Kapitel 4

Chapter 4

Technologie-Qualität

Technology-quality

4.1 A FUTURE VIEW OF PRECISION FARMING

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4.1.1 Summary

This paper sets out a likely scenario for a future Precision Farming in 2025 from the perspective of the authors. It predicts that the increased use of Information Technologies will allow the care and management of crops in a very different way than we do now. The size of each management unit will continue to fall from hectares to individual plants in high value or perennial crops. Information will be readily available about all aspects of the crop, its environment, the likely yield and factors of risk. We will have the distinct possibility of creating a more intelligent set of machines that can behave sensibly in a semi-natural environment, unattended over long periods of time. The mechanisation systems will be redesigned to utilize these behavioural controllers and will likely result in small autonomous, highly specialised machines that modify the crop and its environment with the minimum amount of inputs and energy. This is likely to result in reduced environmental impact, increased economic viability and a more sustainable model for developed agriculture.

4.1.2 Current trends as indicators to the future

Trying to predict what is going to happen in the future is notoriously difficult and prone to errors. Even luminaries like Bill Gates is reported to have said, “Who will ever need more than 640 Kilo bytes of memory?” Most modern PCs now have more than 100 Mega bytes of memory. But a tried and tested way is to look at what has happened in the past, consider the present, and project the major trends through into the future then we can consider the implications. Although this cannot take into account sudden technological breakthroughs or political u turns, it gives us the framework in which we can explore a likely scenario.

4.1.2.1 Factors that drive change

What are the current drivers that promote change in today’s agriculture? Apart from political intervention and technological breakthroughs, it would seem there are two: economic drivers and environmental drivers.

As world prices for food products fall and production subsidies are phased out, many farmers today are under increasing financial pressure to remain a viable business. Farmers are trying different ways to reduce the cost of production. Many farmers are taking advantage of economies of scale in their farms such as increased farm size, larger fields and bigger tractors. This is leading to a more industrialised type of agriculture, which is at odds with the second driver – environmental considerations.

High production agriculture has utilised agro-chemical inputs such as fertiliser and sprays to increase and protect crop production. Recent food scares (PCBs in Belgium and BSE not only in the UK) have highlighted public concern about food safety that supermarkets are now willing to pay a premium for food products that have a record of all the treatments carried out on them. This public need for apparently clean and healthy foods have also been demonstrated by the rise in organic food production to such an extent that demand for organic produce outstrips production. Similarly, the public perception of herbicides and pesticides is so low that legislation in Denmark has been put in place to limit and tax the use of agrochemical inputs to minimise their use.

Both of these drivers promote a more efficient type of agriculture that is sustainable in the short and long terms. This type of crop production must be economically viable as well as environmentally sound. One way of achieving this has been embodied in the development of Precision Farming.

4.1.3 Precision Farming

Precision Farming (PF) is a systems approach to managing crops and land selectively. PF has been defined by the authors as "The management of spatial and temporal variability to improve economic returns and reduce environmental impact". This type of management approach utilises many forms of information technologies to help understand the complexity of spatial and temporal variability found on all farms. Management is the essential factor to achieve a stated outcome for the farm. A number of management strategies have been identified and developed to improve the overall efficiency, while taking into account specific crop, soil, economic, environmental and risk factors. Managers need to identify their own strategies and practices that allow them to deal effectively with the variability found on their farm in line with their personal values.

Three types of variability have been identified. The first type is spatial variability, which can be seen as changes across the field. An example would be where one side of the field yields higher than the other side. The second is temporal variability, where factors change over time. This can be seen when a crop starts by growing well but results in a poor yield. The third type is predictive variability. This is not a physical term like the other two but is the difference between what the manager predicted would happen and what actually happened. The classical example of predictive variability is where the manager predicts that a certain yield will be achieved if a certain amount of fertilizer is applied, but the crop does not achieve it because the weather changes. Each type of variability must be measured, assessed and possibly influenced, according to how significant it is.

Before the steam engine, and later the diesel engine, farms were managed on a small scale. After mechanisation, the field sizes increased, and now we have economic pressures forcing the scale even larger where a few people are running a number of farms. This means that the scale of management has changed from a few acres (the area a horse can plough in a single day) up to thousands of hectares. When farms are managed at this level it is difficult to have intimate knowledge about the soil types and field conditions.

Precision Farming technology has allowed managers to have a better understanding of field parameters at the sub field level while running a large farm. As these large farms are highly mechanised, additional instrumentation to measure the variability (e.g. yield mapping) and controllers (e.g. spatially variable fertiliser application) to help manage the inputs, can be easily added.

4.1.3.1 Measuring Variability

The first stage in the PF process is to measure important factors that indicate or affect the efficiency of the growing crop. The two main approaches are to create yield maps through instrumenting the harvesting system or assessing soil parameters by sampling. Both techniques give information about different parts of the cropping system. Yield maps are historic and cannot be used while the crop is growing, but record the actual yield during harvest. Soil sampling can be expensive but many soil parameters such as texture and horizon depths do not change over time, so is a good investment. Measuring soil nutrient status must be treated with care as repeatability, let alone accuracy, is difficult to achieve. Sampling strategies based on a simple grid tend to be expensive and better-targeted sampling techniques are being developed (Thomas, 1999). Furthermore techniques for monitoring crop properties during the growth period allow variable rate applications (VRA) with fertilisers or sprays in real time or as a subsequent cultivation (Heege & Reusch, 1996; Reusch, 1997). The crop management then directly reacts on the specific growth situations mainly influenced by the specific yearly weather conditions. Asset surveys can also be carried out to record physical features, such as field and crop boundaries, high trees that may cause shading, compaction in gateways, etc. Other high-density rapid assessment techniques are becoming more important such as remote sensing and aerial digital photography or non-contact sensing such as electro-magnetic induction (Wayne et. al., 2000). Aerial digital photography can give real-time information of the crop canopy and allow management to be modified while the crop is growing.

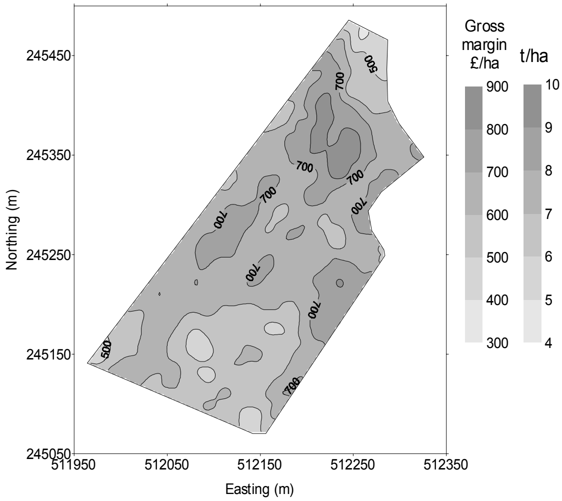

Fig. 4.1-1: Gross margin map with yield scale (1GBP = 1.62 €) (Data courtesy of Cranfield University, Massey Ferguson and Shuttleworth Farms, Bedfordshire, England

4.1.3.2 Assessing the Significance of Variability

Once the variability has been measured, it should be assessed to see how significant it is to the manager. Normally this is done by looking at the spread of the yield histogram or seeing if the extreme values lie outside acceptable thresholds, such as indices for soil nutrients. One technique is to reclassify yield data into 'gross margin' maps (Blackmore, 2000) as shown in figure 4.1-1. This technique deducts the variable costs from the income, which varies spatially with the yield, resulting in a gross margin map that shows which areas generated more income than others. Some gross margin maps have shown areas that actually loose money. Given enough detail, a similar map based on inputs could be produced to show environmental impact such as nitrogen fertilizers in a nitrate sensitive area.

4.1.3.3 Management of Inputs

Most traditional systems over-apply inputs such as seed, spray and fertilizer to reduce the risk of crop failure. With better assessment techniques, the inputs can be reduced or redistributed to optimal levels and the risk of failure can be managed. This results in making the overall production system more efficient.

Regardless of the country or crop, efficient management of an agricultural cropping system is complex. To improve the efficiency, computer based Management Information Systems (MIS) must be sophisticated enough to deal with this complexity and the manager's strategies and practices (Blackmore, 1996). The management input and computing support is the same in each country and each crop. Some crops may well have special considerations that should be taken into account when designing the MIS, such as planning the harvesting logistics when supplying crop to a processing factory.

Current positioning systems (usually based on the Global Positioning System) can now attain sub-metre accuracy. Although we can measure variability at this level it is not yet practical to manage at this level. The size of the management unit depends on the ability to measure, understand and manage it. The smallest management area may be limited by the machine width. A draft methodology for dealing with this in-field variability has been proposed (Blackmore & Larscheid, 1997).

Precision farming has now developed to such a level that the underlying principles are being identified (Blackmore, 2000). These principles show that PF can be applied to any country and any crop but the way in which PF is implemented (and hence the cost) will vary according to the local situation. But it is the management strategy adopted by the farmer that has the greatest economic and environmental impact.

4.1.4 Current trends in mechanisation

As farmers continually use economies of scale to push down costs, tractor and combine sizes increase. In conversations with some of the major tractor manufacturers, this trend will continue into the foreseeable future. This is partly due to the increased work rates, but mostly due to operator costs. If an operator's salary is to be paid, then is better to ameliorate it through higher work rates that come from the large equipment. With a large modern tractor such as a crawler type (figure 4.1-2) a single driver can spend less than 3.8 hours per hectare throughout the complete crop cycle of winter wheat (Rupert Gorm Reventlow-Grinling, Krenkerup, Denmark, personal communication). This very high level of working efficiency will be difficult to match with any smaller vehicle. These large tractors (the Challenger is 15 tons) also have drawbacks as the soil structure must support this weight as well as allow the crop roots to develop. The soil compaction caused by big equipment varies with soil conditions (soil texture and moisture content) and vehicle geometry (wheels or tracks), but whatever the conditions, the sub-soil still has to support 15 tons. Long-term deep soil compaction could be a serious problem in the future as it would be very difficult to carry out remedial action at such depths (Danfors, 1994).

Fig. 4.1-2: A crawler tractor (The Claas Challenger)

In 1994 Tim Chamen identified that a 70% energy saving can be made in cultivation energy by moving from traditional trafficked systems (Tractors and implements running on the soil) to a non-trafficked system (Gantry tractor running on tracks) (Chamen, 1994). This was for shallow ploughing and did not include any deep loosening. From this we can estimate that 80-90% of the energy going into traditional cultivation is there to repair the damage done by the tractors in the first place. If we can find ways to reduce the overall load that the soil must support, a significant proportion of this energy could be saved.

4.1.4.1 Technological breakthroughs

It is difficult to identify trends from technological breakthroughs as they inherently show a disjointed developmental profile. Nevertheless, certain avenues of research may well yield very great benefits and change the face of agriculture completely. Such examples are genetic engineering, new industrial crops and information technology.

The genetic manipulation of plants to provide previously unavailable characteristics is the goal of all geneticists. Whatever modifications are made, controversy follows. Specific improvements to a plant may well have distinct agronomic benefits such as making a tomato plant tolerate significantly higher levels of soil salinity, allowing it to be grown in areas that it could not have been grown before, has obvious benefits (New Scientist, 2001). Companies have taken this a stage further by patenting the use of certain genes and developing herbicide resistant strains of crop plants (e.g. sugar beet that is resistant to glyphosphate). Modifying the genetic markers in this way is a very hit-and-miss affair, as we do not yet know all the effects, let alone the implications of making these modifications. Progress will no doubtedly continue and improve our understanding but there is always the risk that a genetically engineered organism will be released into the natural environment that has significant undesired and irreversible effects.

Most of the developed agricultural production systems are dedicated to produce food crops. As global competition drive the prices down, alternative industrial (or non-food) crops may well prove an attractive economic alternative. Long-term trials are being carried out to look at the economic and environmental viability of alternative fibre crops such as willow (Kummel et. al., 1998). If tax regulations were relaxed, bio-fuels derived from oil seed rape (and sugar cane in tropical countries) could be commercially viable today. The political will to oppose the oil companies and loose lucrative tax income, is not strong enough yet. A detailed analysis of common industrial processes should be carried out to understand the possibilities of growing (and processing) alternative crops for industrial, non-food use.

Information technology holds the greatest predictable promise for development in crop production. Trends have been established over the last fifteen years that would appear to be stable enough to continue into the future. The Internet now holds the distinct possibility that any information that is needed, is on the Internet somewhere.

On a recent visit to Guangzhou province in China, there was a fish farmer who was struggling to sell his fish in the local market. He decided to join an Internet agricultural marketing service and he now sells his fish directly to an expensive restaurant in New York at many times the local price. The only difference between the two situations for the farmer was the information about a new potential customer and this was brought about via contact over the Internet.

4.1.5 A scenario of Precision Farming in 2025

It is inevitable that any forecast of agriculture is going to involve a significant amount of information technologies. Moore’s law states that processing power doubles every 18 months, so by the time we reach 2025 the computing power is probably unimaginable. What do we do with this computing power now? Effectively, the more computing power we have, the more complex problems we can solve. So as processor speeds have just gone through the 1 G.Hz barrier (in 2001) what complexity can we deal with when we have a 65 Terra Hz (65 terra hertz = 65000 Giga Hertz) computer? Presumably we will also have the associated memory, display and storage facilities to match this awesome processing power. Perhaps by then we will have developed programmes that can model the real world in better ways than we do now (Semenov & Porter, 1995). Most computer programmes are still highly deterministic (finite state machines) that reflect the views and values of the programmers, but with this power we should be able to have more sophisticated self-modifying software that can adapt itself to the individual needs of the users as well as improved modelling of the real world.

4.1.5.1 Management Information Systems

The embryonic Management Information Systems (MIS) we see now are no more than glorified databases. When we effectively remove the processing constraints, add in the data availability from the internet, integrate real world sensing systems, we have the possibility to develop an ideal information system that can give highly personalised management information on demand. We should be able to have answers to questions like: What are the optimum fertiliser rates for this field, taking into account recent weather, current crop price trends, actual soil nutritional status, risk of pest attack? etc. We can see the complexity rising exponentially with each factor we add, but these are only some of the factors a farm manger takes into account when making a decision. Although computers cannot and will not be able to predict the future with any real certainty, they can help us deal with these complex issues. What we need to develop alongside the hardware is the ability to embrace complexity without becoming swamped by it.

4.1.6 Future machinery systems

If we take a systems approach to forecasting what a future crop production will be like in 2025, we need to make some assumptions.

1. Land will still be used for crop production and hence will need mechanisation
2. IT progresses at the current rate enabling more intelligent systems
3. Economic and environmental drivers still promote efficient use of inputs

Over the last decade new information technologies, such as GPS (Global positioning System) and GIS (Geographical Information System), have been introduced that has allowed the scale of management to be reduced from farm level, down to field level and occasionally to sub field level. With the advent of new information technologies, such as behaviour-based robotics, this process can be continued into the future by looking at an even smaller scale such as plant scale technology or Phytotechnology. (From the Greek phyto, which means plant) These new Phytotechnology units will be small autonomous systems that can behave in a sensible manner for long periods unattended, caring for the individual plant from seeding through to selective harvesting. With this level of sophisticated equipment, it is likely that higher value crops such as in horticulture or forestry will be able to justify such an investment first. Very little new hardware will needed but the challenge will be in defining and implementing *sensible behaviour* and developing the systems architecture to support it.

If we try to utilise IT to the full extent we could replace many of the high-energy inputs such as fuel, herbicides and fertiliser, with more intelligent processes to achieve the same ends.

4.1.7 Autonomous vehicle requirements

To further improve the efficiency of developed agriculture, horticulture and forestry, found in northern Europe we are developing a new concept that proposes multiple small autonomous machines are more efficient than traditional large tractors. In order to meet this hypothesis a *small tractor with intelligent control* is required. These vehicles will be able to work longer hours at a slower rate, giving the same, or even greater, overall output as conventional systems. Each vehicle would be capable of working 24 hours a day all year round, in most weather conditions and have the intelligence embedded within it to behave sensibly in a semi-natural environment such as horticulture, agriculture, parks and forestry, whilst carrying out a useful task. Moreover, it may have less environmental impact if it can replace the over-application of chemicals and the high usage of energy, such as diesel and fertiliser, by control that is more intelligent. Additionally, it will require smaller incremental investment and will have lower labour costs. Finally, it may have very low soil compaction that would lead to a more sustainable production system (Blackmore, 2001).

The requirement for a more integrated approach to the varied agronomic operations that take place, starting with primary tillage and ending with crop harvesting, can be demonstrated by undertaking a systems analysis of the processes associated with the management of spatial variability (figure. 4.1-3). The decision-making process is complex but ultimately results in the production of a field operations map that contains the necessary control and guidance instructions required for a specific agronomic operation. A number of specific processes are involved.

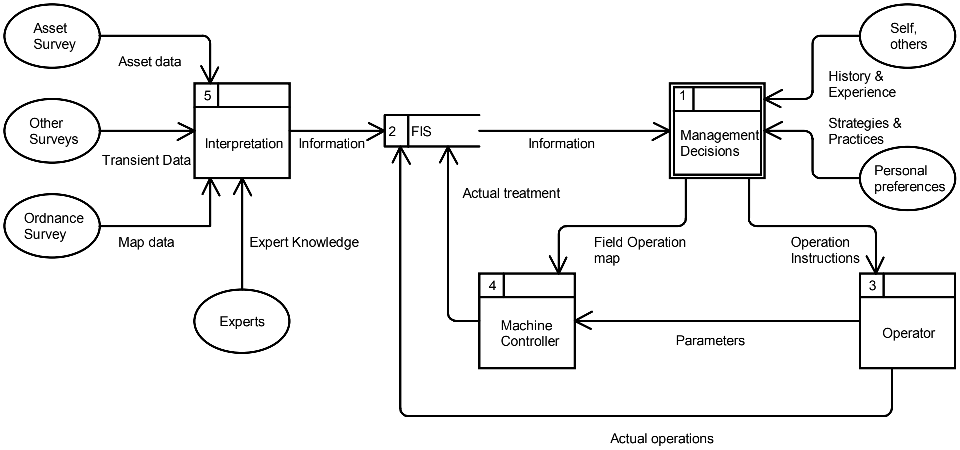

Fig. 4.1-3: Logical data flow diagram of the management process

Managers call upon their personal preferences and previous experience (1 in figure 4.1-3) as well as agronomically sound interpretations (5) of data from the farm information system (FIS, 2). In the field, the operator (3) may adjust various parameters on the machine and controller (4). These should be recorded as well as any other pertinent factors regarding the actual use of the machine, such as discrepancies, faults and blockages. The controller should also record the actual treatment, which may differ from the desired treatment, as this maybe useful management information when treating the field next time or trying to understand reasons for subsequent variability (Earl et. al., 2000).

If a suitable intelligent control system that exhibits sensible long-term unattended behaviour in a semi-natural environment can be developed then a completely new mechanisation system can be designed. To be able to achieve this the vehicle must have certain attributes and behaviours.

The main design parameters for this proposed vehicle are that it is:

- Small in size (and therefore unmanned)
- Light weight
- Exhibit long-term sensible behaviour
- Capable of receiving instructions and communicating information *
- Capable of being co-ordinated with other machines *
- Capable of working collaboratively with other machines *
- Behave in a safe manner, even when partial system failures occur *
- Carry out a range of useful tasks *

* These parameters are not discussed further here but a more detailed description can be found in Blackmore (2001).

4.1.7.1 Small size

A small vehicle size is very meaningful as it ensures a higher precision of operation, lower incremental investment, achieve greater public acceptance and is relatively safe during system failures. The main multi-purpose vehicle will probably be 1-2 metres long and in the 10-20 hp range, to be able to have sufficient power to carry out useful agriculturally related tasks. Even at this size, it may be too big and cause compaction. It will require an internal combustion engine unless fuel cells or equivalent technology have been developed. (Current battery technology is not good enough.) Smaller vehicles of less than a metre and around 5-10 hp could be developed for highly specialised tasks with low energy requirements such as non-contact sensing. Much smaller systems could be developed when higher density energy sources become available.

Incremental investment and replacement of the vehicle and high production runs could be achieved by using standard car components. Inevitably, the smaller vehicle will have a lower work-rate but as it will be unmanned, it can work for longer hours to compensate. Using site-specific fertilising and spraying, it can achieve a further reduction in inputs, if combined with appropriate sensors These small machines will be able to do selective and more precise treatments and can potentially be developed to sense and care for individual plants or sub plant manipulation, e.g. thinning, pruning, selective harvesting etc.

4.1.7.2 Light weight

The lightweight design parameter is important as it implies reduced soil compaction and lower energy requirements to move itself around. From Chamen's work we estimate that 80-90% of the energy going into traditional cultivation is there to repair the damage done by large tractors. If we can accept the premise of a light intelligent vehicle replacing the large tractors, there is the possibility to develop a completely new agricultural mechanisation system. As we have the possibility of very low compaction and mechanical weeding, then we do not need to plough, but use micro-tillage and direct drilling, which could play a major role in conservation agriculture. As the natural healthy soil bio-system modifies the soil structure into a near ideal situation for root development, almost zero compaction agriculture could be developed that allows the natural processes to enhance production rather than introducing energy to compact and then recreate a good soil structure. As the vehicle is inherently light, it should also require lower energy inputs although this is offset by the higher efficiencies of the larger engines.

4.1.7.3 Autonomous behaviour

The main behavioural requirement of this vehicle is that it will have sensible long-term unattended behaviour in a semi-natural environment such as horticulture, agriculture, parkland and forestry. This sensible long-term behaviour is made up of a number of parts. Firstly, sensible behaviour needs to be defined, which at the moment is device independent. Alan Turing defined a simple test (the Turing test) for artificial intelligence, which is, in essence, if a machine's behaviour is indistinguishable from a person then it must be intelligent. We cannot yet develop an intelligent machine but we can make it more intelligent than it is today by defining a set of behaviour modes that make it react in a sensible way, defined by people, to a predefined set of stimuli in the form of an expert system that can learn. Secondly, it must be able to carry out its task over prolonged periods, unattended. When it needs to refuel or re supply logistics, it must be capable of returning to base and restocking. Thirdly, safety behaviours are important at a number of levels. The operational modes of the machine must make it safe to others as well as itself, but it must be capable of graceful degradation when sub-systems malfunction. Catastrophic failure must be avoided, so multiple levels of system redundancy must be designed into the vehicle. Fourthly, as the vehicle is interacting with the complex semi-natural environment it must use sophisticated sensing and control systems, probably in an object oriented manner, to be able to behave correctly in complex situations.

Behaviour in general terms is a thematic set of reactions to a stimulus. Behaviour-based systems provide a means for the vehicle to execute a behaviour e.g. navigation, by endowing the vehicle with behaviours that deal with specific goals independently and coordinating them in a purposeful way (Arkin, 1998). Four main behavioural modes for this vehicle have been identified as: navigation, exploration, self-awareness and implement task mode.

1. The vehicle must be able to navigate safely to a desired position. We estimate that the vehicle will be in navigation mode around 80-90% of its time, as positioning itself and its working tool is the vehicle's main requirement. The vehicle must be able to plan an efficient route to the target point taking into account known objects, tracks, paths, gateways etc., as well as being able to react to unknown objects or situations. This high-level behavioural mode subsumes other lower level behaviours such as route planning and object avoidance.

2. The vehicle will be fitted with local environment sensing systems, which will enable it to explore and record an unknown environment. If the vehicle is initialised in an unknown area with an empty GIS, it can start to populate the GIS with its own data. In the exploratory mode, the vehicle will record data from all its sensors at the current position. If it assesses that it is safe to move ahead it will then move slowly recording relevant data as it moves. Once an area has been explored and surveyed, more optimal deterministic route plans can be made to carry out further detailed surveys. A good example would be a self-adaptive soil survey based on the position and the results from the sensor. Fewer readings could be taken from seemingly homogenous areas, while more intensive sampling can occur in areas of heterogeneity.

3. The vehicle will also be fitted with self-sensing systems built into it to keep a check that all the major parameters are within normal limits. Some of these parameters will be fuel level, engine temperature, tilt angle and outside temperature. It may be beneficial to add a small weather station as well so that it can return to base or close down if conditions get too bad. This behavioural mode is not mutually exclusive to any of the other modes so may be run entirely in parallel as a separate process.

4. Each implement will have its own special requirements for calibration and error checking. It is envisaged that each implement task will have sub-behaviours and that all the processes can be properly calibrated or checked. This will allow the task to periodically carry out a self-check to ensure all functions are working correctly. If an implement task recognises that the weeding tines are worn or that the camera lens is obscured it can carry out remedial action or instruct the autonomous tractor to return to base for servicing

4.1.7.4 Autonomous tractor

There are many different possible mechanical layouts for the autonomous tractor, varying from a multi-purpose vehicle similar to a small tractor today, through to highly specialised vehicle fit for only a single purpose. Four vehicle layouts are considered in Blackmore (2001)

1. A Conventional small tractor is a multi-purpose vehicle and it has mechanical, electrical power and communication interfaces to allow a range of implements to be fitted so that the vehicle and implement can undertake specific tasks such as mechanical weeding or crop sensing.

2. A small portal tractor has high ground clearance and can straddle a number of crop rows. It is likely to be single purpose and will have the implement task mounted within the portal frame. (An example is given in figure 4.1-6)

3. A medium sized portal tractor is similar to above but larger. It may have a standard mechanical linkage system similar to the Japanese paddy field tractors (s. fig. 4.1-4, s. annex, s. Anhang).

4. An example of a highly specialized very small vehicle would be an autonomous lawn mower.

Klaus Ellenreider reviewed alternative autonomous platform designs in 1996 (Ellenrieder, 1996) and a review of automatic steered tractors is given in Wilson (2000).

4.1.7.5 Autonomous cultivation and seeding

Ploughing is the classic form of inversion tillage and has been practised since mechanisation started in agriculture. The purpose of ploughing is to loosen the soil structure so that seedlings have mechanical support, access to soil moisture and nutrients, as well as to bury surface weeds to reduce competition. If soil is left alone with a healthy balance of flora and fauna, the structure needs no modification other than what the natural organisms provide. This means that the best thing to do with soil is leave it alone. When we run machinery over the soil we compact the structure and hence have to cultivate it to remediate the damage we have caused. If, in 2025, we were to use small very low compaction machines with intelligent control, ploughing could be replaced by micro-tillage (a few cubic centimetres) at the position where the seed is to be placed. The position of each seed (or row) could be recorded to assess the development of each plant and help guide a mechanical weeder around it. Furthermore the distribution of seeds over the area could be improved by autonomous techniques by placing seeds in special patterns. More even distributed plants achieve higher yields and have a better ability to suppress weeds (Weiner et. al., 2001). The upper graphic in figure 4.1-5 shows that with irregular seed spacing, there is significant internal competition for space (and nutrients). The lower graphic shows a more even distribution, and hence a more even access to space.

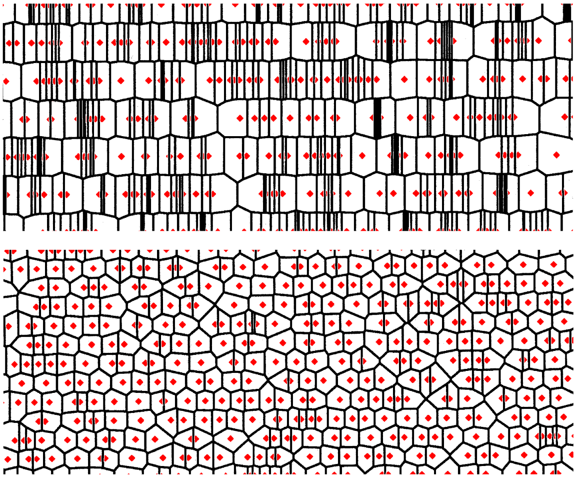

Fig. 4.1-5: Seed distribution over the area of wheat for conventional seeding and using more advanced seeders (Griepentrog, 1999)

4.1.7.6 Autonomous weeding platform

Chemical weeding is likely to be eventually be replaced by more intelligent mechanical weeding. This is a good example of replacing an environmentally unfriendly practice with a more intelligent process. There are many mechanical weeding implements available but the limitation of their use has been in differentiating between crop plants and weed plants. Recognition of species through multi-spectral machine vision may be one approach (Vrindts et. al., 2002), as could measuring the position of every seed as it was planted by using a high accuracy positioning system (Ehsani et. al., 2000; Griepentrog & Nørremark, 2001). If the weed (or crop plant position) is recognised then a suitable weeding mechanism can be employed to remove weeds even close to the crop plants (s. fig. 4.1-6, s. annex, s. Anhang). One mechanism could be the use of a high-powered laser to kill or damage each weed (Heisel, 2001). A system of this type would be able to kill or retard recognised weeds without any moving parts or the use of chemicals.

4.1.7.7 Autonomous scouting platform

Soil and crop scouting could be carried out by a very light, high ground clearance platform equipped with many solid-state, non-contact sensors to continuously record soil and crop conditions at different points within the field. This data could then be used to populate a GIS and be one of the basic inputs to the MIS. As weeds develop, or pest intensity increases, data could be stored over time and if certain thresholds exceeded, warnings sent to the MIS to alert the manager. A project to develop this type of machine has already been started within Denmark (Danish Research Project API).

4.1.7.8 Autonomous application platform

When chemical inputs are needed, such as fertiliser or pesticides, it is likely to be highly targeted. Information about the potential target could be gained from the scouting platform and used together with other information to apply the correct application rate to the target.

This vehicle could have a mobile weather station mounted on it so that it would only operate in suitable conditions.

4.1.7.9 Autonomous irrigation

An autonomous irrigation system would involve a precision applicator (example shown in fig. 4.1-7, s. annex, s. Anhang) combined with a water deficit model and an array of sensors. The robotic rain gun has a wind vane and anemometer to measure the wind conditions so that the rain gun head can be adjusted to compensate. This ensures accuracy of water application in all conditions. If the wind gets too high then irrigation will stop.

The system can accept a water application map to be able to vary application according to soil type. As there is complete control of the head, it can adjust to irregular wetted boundaries such as field corners and fence lines. It can also accept a second application map for chemigation at the same time. Chemigation is the introduction of agro-chemicals into the irrigation water, such as fertiliser or pesticides.

4.1.7.10 Autonomous selective harvesting

Current combine harvesters are huge machines costing up to € 400,000. They have very high work rates and separate the grains from the other biomass during harvest. This requires the transport of the bulky threshing mechanism.

An alternative system for 2025 would be to use a 1-metre stripper head (Tado et. al., 1998), which strips the ears directly from the straw, as part of a small autonomous harvester. The grain and chaff could be brought back to the farm for threshing with a stationary threshing machine similar to the hand harvesting system used many years ago. To transport the harvested mass to the farm it will still require large vehicles like tractors with trailers or trucks because of using public roads for longer distances.

Ten of these small autonomous harvesters have the same cutting width as a modern harvester, but have the possibility to carry out selective harvesting. This is where only the parts of the field that are ready for harvest will be cut or have a particular protein content. Varying seeding date and variety to widen the harvesting window is a currently used strategy that could extend the harvest window for smaller harvesters. They also have the same advantages of the other small autonomous machines of incremental investment, group reliability and have low soil compaction.

4.1.8 Discussion and Conclusions

The outcome from introducing this mechanisation system could be a very different way of achieving the same goals. Efficient, cheap production of crops with minimal environmental impact has been the farmer's goal for many years, but the opportunities offered by advances in IT now make it realistic to consider new alternative ways of achieving it. Most mechanical, hydraulic, electrical and computing systems are available today, but with the prospect of 'unlimited' computing power, we need to design new systems and control architecture to take advantage of it.

These new machine concepts can now start to be formulated with on one assumption and that is this computing power can be harnessed to give the machines (both MIS and autonomous vehicles) the desired behaviours. The main advances will be made in developing an information system architecture that allows emergent behaviour that can be recognised by people as useful. The associated cost will be relatively low as existing hardware can be used and the cost of processing power is always reducing. The only real development is in the architecture and software. If this is a valid assumption, a new generation of agricultural equipment can be designed, with integrated management support that gives an understanding of the economic and environmental impact of each action carried out. If environmental issues are of concern then environmental management practices must be adopted.

There will be a significant opportunity for small businesses to offer these machinery systems, competing directly with the existing big equipment manufactures. The first systems will no doubt be in high value niche areas, but once some machines have shown the viability of this approach, there will be a mass move with many competing products. Inevitably the first successful products will give the owning company the best reputation and the possibility of the largest market share.

Although these concepts have evolved with a developed agricultural system in mind, some of the ideas are equally applicable to less developed areas that have labour availability problems, high value crops or want to reduce agrochemical inputs. If they can be made sufficiently reliable, then they could also be used in countries that have lower technological support services as well.

If the desired behaviours can be embodied in the machines and new equipment allows autonomous plant scale interaction the cost of crop production should reduce dramatically. As we would also have more detailed crop information, we could achieve higher levels of crop care tuned to individual areas within the field. As all this will be automated, the associated data can be used for management and marketing as well as giving the required traceability. Individual grades of crop could be harvested at one time rather than harvesting everything (as is done now) and sorting it later. Knowledge of the quantity and qualities of the crop in the field before harvest would be a boon to the manager who could arrange their own futures market. It is important to find ways of adding value to products before they leave the farm.

4.1.9 References

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