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# The Organic Seed Market and
# Computer Vision Guidance Systems for Agriculture
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## 1. Introduction

Canterbury is an increasingly important area for the multiplication of vegetable seed for European seed houses (breeding and multiplication companies). Such crops are a useful addition to the typical Canterbury farmer's crop rotation and are also a potentially high value crop. Due to the implementation of The EU (European Union) Regulation 2092/1991 and the USA (United States of America) NOP (National Organics Program) requiring the use of organically produced seed in organic production systems, there is increasing demand for organic seed. New Zealand (NZ) seed multiplication companies have been approached by EU seed houses wanting organic vegetable and pasture seed and have been offered considerable premiums over conventional prices, in some cases guaranteed for multi-year periods. Considerable interest in organic vegetable and pasture seed multiplication has therefore been stimulated in the Canterbury area.

However, vegetable seed production is technically difficult and beyond the skill or experience of many farmers and growers. The NZ seed multiplication companies, with the technical support of the EU seed houses they contract to, have built up considerable in-house production experience and expertise. They work very closely with their farmers and tell them what they need to do to produce the crop. However, the NZ seed multipliers have little understanding of organic systems, so for successful organic vegetable seed production the relationship with the farmer is more a partnership of equals with both bringing equal amounts of expertise to bear. Even with this partnership there are a large number of unknowns in organic vegetable seed production in NZ, especially in the areas of pest and disease control, for which there are very few organic alternatives to the synthetic chemical controls available to the non-organic producer. Vegetable seed crops often face quite different pest and disease problems than they do as food crops, so success in growing a food crop is no guarantee of success in producing a seed crop. Organic vegetable seed is therefore a potentially high value crop but with commensurate high risk.

Charles Merfield and Tim Chamberlain were given a Lincoln Foundation grant to travel to the EU to study organic vegetable seed production and computer vision guidance for agriculture. Charles is a PhD student researching organic carrot seed production. Tim is an organic farmer who is growing a range of organic vegetable seed crops as part of his farm's cropping and livestock system.

The focus of the trip was to:

- Attend the first scientific conference on organic seed production, jointly organised by IFOAM (International Federation of Organic Agriculture Movements) the FAO (Food and Agriculture Organisation of the United Nations) and ISF (International Seed Federation);
- To discuss the organic vegetable seed market with key industry organisations in the UK to understand their positions and form an impression of where the market is heading;
- To meet and form linkages with scientists conducting research relating to organic vegetable seed production;
- To view and meet with the manufactures of interrow hoe companies and computer vision guidance systems (CVGS) to review current technology.

## 2. The Conference and the organic seed market

The conference was a first, not just for organic seed, but also for the FAO as it was the first conference it had organised and also hosted with NGOs (Non Governmental Organisations). For an inter-governmental organisation such as the FAO this was a major step, one they consider worked extremely well and is likely to be repeated.

The conference confirmed and extended the discussions we had had with seed companies, scientists and members of the organic movement prior to the conference, so we detail all the results of such discussions in this section.

There is a clear demarcation between the developed and developing countries, which mirrors the situation in the non-organic seed market. In the developed world, principally, the wider European area, North America, Australia, New Zealand and to a less clear extent, the developed countries in Asia, vegetable seed production is a highly specialist activity concentrated in an often very small number of large seed breeding and multiplication companies (seed houses) who often outsource the final multiplication of basic seed to other companies based not only in their geographical area but also other continents. Often these seed houses specialise in certain groups of vegetable species. The production of arable and pasture species is more diversified but large seed houses are still key players. The developing countries are much more diversified than the developed countries' systems. Often farmers are in subsistence, sub-subsistence or subsistence plus limited cash crop production farming. Farm saved seeds, and swapping with other local farmers is more the norm, compared to the highly technical production of the developed countries, especially for F1 hybrid production. Indeed the difference in the issues between the two was so stark the conference could be viewed as two separate, intertwined conferences such were the lack of cross over issues. While the issues of developing countries could well be viewed as more urgent and applicable to a much wider number of farmers and their dependants this report will focus on the developed countries' systems as they are the most applicable to the New Zealand situation.

## 2.1 EU legislation and the political and economic climate

It was clear from the conference that the non-organic participants, particularly those from the EU seed houses have a very limited, to non existent, understanding of the organic movement, its philosophy, the current status of the practical implementation of that philosophy and the compromises required in the current technological and economic climate. The majority of the large seed houses are involved due to the pressure of the EU and USA legislation, the clamouring of the organic movement, and taking a bit of a business 'punt'. Vegetable seed production is a 'difficult' business; it involves complex techno/biological issues in terms of plant breeding, especially for F1 hybrids. The time from the initiation of breeding of a new cultivar and its final stabilisation can be over a decade with many failures along the way. The multiplication process can easily exceed four years, while the final market of delivering fresh vegetables to consumers is subject to year to year vagaries. Organic seed production, which may account for between 0.5 to 2% of the amount of non-organic seed produced, has similar fixed costs and much higher production and retail risks, so is therefore an even more difficult business. Unsurprisingly, participants from the seed houses made it very clear that they see organic seed production as highly risky and completely unprofitable at present. Indeed some of the EU seed houses have decided not to become involved in the production of organic seed at this time, and those involved are taking a long term view of when it will prove to be profitable.

A key complaint of the EU seed houses was the status of the EU regulations. The regulations have required, since 1991, that organic seed be used in organic production systems. This was viewed at the time as impossible as no commercially produced seed was available, so the implementation was deferred until 2000, at which time it was expected that seed would be available. However, as 2000 approached little progress had been made, especially in vegetable seed, so a series of derogations were implemented so that non-organic seed could still be used. The process for managing the derogations / transition to organic seed in the EU was to set up national databases for seed retailers (mostly the large seed houses) to list the organic seed they had for sale. If a cultivar is placed on these databases (most if not all have a web interface, for example, www.cosi.org.uk ) then organic producers are required to use them. Originally there was supposed to be one EU-wide database but this was considered too difficult to implement. In addition to the databases that list what organic seed is available, there is also supposed to be an annex to the EU regulations listing those species which the regulating authorities consider to have a sufficiently wide number of cultivars available, so that there will be no derogation available for that species and only organic seed can be used. As with many EU regulations, especially those relating to agriculture, there have been a number of problems and compromises with this system, especially from the viewpoint of the EU seed houses. National databases require much more work to maintain than a single EU wide database. The EU annex has yet to list any crops, although some countries have started country annexes, e.g., the Netherlands, a process the seed houses warmly welcomed. There are significant issues with listing cultivars on the databases due to the organic certification rules on parallel production whereby producers who have both organic and non-organic production systems are prohibited from producing the same cultivars in both systems. The seed houses are concerned, that if they list their best selling cultivars on the databases then their large customers who are producing both organically and non-organically will change to a rival seed house's cultivar that is not available organically for their non-organic production. There is anecdotal evidence that this has already happened. As the non-organic accounts for the vast majority of seed sales this would be a major loss to the seed house. The situation has therefore arisen where seed houses have organic cultivars in their catalogues but they refuse to list them on the databases. As the databases are supposed to be the definitive list of organic cultivars the lack of such listings mean that progression of a species from derogation to annex is slowed. In short, it is a typical 'chicken and egg' situation, with all parties waiting for the others to sort their issues out before they will address their own!

## 2.2 The desires of the organic movement

As noted above the representatives of the seed houses have a very poor to non-existent understanding of the organic movement. They appear to view organics as a marketing system supplying a niche product to a niche market, and that the buyers are fully aware of the whole production system. The reality is the opposite, in that organics is a system of agriculture based on a philosophy of environmental sustainability. Most customer's understanding of what organics is about is very poor and they are even less well informed about the compromises from what is considered an optimal organic system and that which is feasible under current economic and social conditions. Nearly all organic customers rely on the various certification agencies to tell them what is organic and what is not. The IFOAM president had to reiterate and explain on several occasions that it is the organic movement, not its customers, that are driving the requirement for organic producers to use organic seed, as driven by a desire to improve the integrity of organic products. This has become more pressing with the introduction of transgenic ('genetically engineered / modified') crops, which are not allowed in organic systems. This has introduced a desire for 'ring fencing' organic reproductive materials to minimise the potential for contamination from transgenic organisms. A whole plenary session was devoted to the issue of co-existence of transgenic crops and organic ones; many opinions were given but no clear consensus or outcome was reached. This is to be expected from such a format and topic.

### 2.2.1 Organic seeds, organic cultivars and organic breeding

At present the focus of the organic movement and the seed producers has been on producing organic seed. The term 'organic seed' was given a clear definition at the start of the conference as meaning seed produced under an organic production system, ideally one that is certified. This definition was proposed as it was considered that there was potential for 'organic seed' to also mean a cultivar that has been bred to perform optimally in organic systems. For this the more accurate term 'organic cultivar / variety' was suggested as clearer terminology to avoid confusion. This differentiation is important because the long term desires of the organic movement are not just to have organic seed but to have organic cultivars that have been produced in a breeding system that is also organic, which could be called 'organic breeding' (within this document we use the terms as per the definitions just given). Such systems would not only outlaw such practices as transgenics but also other current breeding and multiplication procedures (often technically complex and laboratory based) that are incompatible with organic philosophy. This is a much longer term vision and one that the non-organic participants had considerable difficulty grasping with their conception of organics as a market led system. Implementing such a system would also be a major challenge for the large seed houses, in that it could entail two, possibly entirely separate, production systems from initial breeding to final multiplication; a hugely more complicated system than that required for 'just' producing organic seeds. Attempting to predict the implementation of such a vision, when the introduction of organic seeds is in its turbulent infancy would be foolhardy. However, members of the organic movement were happy to contemplate timelines of twenty to forty years for such a project.

### 2.2.2 Farm saved local cultivars

In addition to the desire to eventually have organic breeding, organic philosophy prefers seeds to be produced on farm using locally adapted cultivars, rather than a reliance on a limited number of large companies that breed, multiply and sell seeds, especially hybrid cultivars and cultivars that are protected by plant variety rights. Such a desire is going to be much easier to meet in arable and pastoral systems, and self sufficient situations in developing countries where on farm seed saving and selection is not significantly more difficult than producing the equivalent crop. For vegetables, as outlined earlier, on farm seed production and breeding are hugely more problematic. The existence of the specialist vegetable seed breeders and multipliers is strong evidence of improved efficiencies due to separation of crop production from breeding and seed production. It is therefore likely that vegetables will be the hardest to bring into line with aspect of organic philosophy in this respect. As an example, in the EU there are alternative vegetable seed production models in keeping with organic philosophy (for example, farmer seed production co-operatives), but they are very rare.

### 2.2.3 Determinants of seed and crop quality

Another important example of the different mindset of the non-organic and organic sectors is quality. A presentation at the conference by Bernard Le Buanec of the ISF presented convincing data of the yield increases that hybrid cultivars have produced, and questioned the belief of organic proponents that locally adapted, producer selected, open pollinated cultivars bred for organic systems were better, and that hybrids and modern cultivars out-yielded other cultivars even in production systems that they were not bred for, e.g., no synthetic nitrogen fertilizer inputs. While this is a compelling argument from a non-organic producers perspective who are paid by the weight of crop within market specification (typically size and visual appeal i.e., uniformity and freedom from blemishes), for the organic movement yield is only one of many quality factors including taste and nutritional quality, as it has a focus on the product quality from the perspective of the end user as well as the producer. Indeed the organic and environmental movements have criticised many non-organic and green revolution cultivars because of this focus on yield alone, pointing out that extra yield is of little value if it is due to higher water or carbohydrate content of the crop at the expense of other essential constituents such as vitamins and minerals. A situation they claim has led to nutrient deficiency in populations dependent on such high yielding crops, even though total calorific intake is more than sufficient.

## 2.3 Demand and supply of organic seed

While there is much turmoil, uncertainty and misunderstanding between the parties involved in organic seed production and supply, the situation 'on-the-ground' is somewhat more settled. There is an increasingly wide range of species and cultivars of organic arable, pastoral and vegetable seed now available. The perception we gained is that for arable and pastoral seeds most of the common species and cultivars are now available in sufficient quantities organically. This is somewhat to be expected as the marketed crop parts for arable crops is mostly the seed so the production systems for the crop and the seed crop are very similar. For pasture species the seed production system is relatively similar for seed and crop production. Seed production for these crops should not be significantly more difficult than crop production. For vegetables the crop and the seed production systems can be very different, especially for hybrid crops and biennials. It is therefore not surprising that vegetables have proven to be more difficult to produce organically and that their supply is the most limited.

### 2.3.1 Boom to bust?

However, we believe there is a significant caveat on the availability of organic vegetable seed based on the considerable seed multiplication rates that many vegetables exhibit. For many large seeded crops such as cereals seed multiplication rates can be as low as twenty, i.e., for every unit of seed sown, 20 units are produced. Vegetable seeds can have multiplication rates in the thousands so that only a small percentage of the cropping area is required to produce seeds. While many vegetable seed crops suffer from pests and diseases that are difficult to treat organically, the global nature of the seed trade and the small areas required, mean that optimal areas in terms of lack of pest and disease and ideal climate can be chosen, e.g., for carrot, hot, guaranteed dry summers, cold winters with surface or subsurface irrigation such as found in the inland Washington areas in the USA mean that sufficient seeds could be produced without great difficulty.  For example, our rough calculations for organic carrots indicate that one to two hundred hectares of organic carrot seed crop would be sufficient to supply all the organic carrot seed requirements of the developed world.  While some may consider this a large area, from the global vegetable seed production perspective it is insignificant.  Taking into account the areas we are growing and information on production in other countries, this area of carrot seed crop already exists or is close to being grown.  It is reasonable to suspect that the situation may be the same for other vegetable crops.

As demonstrated in many other organic sectors, e.g., dairy, meat, and even frozen organic vegetables in New Zealand, there is considerable potential for boom and bust cycles to occur when, in a short period of time, considerable resources and/or business interests are focused on a particular area that is seen as lucrative or behind the rest of organics.  The result is that in a few short years significant oversupply and consequential price collapse occur.  As producers of organic vegetable seed we are keen to ensure the current difficulties and undersupply in this sector does not rapidly result in rapid oversupply and price collapse, resulting in a series of market cycles before stability is reached.

### 2.3.2 Organic growers vs. growers of organics

A number of seed suppliers drew a distinction between different types of certified organic producers. This was neatly summed up by one supplier as 'organic growers' and 'growers of organics', where 'organic growers' refers to producers who are committed to the organic philosophically while 'growers of organics' are not philosophically committed and are generally in organics for economic reasons or they have been required to produce organic crops by their suppliers, e.g., the supermarkets.  Organic growers were viewed as determined to use organic seed while growers of organics were determined to avoid organic seed unless there was a financial benefit.  This description is of course not a polar one, as producers are likely to sit on a continuum between the two poles determined by their philosophical commitment and economic circumstances.  This situation helps illuminate the causes of some of the problems surrounding the listing of species and cultivars on the national databases and annexes, as discussed in section 2.1.

### 2.3.3 Seed houses and seed retailers

On the supply side as has already been noted some of the large seed houses have decided not to be involved in organic seed supply, and the ones that are involved are not philosophically committed and if the organic seed market does not prove profitable in the longer term they are highly likely to exit the market.  It appears that those that are currently involved are seriously committed to make it a success.

In addition to the seed houses who have breeding and multiplication programs there are a number of seed resellers who have no such breeding or production programs and act as wholesalers, re-packers and retailers, as there are in any other marketing chain.  Some of these are dedicated organic seed retailers who generally have a philosophical commitment to organics and also see the potential of such niche markets, and others who supply both organic and non-organic seeds for a range of reasons such as customer demand or a favourable disposition to organics without a necessary wholesale commitment to organic philosophy.  The views of such organisations are as diverse as themselves and their main markets; for example, home gardeners vs. commercial growers, which all adds to the complexity of this market.  It is noted, though we did not pursue it in any detail, that the non-commercial seed market, e.g., home gardeners, is a quite substantial market in its own right with often quite different demands from the commercial market.

### 2.3.4 The need for quality assurance in all organic seed

There is a feeling among the organic seed merchants and end users that some of the organic seed produced on a small scale outside the large seed houses systems is of dubious quality.  Anecdotal reports indicate that whole crop failures have occurred using such seed.  It would appear that the rigorous quality assurance systems developed by the seed houses and organisations like ISTA (International Seed Testing Association) are not being used for some of this seed. There were clear calls from representatives of organic movement at the conference that it was essential that organics did not repeat the mistakes of the 70s and 80s and offer substandard product to the market. While the idea was mooted of having different quality standards for organic and non-organic seed, there was a clear message that organic seed needs to meet not only organic standards but also seed production quality standards as well.

# 3. Computer vision guidance systems and interrow hoes

## 3.1 Introduction

With the area of organic cropping land continuing to increase globally and the increasing numbers of herbicides that are being deregistered, particularly in the EU, weed control by interrow hoes is increasing rapidly in both organic and non-organic cropping systems. However, the interrow hoes that were used before the widespread introduction of herbicides were designed for much smaller scale production, and their work rates are insufficient for current large scale production units. The labour market has also changed considerably, and the large amounts of semi-skilled labour that could be drawn on for many seasonal horticultural tasks, such as weed control, no longer exist in many developed countries. This situation has resulted in increasing numbers of brands (makes) of interrow hoes being developed and sold, with the authors having identified over thirty five different brands (excluding potato ridge hoes) in the EU alone. Many of these interrow hoes are substantial pieces of equipment, with working bouts as wide as twelve meters for multi section implements. There are a range of types of interrow hoe. There is the traditional hoe with various shapes of metal blades that cut though the soil which is the most common type; there are PTO powered machines, e.g., using a small rotovator (rotary hoe) unit between the rows, the horizontal and vertical axis brush weeders, and the ground driven basket weeder. The basket and brush weeders are somewhat specialist machines generally only used on intensive horticultural operations. The rotovator hoes are best suited to wider row widths and are popular for potato and other ridge crops. The metal blade hoes are mostly based on the principle of a toolbar to which are attached, via parallelograms, a number of independent hoe units with their height controlled via a depth wheel. There are a considerable range of different hoe knives and crop protectors to suit different crops, however they can generally be classed into two groups that are suitable for, (1) arable crops such as cereals and sugar beet that are large seeded, quick to emerge and grow, compete with weeds, and are relatively robust and (2) vegetable crops that are smaller seeded, often slow to emerge and grow, often quite delicate and are poor weed competitors. For the first group some soil movement into the crop row and disturbance by the hoe has little to no effect on yield while the second group is generally much more sensitive to disturbance. Therefore while the need for accurate hoe placement is important in the first group of crops it is critical for the second group.

In the pre-herbicide era accurate hoe steerage was achieved either by mounting hoes on specialist tractors such as tool carriers where the tractor driver could see the crop passing though the hoe from their normal driving position, or the hoe was rear mounted and an additional operator steered the hoe. Such work demands continuous high levels of concentration and even in optimal conditions the reflex times of human operators lowers working speeds significantly below than which the hoe could operate at. With the increasing size of implements and need for higher work rates these old steerage systems are increasingly untenable.

## 3.2 The manufactures of computer vision guidance systems

With the exponential increase in the complexity and power of computer technology in the last three decades the point has been reached where computer vision systems are so sufficiently advanced and cheap that it is now economical to use them to replace the human operator for hoe guidance. This technology is still very much cutting edge and while it is already in use on hundreds of farms it will undergo considerable evolution and improvement in the next five years. There are only three systems on the market at the moment Eco-Dan, Robocrop, and Autopilot.

Eco-Dan (www.eco-dan.com) is a Danish company started in 1999 with venture capital, dedicated to the design and production of its CVGS, which it terms a LPS (local positioning system) an acronym that has been deliberately chosen for its connotation with GPS (global positioning system) which is also being used to guide and steer tractors and other machinery to accuracies of a few centimetres. Eco-Dan are at a consolidation phase in the business cycle and are focusing on selling their existing system (approx. 300 units p.a. at present) rather than developing new systems or making major improvements / upgrades.

Garford (www.garford.com) who manufacture Robocrop, is a UK based agricultural engineering / manufacturing company with a background in sugar beet harvester manufacture. With the reduction in sugar beet production they diversified into interrow hoe design and production and linked up with SRI (Silsoe Research Institute) who had designed the software for the Robocrop CVGS. Garford are more recent entrants to the vision guidance market and have sold a total of approx. 50 units to date. They continue to work in close collaboration with SRI who are continuing to improve and refine the system.

Autopilot (www.fp-engin.dk) is being developed by Frank Poulsen an independent inventor. It is the newest entrant and not really market ready yet, however the vision technology being developed is far more advanced than Eco-Dan or Robocrop.

## 3.3 The principles of CVGS

While the details of CVGS are very complex the basic approach is relatively straight forward. A colour digital camera takes a continuous picture of the crop in front of the hoe, a computer program then determines the difference between the location of the crop row and the hoe and then aligns the hoe with the crop row. The complex / difficult part is creating the algorithms and software to work out where the crop row is. The rest of the hardware and software can be off-the-shelf componentry, for example Robocrop uses Microsoft Windows as its operating system and runs on standard PC hardware. All the companies use off the shelf hydraulic and electronic equipment and configure it to suit their needs as would any agricultural engineer. Both Eco-Dan and Robocrop ‘look’ for the crop rows by looking for the green pixels of the crop row that appear in a uniform straight line against a background of brown soil and randomly distributed weed cover. There are minimum requirements for the system to be able to detect the crop row:

- The crop must be of a sufficient size and density
- The crop must be green (red crops can not be detected at present)
- The weed population must be sufficiently low and random for the crop rows to ‘stand out’
- There must be sufficient area of bare soil between the crop rows

In essence CVGS needs a crop row that stands out against the background to be able to work. It is currently nowhere near the ability of the human eye and brain to identify crop rows. However, the difference between CVGS and human capability is likely to decrease as higher resolution cameras become available and better software is written. It is likely that, with the ability of cameras to see in parts of the electromagnetic spectrum that the human eye can not, e.g., UV and infra-red, that eventually computer vision detection of crop rows will be better than human.

While current computer vision is not equal to human vision, computers exceed human reaction time and accuracy many times and do not suffer fatigue. The computer can adjust the position of the hoe many times a second and position the hoe more accurately than a human ever could. The computer also does not suffer from lapse of attention or fatigue, which a human having to concentrate on steering a hoe does. This means that while the computer vision system can not detect rows as well as a human, when it is in a situation that allows it to accurately determine the rows it will outperform a human several fold. The reaction time is such that it is the tractor and hoe design that limits forward speed, e.g., tractor bounce and soil throw, rather than the speed and accuracy of the hoe steering. Plus the system can operate continuously with no loss of performance - even at night with artificial illumination.

## 3.4 Differences in the technologies

The key differences between the Eco-Dan and Robocrop systems is the Eco-Dan cameral looks vertically down at a single or two rows using one camera per row while the Robocrop looks ahead at multiple rows with a single camera. There are pros and cons for both approaches. The Robocrop deals with gaps in the crop rows better as it is averaging information from many rows. However it needs a clear view of several meters in front of the hoe, which if the hoe is rear mounted and is only the width of the tractor is a problem. In such situations Eco-Dan looks at the crop in the gap between tractor and hoe. In addition the Robocrop software can currently deal with multiple seed lines within a single drill row, and will be easier to adjust for different crop row spacings and numbers as these are programmed into the software and can be saved and then retrieved at a later date. Eco-Dan has no ability to deal with multiple seed lines in the row and has the potential to jump from one of the seed lines to the other potentially resulting in crop loss. Further software work is required to address this. One complication of the Robocrop system due to it looking forward is that the system needs to know how far ahead it is looking and what the forward speed is so that the required delay in the hoe tracking can be calculated. Eco-Dan does not apparently suffer from this as it is looking at the crop just in front of the hoe. The Robocrop system is also very sensitive to changes in camera height from the ground, to within ±100mm, while again Eco-Dan does not suffer from this due to its vertical orientation.

### 3.4.1 Autopilot - the 'holy grail' of intrarow weed control?

The Autopilot system is different in that it is detecting individual plants and working with a wider frequency of light. The focus on detection of individual plants is due to a prior research contract for a horticultural research organisation to be able to mechanically thin plants to a specified density along the crop row at early growth stages, e.g., four true leaves. There are two approaches to kill the unwanted plants, micro-herbicide applicators and instant-on-off micro flames, both of which are at the near market stage. The micro-applicators have a tighter control 'space' than the flames because regardless of how small the flames are there will always be heat dissipation though radiation and convection from the flame. There is likely to be potential for the synthetic herbicides that are currently used that are banned from organic systems to be replaced with organic approved herbicides or food products that could also kill the weeds, e.g., 20% acetic acid (vinegar). Current working speeds of this system are 5km.

This system has the potential to expand beyond crop thinning. As the algorithms and software is developed to identify both crop plants and weeds the system has the potential to control weeds and thin the crop within the crop row at early stages of crop growth e.g., two to six true leaves. The ability to do this could be considered the 'holy grail' of mechanical weed control. Interrow weed control is no longer an issue for most organic cropping situations. The level of knowledge of weed management from whole farm system / rotation design, though cultivations and interrow hoeing equipment is now more than sufficient to allow growers to have very good interrow weed control. Good intrarow weed control to date has been mostly dependent on good whole farm system design, appropriate cultivation and pre-planting operations, e.g., stale and false seed beds, and a limited number of intrarow weeding techniques such as torsion weeders, finger weeders, and mini-ridging. These latter intrarow techniques rely on the crop being considerably more resilient, i.e., generally much bigger, than the weeds, a situation that is most often not the case. Where such techniques can not be used the final weed control methods are hand hoeing and hand weeding. Both jobs are physically demanding, and highly monotonous. Finding suitable labour at reasonable cost to do this kind of work to the required quality level (and other large scale manual horticultural operations) is often difficult, and even the use of tools such as weeding platforms only improve a difficult situation. Often weeds have to be allowed to develop to a much larger size than is desirable from a crop competition perspective as they need to be of sufficient size for the weeders to be able to identify them and selectively remove them from the crop.

The Autopilot computer vision system coupled with the micro herbicide or flame system would allow a grower to kill the weeds in the crop row and also thin at the same time at an early stage of crop growth before the critical weed free period for the crop ends, so minimising weed competition effects, and ending the need for hand weeding of crops. While such a system is likely to be expensive to purchase the running costs will be little more than the cost of the tractor and operator's time, as the consumables of the system (gas or herbicide) will be very low as they are applied to individual weeds. In comparison hand weeding requires little capital investment (perhaps a weeding platform) but the ongoing annual costs are often very high.

An alternative approach being considered instead of programming each crop into the computer in advance, (a time consuming process as there are 1000's of potential crops at a range of growth stages), would be to 'teach' the computer in the field on the crop to be weeded, by manually clearing a short length of row of all weeds, leaving only crop plants and showing the crop to the computer system which then 'learns' what the crop looks like so allowing it to 'assume' that everything that does not look like a crop plant is a weed. However the programming required to achieve this is very considerable and may require the use of advance computational systems such as neural nets.

## 3.5 Competing approaches to hoe steering

Once the computer vision system has determined the corrections needed to keep the hoe in the correct place the hoe needs to be moved into the right place. There are a range of different approaches to achieve this with various advantages and disadvantages for each. Dr D Pullen of Cranfield University recently completed a PhD looking at optimising hoe steering systems.

The most mechanically simple approach is to lock the tractor link arms and use a hydraulic ram to 'shunt' the hoe from side to side, or in a more refined approach to have a horizontal parallelogram between the locked link arms and the hoe. Both these approaches, while keeping the hoe at 90° to the crop row suffer from the basic law of physics that every action has a reaction, i.e., when pushing the hoe in one direction there is an equal and opposite force pushing the tractor in the other direction. For small hoes on a large tractor this force is inconsequential, but as hoe size increases the weight of the hoe and the frictional forces of the ground engaging parts means that the tractor can move quite appreciatively. This problem is even more important for front mounted hoes as most of a tractor's weight is over the rear wheels which do not turn so providing significant resistance. Front mounted side shift hoes are unworkable as the hoe pushes the front end of the tractor from side to side and complex interactions between the tractor steering and hoe steering can occur. The alternative method is to use guide wheels which are normally a pair of flat ground engaging disks on a vertical axis pivot, which are turned to steer the hoe. For this system there are two tractor attachment options, leave the three point linkage arms free to swing or have the link arms fixed and have a slider plate between the arms and the hoe. The former is cheaper and easier, but as the hoe moves further from the centre line of the tractor the hoe moves away from a 90° angle from the crop increasing the risk of crop damage at tight crop gap tolerances. The latter is more complex but ensures the hoe is kept at 90° to the crop row ensuring accuracy is maintained. The other disadvantage of disks for rear mounted hoes is the disks work best in the hard ground of the tractor wheelings, and they are most easily placed out the front of the hoe, which means they need to occupy the same space as the tractor wheels, which requires assorted compromises.

## 3.6 CVGS for tractor steering

For front mounted hoes an alternative to steering the hoe is to have the vision guidance system steer the tractor. Mechanically this is relatively straightforward as the electronic and hydraulic systems moving the hoe are essentially the same as those used to turn the tractor wheels. Mechanically the only addition needed is a sensor to determine the angle of the wheels. This is the same approach used on GPS steered tractors. There are issues with legislation in the EU which forbids modification of tractor steering systems; however the increasing uses of a standard GPS interface for tractors may address this issue in the longer term, as vision guidance systems could use the GPS interface.

There are also no technologically insurmountable reasons why mid and rear mounted hoes could not be steered via tractor, however, they may be practically difficult as evidenced by the difficulty GPS systems have of keeping front mounted equipment in a straight line compared to rear mounted.

The potentially great advances that CVGS tractors have is that multiple hoes can be used on the same tractor without the need for swapping the guidance systems between the different hoes (due to the cost of the units for most producers it is not economic to have one system per hoe). Also the tractor can drive itself freeing the driver to monitor the equipment and operations (whether hoeing or other operations) rather than where he or she is driving. Such a system has significant potential to replace a high accuracy GPS unit for post crop emergence work. The CVGS should be able to drive the tractor with greater accuracy than the best GPS units, and with the CVGS costing about half that of a GPS unit there are significant benefits to be gained. Even the highest accuracy GPS systems are insufficiently accurate to hoe with a crop gap of less than 10 cm without causing crop damage so to have a smaller crop gap a CVGS hoe would be required as well. If the CVGS system can steer the tractor with sufficient accuracy the need for the GPS unit would be totally bypassed. The potential for using GPS in ground preparation and drilling tractors to then be complemented by the CVGS for the tractors performing post-crop emergence operations is considerable, and has the potential for major cost savings.

## 3.7 Pre-crop emergence guidance

While CVGS, in situations where the crop is clearly visible, can outperform a human operator, and within a few years may well be able to 'see' better than any human could, both humans and CVGS can not see a crop that has not emeraged. There are a range of situations where it would be valuable to be able to track an unemerged crop, for example, band spraying of a pre-emergant herbicide or band thermal weeding, followed by interrow hoeing of the remaining soil surface (ideally in one single operation). The are also situations in organic agriculture where it could be beneficial to perform separate operations on the areas where the crop is due to be planted and the future interrow area, e.g., the use of a stale seedbed using thermal weeding for the crop row and much cheaper false seed bed using hoes for the future interrow area. There are a number of techniques being used / evaluated to steer machinery in such situations.

For slow germinating and red coloured crops sowing a quick emerging 'sacrificial' green plant row that can be used to guide the hoe and which is then hoed out at a later stage, is a simple technique and works well, thought it still has its limitations. A second alternative is to create a furrow mark at planting to follow. There are two approaches to this. Eco-Dan creates a wide relatively flat furrow and use a laser beam to illuminate the furrow which is then detected by the CVGS. The system developed by Dr Pullen uses a deep, narrow, highly compressed furrow which is then tracked with a follower wheel. Robocrop is developing their CVGS to detect a furrow. Eco-Dan's system has however been suspended from sale as it requires further work to make it market ready. Furrow marks have a problem if repeated cultivations are done that destroy the furrow mark and then remake it with each pass as there will always be a horizontal space between where the furrow mark is detected in front of the hoe and where it is recreated behind the hoe. With each pass cumulative errors will occur which could eventually lead to crop loss. Furrow marks, especially wide shallow ones, also risk being destroyed by adverse weather events such as heavy rain. The deep compressed furrow mark used by Dr Pullen's system appears to avoid these problems to some extent and it is possible for shallow hoes to hoe though the furrow mark but for it to still be detected afterwards, so that re-creation of the mark is not required.

Dr Pullen's system also benefits from following the KISS (keep it simple stupid) principle in that it uses a simple mechanical device, i.e., the follower wheel, to determine where the crop row is rather than the highly complex CVGS of the alternatives. We believe that while Eco-Dan and Garford / SRI clearly understand the need for pre-crop emergence guidance systems, their prior use of, and availably of CVGS has maybe given them a certain amount of tunnel vision towards alternative approaches. From a farming perspective it would be better to have a CVGS for post crop emergence work and Dr Pullens system for pre-emergence work because of its reduced complexity and the robustness of the whole system under farm conditions. The same computer system could easily handle both guidance systems.

# 4. Linkages with Scientists

While in Denmark we also visited Ms Ilse Rasmussen from the of the Dept. of Crop Protection and Dr Birte Boelt, Head of Research, Dept. of Plant Biology at the Ministry of Agriculture, Food and Fisheries (MAF) Research Centre at Flakkebjerg.

Ilse is part of a group researching physical control of weeds (i.e., non-chemical control) in non-organic and organic arable and horticultural crops. The research topics are widely based and range from the fundamental principles of mechanical and thermal weed control machinery, through whole farm system / rotation design using a range of techniques from laboratory work, field experiments to modelling. They have been conducting research on existing CVGSs for interrow hoes.

Birte is researching the production of a range of organic seed crops including grass, clover, carrot, leek, cabbage and cauliflower both outside and under protection. Denmark is a leading producer of non-organic spinach and clover seed production, and also produces significant quantities of grass seed. Birte was also the leader of a governmental working party reporting on the potential for the co-existence of transgenic, non-transgenic and organic crops, and was a panel member at the co-existence plenary session at the conference.

# 5. Conclusions

## 5.1 Organic seed

The EU and USA organic seed markets, particularly for vegetable seed, are in a turbulent state at present, but this is entirely to be expected for any emerging organic sector, especially one that is being driven by a range of market forces, the organic movements wishes, and corralled by USA and EU agricultural and organic legislation. There are clear techno/biological and economic difficulties associated with organic vegetable seed and to a lesser extent pasture and arable seed. However, the pressure to succeed is such that we believe that organic seed production will move from the experimental to the practical for most crops within five years, especially as the seed houses and the organic movement gain a better understanding of each other. The huge premiums being offered and charged for organic seed at present are unsustainable and should be expected to fall as production issues are sorted out. However, as per its non-organic counterpart, organic seed production will remain more difficult that the commensurate crop production, particularly so for vegetable crops, so it is expected that a limited number of the best and or specialist growers will produce most of the organic seed crops for the foreseeable future. It is likely to take many years for substantial amounts of organic cultivars and organic breeding programs to emerge, that will be able to compete with the current seed production paradigm.

## 5.2 Computer vision guidance systems

Five years ago economical computer vision guidance systems for agriculture were science fiction; today they are at work on many farms in the EU and USA. They are, like GPS, still cutting edge but with continuing exponential growth in computer processing power, rapidly improving hardware and ever increasing software sophistication, continuing rapid evolution in their sophistication can be expected, which will result in significant improvements in precision and a reduced dependence on chemicals and manual labour requirements.

## 5.3 Linkages with scientists

From visiting Ilse and Birte in Denmark, talking to scientists at the conference and looking at the number of technical papers presented there, it is clear that the amount and diversity of research into organic seed production has gone from practically zero five years ago to a substantial and still increasing amount today. Most of the work is centred in the EU and the USA and is highly applicable to NZ. It would be highly worthwhile for those involved in organic seed production in NZ to continue to monitor these research outputs.

# 6. Appendix - people and organisations visited

## 6.1 UK

Sunnyfields Organics, organic vegetable farm with a range of direct to customer outlets including farm shop, delivery, restaurant trade, and farmers markets. www.sunnyfields.co.uk

Tamar Organics, specialist organic seed merchant. www.tarmarorganics.co.uk

Edwin Tucker & Sons Ltd, seed merchant supplying the south west of England, selling both organic and non-organic seeds. www.edwintucker.com

Organic Herb Trading Company, importers and distributors of dried organic herbs and spices. www.organicherbtrading.co.uk

Cyril and Sara Blackmore, Bishops Farm, growers of seasonal vegetables (potatoes, carrots, parsnips, leeks, cauliflower, beetroot, cabbage, broccoli), beef and cider apples.

Dr David Pullen, Senior Research Officer, National Soil Resources Institute, Cranford University Silsoe. Research on optimal steering systems for interrow hoes.
www.silsoe.cranfield.ac.uk/staff/cv/d_pullen.htm

Elsoms Seeds, plant breeder, distributor of agricultural and vegetable seeds, including organic seeds for the UK market. www.elsoms.com

Garford Farm Machinery, agricultural engineers and manufacturers of the Robocrop CVGS. www.garford.com

Stanhey Ltd., agricultural machinery manufacturer, including interrow hoes. www.stanhay.co.uk

Opico Ltd, agricultural machinery manufacturer and importer including interrow hoes. www.opico.co.uk

Rijk Zwaan, a Netherlands based seed breeding and marketing company, including a wide range of organic seeds. www.rijkzwaan.com

## 6.2 Denmark

Eco-Dan, manufacturer of the Eco-Dan CVGS (LPS). www.eco-dan.com

Frank Poulsen, independent inventor and engineer and designer of Autopilot CVGS. www.fp-engin.dk

Ilse Rasmussen, Researcher, Dept. of Crop Protection, MAF Research Centre, Flakkebjerg. www.agrsci.dk/plb/ira/person_uk.shtml

Dr Birte Boelt, Head of the Dept. of Plant Biology MAF Research Centre, Flakkebjerg. www.agrsci.dk/pbi/BIO/bio_uk.shtml