’s opinion that a shift in focus should be implemented away from the majority of research funding being invested in the development of higher efficiency diesel engines. Only a small percentage increase in fuel efficiency can be gained from improving diesel engines, whereas much more significant improvements can be made in other aspects of agriculture. However, stop-start technology and the use of new catalysts in petroleum diesel are potential quick-win solutions to improve fuel efficiency.

The research priority table in Appendix A showed that the greatest gains in fuel efficiency can be achieved through changing farming practices. These were practices that are all currently commercially achievable, but are just waiting for the agriculture sector to start implementing them in larger quantities. The majority of changes in farming practice are available for existing arable and fresh produce farmers, with the exception of vertical farming, which will take substantial investment that is more likely to come from new business ventures. The future of agriculture is anticipated to be a combination of all these farming practices; how long until this becomes reality in Europe is dependent on the sector’s ability to embrace change.

Substantial improvements in machine fuel efficiency can be achieved from the renewable energy sector, with the hydrogen fuel cell and electric motors being important to this success. However, these will not become successful
and widespread until alternative electric motors become available, due to there not being enough copper to mass manufacture electric motors.

The topic of precision agriculture was looked at in detail due to the high quantity of technologies being developed that will have a role to play in improving fuel efficiency. The leading advance in technology to improve fuel efficiency was the use of auto-boom technology and VRA. Different packages are currently commercially available for VRA from various manufacturers. Future systems will see the majority of the precision agriculture technologies combined into one easy to use unit for the operator. The development of such a unit is being developed by large precision agriculture companies in the US, and to a slightly reduced state by Trimble in the UK. It is the author’s opinion that the majority of precision agriculture technologies will only be used by farmers if they become automated, or at least partially automated and easier to use.

Something else that can be done in the present is to further publish and make farmers aware of the importance of machine maintenance. This has been made common knowledge, but can be forgotten when farmers are busy. This is also important in the forestry sector for any mechanised machinery.

In the forestry sector, practice change is pushing the sector towards using wood for woodfuel to produce energy. As a result, the demand for wood fibre will soon outstrip supply. Whilst using sustainable energy sources such as wood to produce energy should be commended, as it improves fuel efficiency, other sources of supply need to be established to ensure huge quantities of wood fibre are not imported into the country. Another important improvement in the forestry sector is to establish the best practice for actively drying woodchip.

11. Conclusions

In conclusion, the farming practices of precision agriculture, controlled traffic farming (CTF), direct drilling and minimum tillage, energy independent farms (EIF), hydroponics and vertical farming were established as priority topics for research and development. As were the technologies of hydrogen fuel cells, electric vehicles, automatic boom and variable rate application. Fuel efficiency improvement in the priority topics was high, ranging from a 20% fuel efficiency improvement in automatic boom technology and variable rate application, to an improvement in fuel efficiency of over 100% in hydroponics and vertical farming when compared to current arable farming. The priority topics ranged from being commercially normal practices from the present with direct drilling and min-till, to fifteen years or more in the case of hydrogen fuel cells, CTF and EIF.

Certain topics outside the top eight should be investigated further, due to their ability to provide a fuel efficiency improvement of over 20%. These topics were alternative methods of woodchip drying in the forestry sector, hybrid vehicles and contour mapping. The first could provide fuel efficiency improvements of up to 100%. Contour mapping could be straightforwardly integrated into the agriculture sector. These topics are recommended for further research and development.
Appendices

Appendix A – Technology & Practice Evaluation Tables

Each of the practices and technologies were scored in Table A.3, according to the fuel efficiency improvement they could offer and the other improvements they could provide to agriculture, as scored in Table A.1 and Table A.2 respectively. The fuel efficiency improvement was taken from the literature reviewed when possible or calculated by the author, in some cases a combination of the two was used and as such all scoring of fuel efficiency improvements are estimations and should not be used as precise figures. If it was not possible to establish the fuel efficiency improvement, a score of N/A was entered in the table. The other improvements to agriculture in Table A.2 led to a scoring of one point for each improvement a technology or practice could offer, these scores were based upon the author’s opinion. Table A.4 shows the technologies and practices sorted by order of priority according to the score they received, along with an estimation of when the topic would be commercially introduced and when it would become commercially normal.

Table A.1 – Fuel Efficiency Improvement Scoring System

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<thead>
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<th>Fuel Efficiency Improvement (%)</th>
<th>Relating Score</th>
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</tr>
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<td>0-5</td>
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<tr>
<td>5-10</td>
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<tr>
<td>75-100</td>
<td>9</td>
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<tr>
<td>100+</td>
<td>10</td>
</tr>
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</table>

Table A.2 – Other Improvements to Agriculture Scoring System

<table>
<thead>
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<th>Other Improvements to Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions Reductions</td>
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<tr>
<td>Improved Power</td>
</tr>
<tr>
<td>Improved Torque</td>
</tr>
<tr>
<td>Improved Yield</td>
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<tr>
<td>Reduced Soil Compaction</td>
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<tr>
<td>Labour Reduction</td>
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<tr>
<td>Improved Accuracy</td>
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<tr>
<td>Enabling Technologies/Practices</td>
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<tr>
<td>Renewable Energy</td>
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<tr>
<td>Time Saving</td>
</tr>
<tr>
<td>Reduces Cost (Exc. Fuel)</td>
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<tr>
<td>Improved Food Security</td>
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<tr>
<td>Improved Energy Security</td>
</tr>
<tr>
<td>Area</td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td><strong>Diesel Engines</strong></td>
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<td>Emission Control</td>
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<td>Piezo Injectors in Common Rail Diesel Engines</td>
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<td>Stop Start Technology</td>
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<td>Biodiesel</td>
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<tr>
<td>Fuel From Pyrolysis</td>
</tr>
<tr>
<td>Hydrogen Fuel Cells</td>
</tr>
<tr>
<td>Hybrid Vehicles</td>
</tr>
<tr>
<td>Electric Vehicles</td>
</tr>
<tr>
<td><strong>Changing Farming Practices</strong></td>
</tr>
<tr>
<td>Precision Agriculture</td>
</tr>
<tr>
<td>Controlled Traffic Farming (CTF)</td>
</tr>
<tr>
<td>Direct Drilling &amp; Minimum Tillage</td>
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<tr>
<td>Hydroponics &amp; Vertical Farming</td>
</tr>
<tr>
<td>Field &amp; Tractor Course Design</td>
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<tr>
<td>Energy Independent Farms</td>
</tr>
<tr>
<td><strong>Precision Agriculture</strong></td>
</tr>
<tr>
<td>GIS Mapping</td>
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<tr>
<td>Yield Monitoring</td>
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<tr>
<td>N-Sensor</td>
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<tr>
<td>GPS</td>
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<tr>
<td>Autosteer Systems</td>
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<tr>
<td>Site Specific Nutrient Mapping</td>
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<tr>
<td>Auto-boom Technology &amp; Variable Rate Application</td>
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<tr>
<td>NDVI</td>
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<tr>
<td>Contour Mapping</td>
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<tr>
<td><strong>Other</strong></td>
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<tr>
<td>Varying Machine Size</td>
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<tr>
<td>Machine Maintenance</td>
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<tr>
<td>Implement Speed</td>
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<tr>
<td>Lightweight Materials</td>
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<tr>
<td><strong>Forestry</strong></td>
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<tr>
<td>Change to Energy Production</td>
</tr>
<tr>
<td>Harvesting Methods</td>
</tr>
<tr>
<td>Active Woodchip Drying</td>
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</table>
Table A.4 – Practices and Technologies Priority Sorted with Estimated Commercial Introduction and Norm

<table>
<thead>
<tr>
<th>Technology / Agricultural Practice</th>
<th>Score (Max 23)</th>
<th>Priority</th>
<th>Commercial Introduction (Years)</th>
<th>Commercial Norm (Years)</th>
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<tr>
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<td>Hydrogen Fuel Cells</td>
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<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Direct Drilling &amp; Minimum Tillage</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Electric Vehicles</td>
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<td>6</td>
<td>5</td>
<td>10</td>
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<td>Controlled Traffic Farming (CTF)</td>
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<td>Active Woodchip Drying</td>
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<td>Autosteer Systems</td>
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<td>Field &amp; Tractor Course Design</td>
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<td>Hybrid Vehicles</td>
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<td>Biodiesel</td>
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<td>Machine Maintenance</td>
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<td>Stop Start Technology</td>
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<td>23</td>
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<td>Piezo Injectors in Common Rail Diesel Engines</td>
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<td>24</td>
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<td>GIS Mapping</td>
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<td>Yield Monitoring</td>
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<td>Lightweight Materials</td>
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<td>GPS</td>
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<td>Emission Control</td>
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<td>31</td>
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<td>0</td>
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<tr>
<td>Implement Speed</td>
<td>1</td>
<td>32</td>
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</tbody>
</table>
Determining the fuel efficiency improvement from reduced use of chemicals required the use of an LCA of a typical agricultural production cycle. A report investigating the lifecycle of wheat by Meisterling et al. [37] was used as the example. Using conventional growing techniques including chemical application, it was stated that chemical production accounts for approximately 25% of all energy used in an agriculture production cycle. Table B.1 shows what a percentage reduction in chemical use translates to as an improvement in fuel efficiency.

<table>
<thead>
<tr>
<th>Chemical Saving (%)</th>
<th>Fuel Efficiency Improvement (%)</th>
</tr>
</thead>
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<tr>
<td>10</td>
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<tr>
<td>90</td>
<td>22.5</td>
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<tr>
<td>100</td>
<td>25.0</td>
</tr>
</tbody>
</table>
Appendix C – Precision Agriculture Survey

The survey results from Professor Khosla, President of the International Society of Precision Agriculture.

1. What research are you conducting or have conducted in the area of precision agriculture?

The main focus of my Precision Agricultural Laboratory at Colorado State University has been on quantifying spatial variability in soils for the purpose of precision nutrient management. However, in more recent years (~ past 7yrs), in addition to soils, we have been involved with crop sensing for in-season precision nutrient management and more recently, Precision Water Management as well.

2. What improvements in fuel efficiency (percentage) would you expect different precision agriculture techniques to give to an average arable farm?

Well that depends on the operation. For operations today, farmers have been able to couple several operations into one and hence have cut down on their frequent trips to farm fields. Quite logically in those situations fuel efficiency has gone up. I am not so sure about other methodically evaluated changes in fuel efficiency due to precision agricultural practices, something our group has not looked at.

3. In your opinion, how long will it take before precision agriculture becomes a normal farming practice? i.e. when a large proportion of arable farms are using this practice.

It is happening today as we speak. However, different people perceive precision agriculture differently. A great majority (approximately > 75%) of farmers in the United States are using some form of GPS equipped guidance systems on their farm tractors. Is that Precision Agriculture? Absolutely!! But are they all practicing variable rate seeding, nutrient, water and pesticide management, of course not. Are they all doing grid sampling, or management zones, or remote-sensing, or crop sensing, no they are not and we are not there yet. It will take additional time for us to be there. Price of technology is coming down and price of farm produce is heading up, with this combination we will get there sooner than what we think.

4. There are quite a few different techniques and technologies attributed to precision agriculture, which in your opinion is most important to the agriculture sector?

That is a tough question, because we do not have a technique or technology in place that is “one size fits all”. There is a reason why Precision Agriculture is also referred to as “Site-Specific Farm Management” what works in one farm, in one field doesn’t necessarily mean is good for all other farms and fields. The type of operation, scale of operation, scale of variability, resources available and many other factors govern what is the most important input/technique or technology that would be most important for each farm. Having said that, ability to accurately predict crop water and nutritional needs to maximize yield and minimize losses would be the one we need to continue to work on till we get there. This will require next generation of crop canopy sensors that can differentiate crop stresses (pest and diseases infestation, versus nutrient deficiency, versus water stress, etc.) Even within nutrients our ability with current sensors is really limited. We do not have technology to differentiate nitrogen stress from iron stress or potassium stress and so forth. We need next generation of sensors that would help us achieve that level of accuracy.

5. What barriers are there stopping the further use of precision agriculture in the agriculture sector?

There are many things we need to overcome for accomplishing further adoption of precision agriculture. I will share a few:

(i) Education and Extension: If you look back, you may realize that too much space-age technology was handed over to agriculture sector in a short span of time. Agricultural institutions, Colleges and Universities were caught off-guard and were not prepared to offer education and training on new agricultural technologies. This has changed over the years, however, more needs to be done to further strengthen University faculty and resources who would impart precision agricultural education to meet the growing need. This will require investment in the agricultural education. Likewise we need to extend this knowledge to “agents of change - technology transfers”, i.e., extension agents, crop advisors, crop consultants, and others. Some of this is happening right now, but it is a colossal task to bring everybody up to speed.
(ii) Compatibility and portability: Often times we hear the frustration from farmers that one piece of technology on their equipment would fail to communicate with other, which limits their ability and choices to expand and be creative with the available resources. That needs to change. Agriculture industry needs to become more transparent and allow compatibility across brand names and platforms.

(iii) Expectation and realization: We must realize that PA has been around only about 20 years that may seem like a long time, when really it is not. In many cases ‘technology is ahead of science. For example, we now have precision irrigation Pivot sprinkler system that can vary the rate of water application at every nozzle level. What we do not have is the science to make a decision on how much, when and where in field water needs to be applied such that it synchronizes with the spatial and temporal crop water use. We need time to research, develop algorithms, and evaluate current technologies to take out the guess work and frustration associated with working with new technologies.

6. What technology needs to be developed or changes need to happen to get past these issues?

I think, I have addressed those in my response to your previous question.

7. In your opinion, how many years would it take for a farmer to be repaid by the benefits of an investment in precision agriculture systems for their farm?

That is a great question. It depends on what component of precision techniques and technologies they are planning to acquire and use on their farm. The answer would vary. For example, agricultural retailers that are offering “precision nutrient management” practices to the farmers (i.e., grid soil sampling, management zone delineation, in-season crop sensing, variable rate nutrient application, etc) claim that most farmers not only could repay for these services they would benefit significantly (with savings in fertilizers and increase in yields) in the same year. Likewise, I have heard farmers telling me (depending upon the size of operation) that their investment in auto-pilot system was paid off in first year itself, because of the reduction in stress and fatigue, number of acres they were able to cover in shorter time span, reduction is skips and overlaps, etc.

8. There is a general, possibly misguided opinion from farmers that precision agriculture systems are too complex, how would you suggest is the best way to encourage farmers to change to this practice?

I would respectfully disagree with you. I believe in what farmers are saying, precision ag is indeed complex. As indicated in my previous answers to your questions, I think farmer’s frustration is well founded. It is them who are using a slate of new technologies and they find it difficult to get easy answers. I also believe that Precision Agriculture is young and there are growing pains associated with precision agriculture. It will take patience, education and extension to overcome this hurdle.

9. Precision agriculture has seen a large uptake from countries such as Australia and the United States, what do you think has driven this change?

There are a number of reasons for that. I can speak from the US perspective. We have seen a significant consolidation of our farms in the last 60 years. Our farm sizes have grown up significantly, for example average farm size in Colorado is currently 1000 acres (~400 ha). Labor costs have gone up and hence mechanization of farms with larger machinery were logically seen as feasible solutions to continue to farm and stay profitable. Precision techniques and technologies injected additional capabilities for the farmers and enabled them to farm even larger acreages in the same time frame. In addition, there are various other advantages of imbibing precision agriculture such as higher input use efficiency, increase in productivity, profitability and overall sustainability.

10. What do you believe should be the main priority for future research in precision agriculture?

It is hard to peg on one particular aspect. We would need to work in synchrony on multiple on numerous new technologies in area of remote sensing, water management, automation / robotics, machine vision and more. Precision agriculture is young and is the wave of the current time. We need to nurture it so that it grows into mainstream agriculture not only for large scale farming systems but also small scale crop production systems for less developed environments and countries. In my opinion Precision agriculture can and will play a pivotal role in achieving global food security working closely together with soil scientists, agronomists, agricultural engineers, ecologists and geneticist. Together we can bridge the gap in potential yield versus attainable yields in various environments around the world.
Appendix D – Hydroponics & Vertical Farming Survey

The survey results from Dr Dickson Despommier, Columbia State University, New York, expert in vertical farming.

11. What is your current specific research area within the topic of vertical farming?

Spokesperson

12. What impact can vertical farming have on the quantity of fossil fuels agriculture consumes and the harmful emissions fossil fuels create?

In the USA, we use some 20% of all fossil fuels just to farm (plow, plant, harvest, store, ship)

13. In your opinion what is the timescale for vertical farming to become a normal practice in cities across the world? i.e. when a large proportion of a city’s food requirements are being met through vertical farming.

10 years

14. What barriers are slowing down the uptake of this technology?

Nothing. The idea has just been out since 2006 on the internet. I wrote the book in 2010 and in 2011 there were three Vfs up! I know of several more in the planning stages or are being built. The one going up in Sweden, 17 stories tall, will become the flagship VF of the near future.

15. Are there any particular technologies in development that are crucial to overcoming these barriers?

LED lights could become more efficient.

16. Are there any commercial projects you have been involved with or have advised that could be used as an example of what vertical farming can achieve?

Sure. The one in Korea (Suwon), the one in Japan (Nuvege), the one in Holland (PLantLab).

17. What research topics would you suggest are most important to enable this technology to become normal practice?

Make LEDs more practical, no question!
Appendix E – Energy Independent Farms

The survey results from Luca Remmert, owner of La Bellotta energy independent farm, Turin, Italy. Unfortunately the language barrier caused some issues with the questionnaire. It is important to understand that Luca has made these technology implementations under advice from experts in the sustainable energy sector and is not an expert himself. However, Luca was very helpful and knowledgeable about his farm, and any further questions can be asked through his website contact form.

1. In your opinion how many years will it take for energy self-sustaining farms, similar to La Bellotta, to become normal across Europe? i.e. when a large amount of farms are completely self-sufficient in terms of energy.

The European situation is very different from state to state. Not familiar with all the other reality. in Italy the problem is that the farms are very small. It may not be a problem if the state would promote

2. Has the money invested in renewable energy technology on your farm (anaerobic digester, photovoltaic panels etc.) been repaid in energy sales and in fuel savings? Please exclude any external funding from this answer.

Even as I expected from the business plan

3. If not, how many years do you anticipate it will take for this money to be repaid?

N/A

4. Do you think there are any major problems which are stopping energy self-sufficient farms being introduced across Europe?

I don’t understand the question

5. Is there any technology you feel needs to be developed to solve these problems?

N/A

6. You are trialling the New Holland NH2 hydrogen fuel cell tractor, how does the farm create the hydrogen required for the tractor?

Not Yet

7. Do you have a biofuel electricity generator or boiler on site? This was not detailed on your website.

No I don’t have

8. There is a large quantity of hens at La Bellotta as your main agricultural product, have you used or considered using the waste from the hens for energy production? Or is it used for fertiliser on the farm?

The manure is used in all digesters to produce biogas

9. Would you expect other farms to have a similar level of success as La Bellotta should they invest in becoming energy self-sufficient? Please explain your answer.

Yes I think so, but I believe that the investment should be very well depth

10. Is there any other renewable energy technologies which you plan to add to the farm in the future?

Yes IDROELETTRICO
Appendix F – Controlled Traffic Farming Survey

The survey results from Tim Chamen, Director of Controlled Traffic Farming (CTF) Europe.

1. What research are you conducting or have conducted on the topic of CTF?


2. What improvement in fuel efficiency (percentage) would you expect CTF to give to an average UK arable farm? Please estimate.

35-50% fuel saving assuming a simultaneous move towards minimal or no till

3. In your opinion, how long will it take before CTF becomes a normal UK farming practice? i.e. when a large proportion of UK arable farms are using this practice.

15-20 years

4. What barriers are there stopping the introduction of CTF in the UK?

An intransigent mindset together with a lack of understanding by practitioners of the level of change that can be achieved through CTF. In addition, the incompatibility and inappropriate design of present machinery for delivering efficient CTF systems and a perceived high cost of conversion when the latter is often not the case.

5. What technology needs to be developed or changes need to happen to get past these issues?

Intransigence and perceptions will only change when farmers and growers start to realise the benefits and share their experiences with others. Machines will also need to become more compatible and there is some evidence that manufacturers are responding to this need. My personal opinion is that machines need to change more fundamentally, not only to deliver more efficiently to the CTF concept, but to bring about lower production costs through a higher level of precision and flexibility. Such a design based on the wide-span vehicle concept is currently under development and likely to be exhibited at Agritechnica 2013.

6. In your opinion, how many years would it take for a farmer to be repaid by the benefits of a full investment in a complete advanced CTF system for their farm? Again please estimate.

The answer to this is probably as variable as are farms! Some may realise a full return on investment in 12 months, for others it could be ten years. The latter reflects the fact that sustainable and cost-effective changes will depend where the farm finds itself in relation to machinery replacement. An example is a 200 ha farm that only invested £2000-£3000 in wholly CTF related changes but adopted an RTK auto-steer system to improve accuracy for potato production and a reduction of overlaps. This farm would probably have seen a return on investment within the first year. Another farm is in a five year programme timed to avoid or minimise any additional costs due to its conversion to CTF. A further farm realised a net saving in machinery investment of £250,000 and from 8-17% increase in profitability when converting over a period of three years.

7. There is a general, possibly misguided opinion from farmers that installing a CTF system is too complex, how would you suggest is the best way to encourage farmers to change to this practice?

Think and plan and in many cases the transition will actually prove to be simple. Farmers can only be encouraged to realise this by the example of others and through more compatible equipment becoming available. Seeing is believing, so sharing knowledge and visiting farms that have converted will be the most effective strategy for dispelling the perception of complexity. This is not to say that there isn’t complexity involved, it’s just something that farmers have not been used to thinking about.

8. What do you believe should be the main priority for future research in CTF?

i.) Management of the cropped traffic lanes. Researching the optimisation of tillage in relation to costs, crop performance and
maintenance of the function of the traffic lanes to support traffic.

ii.) Management of the non-trafficked beds. What tillage if any is needed on different soils and for different crops? Can we have a “designer” soil condition that does not get compromised by uncontrolled wheel compaction? We have never had non-trafficked soils before so there is a great deal we need to learn in how to manage them.

iii.) To what extent does CTF reduce nitrous oxide emissions? Much research evidence suggests that soils with greater porosity and improved drainage will reduce the risk of emissions, so does CTF actually deliver reduced emissions?

iv.) More effective slug and snail control in low input systems. The role of tillage, cover crops and novel highly targeted precision systems.

v.) Does converting to no-till and CTF simultaneously reduce the risk of yield loss and improve the profitability and sustainability of no-till systems?

vi.) Assuming the machinery is in place to maintain CTF through the establishment and harvesting of all crops, to what extent can tillage be reduced in root crop production and what other benefits might be derived from a system of this nature?
Appendix G – Automatic Boom & Variable Rate Application Survey

The survey results from Tom Bals, Chairman of Micron Group, Herefordshire, UK, manufacturers of spraying equipment.

1. How are Micron researching and developing the area of variable rate application and auto-boom technology? How can this link in with your CDA sprayer technology?

Micron sold the first variable rate application sprayer in Europe in the mid-1990s, developed in collaboration with Silsoe Research Institute after Micron purchased the key patents from the British Technology Group (BTG). Micron chose to make this available with standard hydraulic pressure nozzles (using a twin line system with pneumatically controlled valves to achieve continuous flow rate options), despite the fact that rotary atomisers are well suited to this application due to their high turn down ratio, since we felt it was important to focus on the one key area i.e. variable rate application, rather than confuse the market with a double innovation. However, due to the high (ongoing – and global) R&D costs and the need for widespread agronomic advice and support (which was simply not available at the time) we didn’t carry the project forward (although all the components of the system, including our PatchSpray controller, are still available).

2. In your opinion, how long will it take before variable rate application becomes a normal farming practice? i.e. when the majority of farms are using this technology for spraying applications.

In the mid-1990s we thought it would be standard practice by now. We now think it will be standard practice (in some forms) by 2025 on most large scale arable farms in the UK (majority of area rather than majority of farms).

3. What percentage of pesticides, herbicides and fertilisers can be saved by using variable rate application and/or CDA technology?

VRA - 0 – 70%
CDA - 0 – 95% (not fertilisers)

4. Concerns have been raised about spray vortexes being created behind a tractor when fine droplets are used, what solutions do you have or are developing to overcome this issue?

Shielding is an option we are developing e.g. see our Varidome, but we are not principally looking at high speed application to cereals (where air-assistance/air deflection are possibly better options although large scale shields have been used in Canada and a bluff plate in Australia). NB hydraulic pressure nozzles always produce smaller/fine spray droplets whereas CDA atomisers can eliminate their production if required.

5. Mapping of nutrients, yield, contours, obstacles etc. can all be used as an input for variable rate application, is this something Micron have implemented in their products or are looking at implementing?

We were not, and will not be, directly involved – but we implemented maps in our PatchSpray controller that was sold with our VRA unit.

6. In your opinion, is there any technology that needs to be developed or changed to make variable rate application accessible and feasible to the majority of farmers?

Cheap and simple mapping/patch identification are the key ie agronomic models.

7. What do you believe should be the main priority for future research in variable rate application and auto-boom technology?

See 7 above – the technology/hardware is there (and has been since we developed our VRA sprayer in the mid-1990s) NB cost of the technology/hardware is under £10K, and the sprayer we sold recouped its costs in less than two years just on fertiliser savings.
Appendix H – Fuel Efficiency In Agriculture Surveys

The survey results from Andres Annuk, Department of Energy Engineering, Estonian University of Life Sciences.

1. What research are you conducting or have conducted on the topic of fuel efficiency in agriculture?

My main activities are on the field of distributed energetics. Distributed energetics allows more efficient usage of local energy resources as wind, solar, geothermal and solid biofuels. One topic is cultivating and usage reed canary grass as energy hay.

2. What improvement in fuel efficiency (percentage) would you expect in the next three, five and ten years? Please estimate.

2%, 3% and 5%. This is enough conservative estimation.

3. What changing agricultural practices or new technologies do you think are most important for improving fuel efficiency?

Reducing energy consumption on soil treatment, for fertilizers especially for nitrogen. More nitrogen to turn back from agricultural coproduce. Reduce nitrogen evaporation using state of art technologies. From biogas production is possible to get back fertilizers. Optimizing transport distances.

4. What problems are there stopping the improvement of fuel efficiency in Europe?

One problem is insufficient cooperation of local producers. The legislation is enough supported of improvement energy efficiency in agriculture.

5. How do you think these problems can be solved?

More turn resources to inform of energy topics. Fiscal policies are need to revise. Develop new technologies.

6. What agricultural practices or technologies do you think will be the future of agriculture in Europe?

Energy production will be more decentralized. Produced energy used in nearby. More fertilizers used through closed cycle. Smaller proportion of energy capacious tillage on treatment of soils. Development of logistics on movement of materials and products on the assumption that energy saving.

7. What do you believe should be the main priorities for future research in to improve fuel efficiency in agriculture?

Acknowledgements

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Bibliography


