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Precision Farming in Orchard Crops

Doug Hutton-Squire

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Disclaimer

1. Introduction

I am married to Juliet who is a jewellery designer and editor of an online jewellery magazine. We have two children Sophia (9) and Sebastian (7) and live in Woodbridge, Suffolk.

I grew up on a fruit farm in South Africa and went to the University of Stellenbosch where I studied agricultural administration which included economics, horticulture and soil science. I have been a fruit growing advisor with Farm Advisory Services Team (FAST) Ltd since 2001, advising fruit growers on all aspects of fruit growing from establishing new projects to improving fruit quality delivered to the customer.

Fruit growing is in my blood and I have always had a passion for technological advancements that can improve yields and drive down costs, thus staying ahead of the inevitable cost-price squeeze that is the enemy of producers the world over.

2. Background

Fruit growers, like other food producers, have been at the beginning of the food chain and at the end of the cash flow chain. Grower returns have largely remained stagnant over the past 15 years, while costs have increased in line with inflation. The vast majority of fruit is sold through multiple retailers and consequently growers are not in a strong position to influence the retail price. This situation is not likely to change as customers continue to demand the best quality for the lowest price. While some producers barely survive, it never ceases to amaze me that, within this trading environment, some producers manage to thrive. I asked myself why this was and, what were the top producers doing that made such a difference?

Well, there are many reasons but a common denominator is often that they are innovators, paying attention to detail, adopting new technologies with a can-do attitude, to produce higher yields at lower cost. These growers have continued to thrive, driving costs down by reinvesting in new planting systems that are more productive and lend themselves to mechanisation and reduced labour costs, and by increasing yields and quality to reduce the unit cost of production.

Years of research into orchards systems and nutrition have enabled fruit growers to improve yields tremendously and reduce the costs of production to stay competitive, but I believe the fruit industry is are now experiencing diminished returns for our investment in traditional research areas. There are gains to be had, but they are on the scale of 1-10%. I was interested in the next big development in fruit production. Until the benefits of genetic modification are accepted by the consumer, the area where I believe we can have the biggest impact on production is in addressing in-field variability.

It occurred to me whilst out counting fruit on individual trees that there was a very large variation between trees across an orchard, even in what would be considered very good orchards. This tree to tree variation was often in excess of 50%. What if every tree performed as well as the best tree? To my mind this is the key to successful orchard management and profitability.

The ability to micro-manage orchards would be impossible without the use of technology, so I decided to explore what technologies had been adopted in other parts of agriculture which could be applied to fruit growing. Immediately precision agriculture seemed to fit the bill, but I was not sure what aspects could be incorporated into horticulture, as the scale of orchards is generally much smaller that say cereal crops, and greater accuracy would be required.

I had absolutely no experience of precision farming, so it was from this starting point that I set off on my study tour.

3. Travel during my Study Tour

During my study tour I was privileged to travel to The Netherlands, Canada and the USA.

a. Wageningen, Netherlands - Joint International Agriculture Conference (JIAC)

First stop was the Joint International Agriculture Conference (JIAC) in Wageningen, Netherlands. This conference combined the ECPA (European Conference on Precision Agriculture), the ECPLF (European Conference on Precision Livestock Farming, the EFITA conference (European Federation for Information Technology in Agriculture, Food and the Environment), and hosted the international Field Robot Event. It brought together the world's leading researchers, and proved to be exactly the start I needed and I was able to make many useful contacts to further my travels, and get to grips with the terminology of precision farming.

b. Nova Scotia, Canada - International Fruit Tree Association (IFTA) orchard tour

Next was the IFTA orchard tour in Nova Scotia. This event had little to do with precision farming but, as I had hoped, gave me many contacts in the USA and Canada to pursue further. I was able to meet with researchers and growers to find out where the most interesting and relevant work was being done. In addition to meeting interesting people, it was a most interesting tour looking into how Nova Scotia growers where responding to their challenges by planting new varieties on new planting systems and co-coordinating their marketing to maintain their profitability.

c. Geneva, USA - Cornell University

From there I travelled to the New York State Agricultural Experiment Station, where I met Dr. Andrew Landers, whom I had met in Holland. Dr Landers is a world authority on pesticide application technology and he brought me up to date with the latest information on spray technology and precision spraying. We also had the opportunity to visit a number of growers to see the use of this technology in practice.

At Lamont Fruit Farm in Albion, NY, Rod Farrow manages 175ha of apples. Rod reckons he will reduce his spray bill by $30,000 by improving his spray application with the use of the Cornell patternator and adjustable spray machines. Rob is also involved with a mentoring scheme for young fruit growers in his area, to ensure his success is passed on to the next generation. He is an inspiring grower and is well worth a visit if you are planning a trip to the USA.

We also visited Fowler Farms in Wolcott, NY who grow and pack 1000ha of fruit. They are a 6th generation business and despite the perfectly maintained vintage tractors still in use on the farm, they are innovators and early adopters of new technologies. We went to see the trial overhead spray system that enabled them to spray an entire orchard in 2-3 minutes. Practical difficulties with pesticides make this system more suited to the frequent application of less effective organic approved products. FAST Ltd will be installing a similar system for trial purposes.

d. Florida, USA - Citrus Research and Education Center (CREC) Precision Agriculture Program, University of Florida

In Lake Alfred, I met with Dr. Arnold Schumann who specializes in Precision Agriculture, Site-Specific Crop Management, Crop Nutrition, Soil Fertility, Irrigation, Nutrient Best Management Practices (BMPs), Near-Infrared Spectrometry, Crop and Soil Sensing, and Computers & Electronics in Farm Automation and Efficiency. He was able to run through the work they were doing and show me the equipment they were using to apply their technology on farms. We also visited Gapway Groves to see a variable rate sprayer in action and a sensor network for monitoring soil moisture status in a trial comparing an open hydroponic system with standard nutrient programs.

e. Paso Robles, California, USA - Precision Ag, Inc.

In California I met with Dr. Lowell Zelinski who runs his own business, specialising in vineyard management, viticulture production consulting, soil fertility and irrigation management. He has many years of experience in geographic information systems in the cotton industry and was able to show me how these technologies were being employed in the vine industry.

f. Sacramento, California, **USA - Department of Plant Sciences University of California, Davis, USA**

While in California I met up with Professor Patrick Brown, who has done extensive research into spatial and temporal variation in nutrient uptake in almond crops. His team has mapped these differences and their influences on crop yield and quality over a period of ten years. They have also made extensive use of aerial imagery with ground-truthing to enhance their understanding of cropping patterns.

g. Prosser, Washington State, USA - Washington State University Centre for Precision Agricultural Systems (CPAS)

Driving up the west coast of the USA, I met with Dr Fran Pierce, Professor of Crop & Soil Sciences and Biological Systems Engineering in Prosser and Dr. Qin Zhang who had just been appointed to focus the centre's work on automative solutions for speciality crops. The centre also does research on**:** Remote Sensing/GIS and Assessing and Managing Spatial and Temporal Variability in Cropping Systems. In particular their work on soil mapping was very interesting. I was also able to see the work being done on novel cherry cropping systems to facilitate mechanisation.

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h. Wenatchee, Washington State, USA – Washington Tree Fruit Research Commission

Up the road in Wenatchee, I met with Tom Auvil and Tory Schmidt who are Research Horticulturists. They showed me their new research site with different planting systems for mechanisation and crop sensors.

I was also able to meet up with Karen Lewis**,** who is an Extension Educator for Washington State University. She also works on Comprehensive Automation for Specialty Crops (CASC) which develops comprehensive automation strategies and technologies for the specialty crop industry. They are a multi-disciplinary, multi-institutional group comprised of engineers, scientists, extension educators, growers, and industry representatives in universities, government labs, and companies spanning five states. Some of the work they have done includes: developing information, mobility, and manipulation technologies that will provide the infrastructure for the deployment of sensors and tools that will enhance crop monitoring, foster better and quicker decision-making, reduce labour stress, and increase fruit quality and yields.

They have also developed systems to automatically detect plant stress and disease and insect infestations, systems to inventory nursery trees (including caliper information) and crop load; and to integrate this data into information management databases that allow growers to quickly and efficiently assess fruit, tree, and farm conditions.

j. Yakima, Washington State USA - Simplot Grower Solutions

While in Washington State I met Dave Fraser who is the manager of precision agronomy operations of the J.R. Simplot Company. They are essentially a fertilizer company who offer an application service to growers, by utilizing the latest in equipment and software to create management zones, and variable rate fertilizer maps. His practical insights into the use of this technology were most enlightening.

k. Wageningen, Netherlands - 10th Workshop on Sustainable Plant Protection Techniques in Fruit Growing (Suprofruit 2009)

My travels ended with a trip to Holland to attend Suprofruit 2009. These workshops serve as a platform for discussion between researchers, manufacturers, and policy-makers involved in fruit growing, crop protection, application technology and environmental issues. The workshop covered the state of the art, novel ideas, new approaches and latest developments in technology and methods that will increase the precision in application of plant protection products and reduce the risks for consumers and the environment. The most recent advances were presented in lectures by scientists and guest speakers and in poster sessions.

4. Lessons learned

Quite simply I saw too much detail to report on everything, so I have focussed on the two key areas of study that I believe will make the biggest impact on fruit growing in the near future. These are:

- New Developments in Spray Application
- Precision Farming – possible applications for orchard crops

5. New Developments in Spray Application

During my travels, I have had the opportunity to focus on sprayer technology by attending JAIC 2009, Suprofruit 2009 and travelling to the USA where I met with researchers at Cornell and Florida Universities.

The two main areas of focus are residue and drift reduction. While we continue working to reduce residues, cisgenesis technology GM varieties are being developed that don't need as many pesticides. Once this technology is accepted we can move on to other challenges, but in the mean time we will still need to spray for the foreseeable future.

The issues that are going to shape sprayers of the future are:

- Public perception
- Deposition efficacy
- Environmental contamination
- Operator safety

If we assume that the average orchard sprayer sprays about 20ha a year and average spray costs are about £1100 per ha, then the average sprayer is used to apply about £22,000 worth of product a year.

Research from Cornell University shows that early season spray applications result in 10-15% losses into the air, 35-50% deposited in the canopy and 40-60% on the ground. Applications made to a full canopy result in 10-15% lost into the air, 55-60% deposited into the canopy and 20-35% onto the ground.

A total loss of say 30% represents about £6,600 per sprayer per year. On top of this, research has shown that a further 30% reduction is possible with improved spray cover! This aspect of fruit growing clearly deserves our attention.

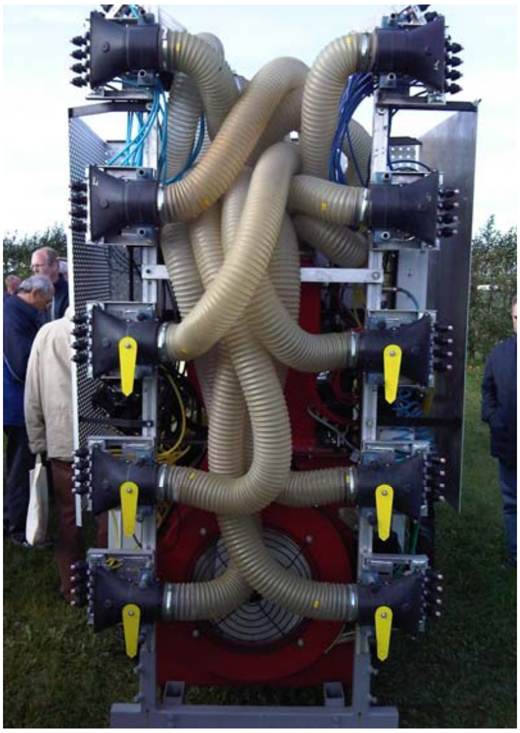
It is imperative that we ensure our sprays are on target with minimum drift or loss to the environment. I don't believe we can continue to blast spray into the sky until there is a public outcry. I believe we should be proactive, so that we are seen to be trying to do the right thing and also have something with which to promote our industry. We should aim to be the most progressive and sensitive users of agrochemicals, to not only look after our environment, our staff and our neighbours' and our customers' interests, but also our bottom line. We need to be seen to be implementing best practice.

5a. CASA Sprayer

The most advanced orchard sprayer developed to date is the ISAFRUIT Crop Adapted Spray Application (CASA) sprayer. Its aim is to ensure precise, efficient and safe spray applications in orchards, taking into account the actual needs of the crop and minimising the effect on the environment. It does this with the help of 3 subsystems:

- the Crop Health Sensor **(CHS)** identifies the health status of the crop
- the Crop Identification System (CIS) identifies the tree canopy size and density
- the Environmentally Dependent Application System **(EDAS)** identifies the environmental circumstances during spray applications.

These systems are coordinated with GPS to alert the controller to predetermined watercourses, field margins and other environmentally sensitive areas.



CASA Sprayer

The CHS still has some way to go in its development, but is developing spectral sensors to detect infections of pests and diseases. This information is used to adjust the spray application to the presence and development of the disease. Laboratory tests have shown that apple scab can be detected within 4 hours of infection based on spectral reflectance measurements. The 670-680 nm range was found to be useful in detecting scab and mildew infections. Translating this information from the mm^2 level to the orchard, at the leaf and tree level, is still a big step. There is potential for early disease detection, reduced chemical use and better timing of applications.

The CIS identifies the tree geometry with ultrasonic or infrared sensors so that it can adjust the spray volume and programme nozzles to be activated according to the tree shape and size. For example, gaps between trees, missing trees and shorter trees are not sprayed. Orchard assessments show substantial (31-82%) reductions in pesticide use without significant reduction of average deposits on leaves, while maintaining good biological efficacy. Chemical losses were reduced and sprayer working capacity was increased. This improved the timeliness of applications and reduced the costs too.

The EDAS identifies environmental circumstances and coordinates them with GPS navigation to reduce spray drift and protect sensitive areas. Wind velocity and direction are measured with an ultrasonic anemometer to adjust the application parameters by selecting different nozzle types and adjusting the airflow volume and direction accordingly. Nozzles are automatically selected for: no spray, coarse spray or fine spray depending on the risk zone. Airflow is adjusted for one-sided spraying, symmetrical distribution or asymmetrical distribution, depending on orchard zone and wind direction. Field tests have shown that environmental pollution is reduced, buffer zones are automatically adhered to precisely without operator fatigue and full traceability is on record.

5b. Nozzles

Work done by PPO fruit in Holland, and Ctifl in France, clearly shows that there are no significant differences in average residues between fine hollow cone nozzles and coarse air induction nozzles. Large variations in residue levels were found between fruits, independent of fruit size.

Air induction nozzles can reduce spray drift by more than 90% when compared to the standard Albuz Lilac nozzle, with the Lechler ID9001 and Albuz TVI 80025 performing the best. PPO Fruit in Holland found that nozzle choice influenced drift more than sprayer type. Air induction nozzles on axial fan sprayers were as good as cross flow sprayers in reducing drift especially in early season. In midseason the cross flow sprayers were slightly better

A word of caution though – do not use AI nozzles with canopy sensors as they take too long to adjust due to the delay in airflow.

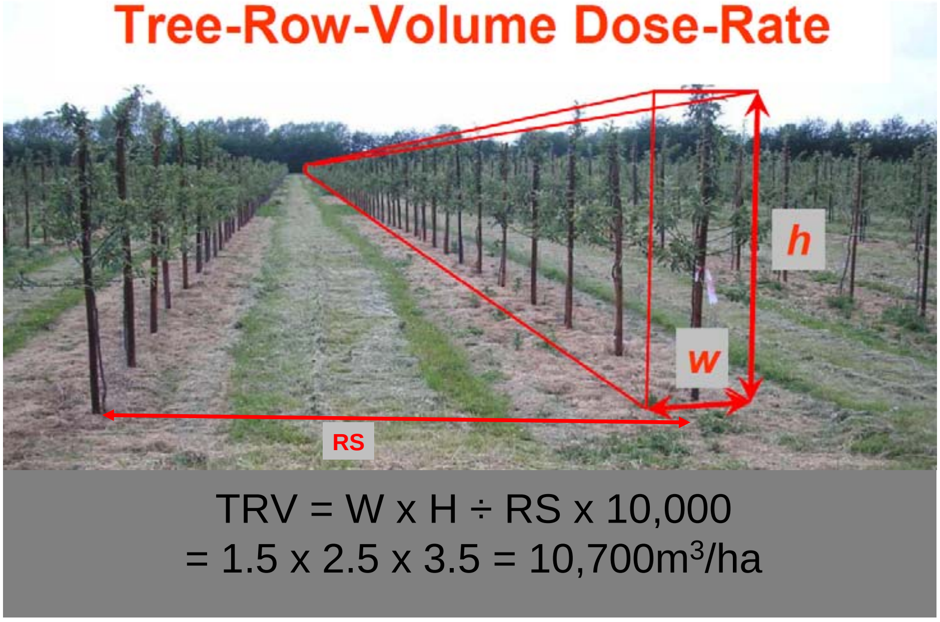
5c. Dose rates

There are several different dose expression methods across Europe. Prof Jerry Cross has been instrumental in setting up the tree Fruits Dose Adjustment Discussion Group. The group comprises about 30 parties representing regulators, agro-chemical suppliers and tree fruit spray researchers, with the aim to find a way to harmonise the different dose expression methods and dose adjustment schemes that are used in different countries. This has very real implications for label approvals across Europe to reduce the costs of registration.

Some conclusions of the discussions that will be reported to EPPO (EU Plant Protection Org.) are:

- Maximum dose per ha of ground area needs to be stated on all labels
- Labels to stipulate maximum and minimum spray volumes
- Concentration only method is not acceptable

- Per ha, per ha LWA (leaf wall area) and per 10000m3 TRV (tree row volume) are agreed dose expression methods
- A dose rate translation service is required
- Tree structure parameters must be recorded for trials
- Terms need to be defined.



Tree row volume calculation

Label dose rates are designed to be effective at 1000L/ha on large trees. Modern orchards have significantly lower leaf areas and so lower dose rates should be as efficient, provided leaf coverage is good. Italian researchers have successfully introduced a system to reduce dose rates by 20% without reductions in efficacy. 12,000m3 of tree volume was used as a reference and dose rates adjusted according to actual tree volumes measured.

Once we have set up our sprayers correctly I believe we should be using the PACE system developed by Prof Jerry Cross, to safely reduce dose rates by up to 50%. This would reduce our residue levels too. See http://www.pjwrc.co.uk/0_Intro.aspx
In the past ULV programs gave very good results at 30% rates, under normal disease pressure.

5d. Air volume and speed?

How much air do we need?

Why do we need air?

The purpose of the airflow created by the fan is to:

- displace air in the canopy with pesticide-laden air from the sprayer
- carry the droplets from the sprayer to the target
- counteract the effects of any wind
- shake the leaves to improve deposition on both sides

Too much air will

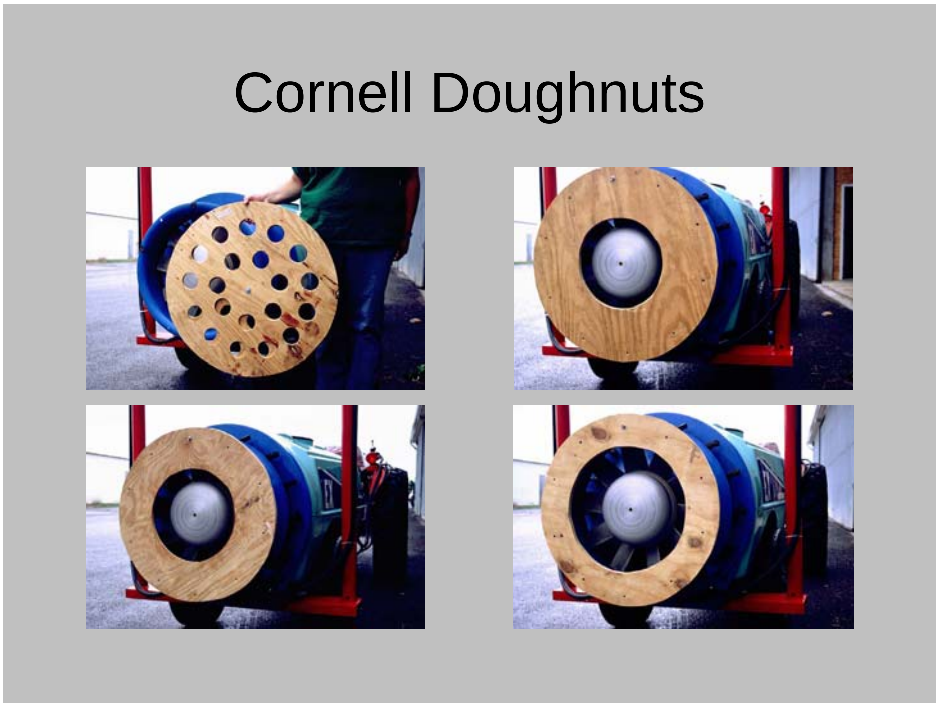
- carry droplets through and past the target
- excessively shake the canopy
- remove droplets already present on the target
- cause shingling of the leaves and reduced coverage

We need to match the airflow with the target/canopy size crop stage
This can be done by:

- changing the fan blade pitch
- changing fan gearbox speed,
- changing the PTO speed but be careful not to lose too much torque, or
- changing the size of the suction by fitting a control baffle such as the Cornell doughnut *(see picture on next page)*

We need just enough air to get the spray droplets to the target and maximise deposition. This equates to about 25-30,000m3/hr. Most modern sprayers produce 40-60,000 m3/hr which is often unnecessary and a waste of horse power.

Air velocity drops off very quickly as the air leaves the fan housing. This creates a problem for axial fan sprayers as the distance from the fan to the top of the trees is twice that from the fan to the bottom of the tree. Typically if the air leaves the fan at 25m/s it will reach the bottom of the tree at 15m/s and the top of the tree at only 5m/s. This low airspeed at the top of the tree makes the airflow vulnerable to wind interference and reduced coverage. For this reason it is best to use a tower sprayer/cross flow sprayer which is set up to have a constant airspeed top to bottom. The world's leading researchers concur that homogenous airflow is the ideal. Some axial fan sprayers (Nobili Geo 90S) have been designed to direct more air to the top half of the plume, but the air trajectory is upwards which causes more drift over the top on the canopy.



Cornell doughnuts

Italian researchers have carried out extensive trials to determine the optimum air velocity for maximum deposition. They found that deposition decreased with increased airspeed above 15m/s at the leaf. For small trees (2.8m) the optimum airspeed at the leaf was 6-10m/s and for taller trees (4m) it was 12-15m/s.

As a general rule, air speed should be set so that the spray plume only just exits the canopy on the other side.

5e. Forward speed

Different sprayer forward speeds (4-13km/hr) where found to make little difference so long as the optimum airspeed at the leaf was maintained. 9km/hr was deemed to be most practical.

The faster your forward speed the higher the airspeed required becomes because the air tends to curve backwards. This can work to our advantage, especially in the spring when there is little foliage. When the air stream bends backwards it lingers longer in the canopy, thus improving deposition.

5f. Sprayer selection

If you decide on an **axial fan sprayer**, try to get a make that has front suction. The rear suction types not only pick up leaves and debris, but also tend to suck some of the spray back into the fan before it gets to the trees, causing contamination of the blades. These sprayers can be adjusted to reduce drift but as a large proportion of air is blown upwards it is difficult to control.

Cross flow sprayers consist of either axial fan sprayers with a tower or a centrifugal fan with an array of directed nozzles. The directed nozzles are good as they can be arranged to point slightly downwards to eliminate any drift. Fantini and Berthoud have good examples where the nozzles can be arranged to give a homogenous airflow. Air induction nozzles can be used at the tops too. Greentech electric fan from Australia and the Micron Turbospray can be arranged to give very uniform spray coverage. The Greentech unit can have its speed adjusted easily as it is electric.

Berthoud air drive cross flow sprayer

Tower sprayers ideally need to be the same height as the trees to be true cross-flow sprayers. If they are lower than the tree height, then air still has to be projected upwards to maintain coverage causing some drift. This is however less of a problem than with the axial sprayer.

Multi row sprayers like:

- the Munckhoff 3Row - sold about 25 in 3 years (Euro 45,000) (*see figure on next page*)
- KWH Holland – sold about 10, hoping to sell about 30 in 2010 (Euro 35,000 - 40,000 with wind sensors), 90% reduction in drift
- and the Wanner Shielded sprayer

offer a good compromise on flat ground where drift reduction is important.

Munckhoff 3 row sprayer

Tunnel sprayers – recycling tunnel sprayers automatically adjust dose rates for canopy size and leaf area. The problem is that you never know how much spray you are going to end up with. Munckhoff only sold about 8 machines, Lipco have the only 2 row tunnel sprayer which can spray 30ha in 12 hrs. (can also be modified to spray 3 rows). Recycling sprayers are not recommended if fireblight is present in your orchard.

Lipco tunnel sprayer

Multi-row and tunnel sprayers generally have higher leaf deposition rates than conventional machines which possibly creates the opportunity to reduce dose rates without reducing efficacy.

5g. Drift reduction

Wanner ECO-Reflex reduces drift by up to 95% by turning off between trees, saving 25-60% of product applied.

Wanner spray reflector reduces drift by 95% if set up correctly and can recycle 15% of the spray applied.

Lipco tunnel sprayers have been shown by the Julius Kühn-Institut (JKI) in Germany to have up to twice the deposition rates of standard axial sprayers, with 95-99% drift reduction and up to 70% product recycling.

5h. Canopy sensors

These sensors are available from most of the leading manufacturers as additional options. They either use infrared or ultrasound to detect canopy presence, height and density to adjust the spray volume accordingly.

Infrared sensors are proving to be more reliable and less expensive. If possible sensors should be attached to the tractor cab so that they can also be used for variable rate fertiliser applications too.

Wanner's – ECO Reflex infrared sensor enables the sprayer to switch off between trees, with savings of around 25%. Hardy, Berthoud and Durand-Wayland's Smart Spray, in the USA, have developed similar sensor technologies.

Wanner ECO reflex sprayer

5i Water volume and distribution – Patternators.

There are a number of patternator designs, but they all fulfil the same role. Spray is collected from different heights in separated graduated cylinders to show the spray pattern. This pattern can then be adjusted so that it conforms to the tree shape that will be sprayed. It is a simple and graphic way of ensuring that the sprayer is discharging spray symmetrically on both sides. Professional systems are quite expensive, but a simple system can be made from window mesh frames. Plans are available if required.

Italian researchers have found that, by reducing spray volumes from 850-450 L/ha, they actually increase spray penetration into the canopy and decreased ground losses by 20%. In Holland 200L/ha is standard practice.

Patternator setup

5j. Recommendations re new sprayer developments/usage

I believe that most types of sprayers can be adjusted to effectively apply sprays to orchards with good coverage and minimal drift, leading to reduced residues. Even if your sprayer has a NSTS certificate, it doesn't mean that it is set up for your orchards. Usually the sprayer is set up for the tallest trees in your orchard and the shorter trees are catered for by shutting off the top nozzles, unless there is a large difference between tree sizes. The following points need to be considered when setting up an orchard sprayer.

- First measure the maximum height of your trees.
- Set the lower limit and the upper limit allowing for annual growth.
- Adjust air volume and air speed to suit crop stage.
- Check air flow with streamers and anemometer.

- Adjust water volume and spray distribution in canopy.
- Select nozzle type.
- Adapt dose rate for canopy size and crop stage.
- Use a patternator to adjust nozzle direction to optimise spray pattern and mark positions.
- Check coverage with water sensitive paper, tracer or kaolin.
- Produce a table for different orchards and crop stages (fan speed, water volume, dose rate %, nozzle type, deflector settings).

When considering the purchase of a new sprayer, one has to consider the types of orchard that it will be used in. In a perfect world, I would go for a multi-row sprayer or multi-tunnel sprayer to take advantage of the time efficiencies offered. One machine can do the work of 2 or 3. Yes they will cost around Euro 40,000, but it means one less driver and tractor too.

If however the intended orchards are on a slope or are covered by hail net, a low tower sprayer will have to do. Although, **van Nijftereik** have now developed a hail net system that can accommodate a 3 row sprayer, if hail nets are being considered.

6. Precision Farming – possible applications for orchard crops

For years we have been aware of the fact that orchard uniformity is one of the key factors in producing high yields of quality fruit. To achieve this we have invested large amounts of capital (± £20,000/ha) to buy productive, uniform trees and plant them on post and wire trellises. To a large extent we have improved uniformity and reaped the rewards, enabling us to stay profitable. Now we must continue to look for new ways to reduce variability, to further lower the unit cost of production.

We all know we have variability in our orchards. One look at your orchards on Google Earth will confirm this immediately. The extent of this variation is less easily quantifiable.

6a. Effect of variability

Areas of an orchard vary in terms of

- Vigour
- Yield
- Fruit colour
- Fruit sugars
- Fruit size
- Storability
- Nutrient availability
- Soil pH
- Water holding capacity
- Soil texture and structure

These are the factors that are critical to our success and need our attention.

Variability also complicates our growing practices, for example, vigour variations require skilled pruning. Many of our actions are based on whole field recommendations, which often make the variability worse!

For example we try to control vigour by reducing nitrogen applications or applying growth regulators. This works well but the weak area of the orchard actually needs more nitrogen and less growth regulator. The weak area gets weaker, increasing the variability.

Likewise, ATS (ammonium thio-sulphate) used for blossom thinning, tends to over thin strong trees and under thin weak trees, there-by accentuating the vigour variation.

6b. So what can we do about reducing variability?

Firstly, we need to investigate the extent of the variability and secondly, measure it. Thirdly, we need to identify the action we can take to reduce the variability.

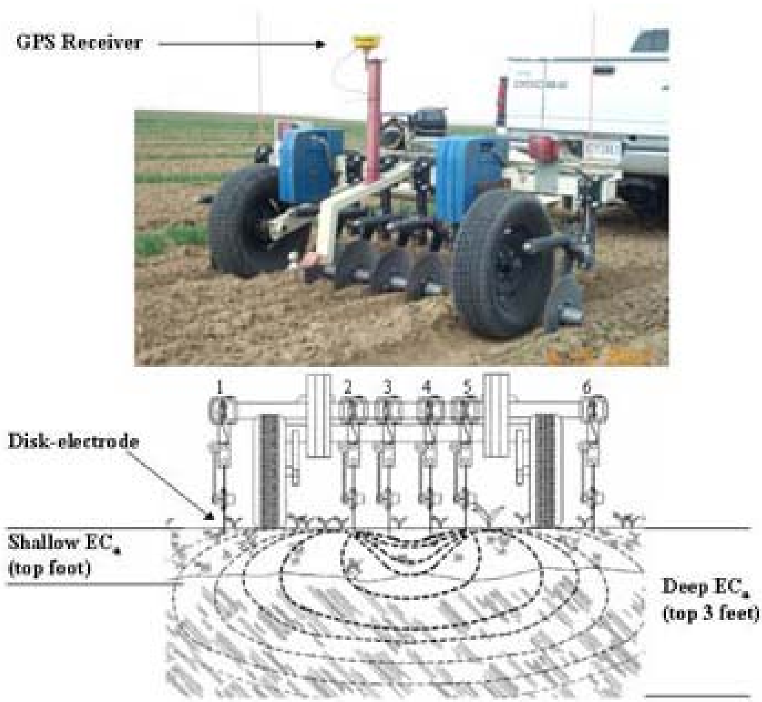
If we can measure this variability and do something about it, there is little doubt that significant gains can be made. Glasshouse tomato growers strive to make every m^2 as good as the best m^2. If we strive to make every tree as good as the best, perhaps we can increase our yields by 20% or more. Many research papers conclude that in-field yield variation of an orchard is often >50%. My own experience confirms this too.

I believe we should be looking at precision farming techniques to unravel the factors influencing the variability in our orchard. Commercial agriculture is adopting these techniques successfully and the fruit industry cannot afford to get left behind.

> *Precision farming is simply defined as "doing the right thing, at the right time, in the right place". It assumes the existence of in-field variability and aims to improve yields and quality while minimising the impact on the environment.*

6c. Soil mapping – targeted soil sampling

Soil mapping is being widely adopted in precision agriculture, as a starting point to identify soil variations. Soil is the main factor in inducing variability across a field, Veris Technologies have designed a tool that measures the soil EC (electro-conductivity) and maps it by linking it to a GPS device.



Veris EC cart

Soil EC is a measurement of how much electrical current soil can conduct. It's an effective way to map soil texture because smaller soil particles, such as clay, conduct more current than larger, silt and sand particles. Soil EC measurements have been used since the early 1900's, but Veris mobilised the process and added GPS. As the **Veris EC** cart is pulled through the field, one pair of coulter-electrodes injects a known voltage into the soil, while the other coulter-electrodes measure the drop in that voltage. The result is a detailed map of the soil texture variability in the crop rooting zone.

EC maps relate to soil texture and salinity; this has been verified by extensive scientific research. Where the soil EC map shows the soil changes, a change will be found at that location. Mapping only needs to be done once as EC maps made a decade apart show the same soil management zones.

Once you have a soil EC map, the field can be divided up into management zones from which strategic soil samples can be taken to give a more accurate picture of the fertilizer requirements. You may not use less fertiliser overall, but you will place it exactly where it is needed, instead of making field scale blanket recommendations.

Most growers know roughly where their soils are different but a soil map is still required to tell a variable rate controller where to change application rates.

If soil EC mapping is done before planting it would be possible to vary planting density or rootstock choice accordingly. It would also be possible to design irrigation systems to suit different soil textures. Soil texture matters!

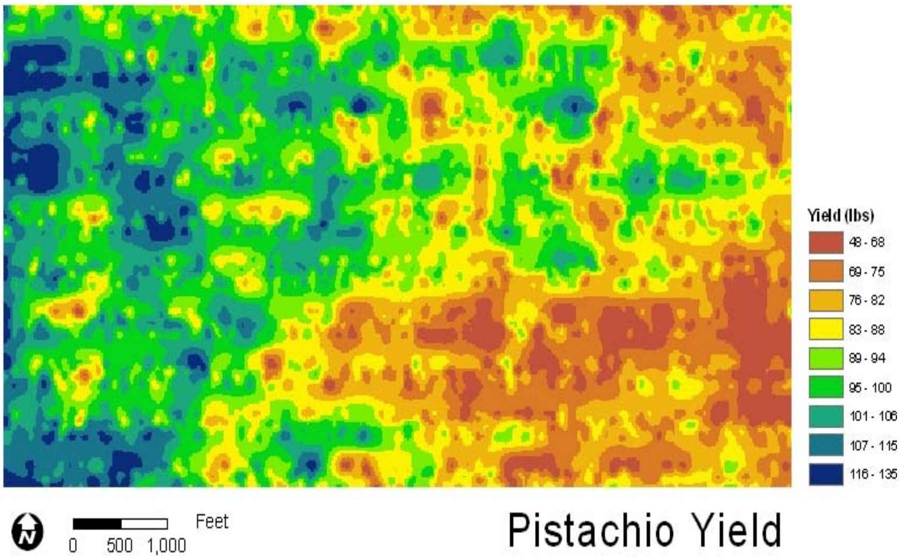
"On-the-go" pH measurement with a specific attachment every 5 seconds, and carbon mapping is also possible with the **VIS-NIR shank.**

6d. Yield mapping

Another important measure of variability is yield. Overall yield, on an orchard by orchard basis, is relatively easy to measure and is standard practice in the fruit industry. What is more difficult is measuring the variability within an orchard.

Prof. Patrick Brown of UC Davis has been involved with a long term project, monitoring the factors that influence yield in pistachio. His team have found that production measured on more than 10,000 individual trees over 8 years, can vary by more that 50%. Not only is there a large variation in yield, but the best performing areas are not consistent, despite being treated the same. This fact was not known before and can be explained by other factors such as weather, pollination and biannual bearing patterns.

Yield is not uniform in any field.
Yield of 10,040 trees Pistachio trees (40 ha)



Pistachio yield map

These findings add to the importance of use being able to monitor apple yields more accurately in order to reduce variability. The main reason why this has not been done already is because apples are harvested by hand and often picked over a number of times. This makes it very difficult to record how many apples came from a particular part of an orchard.

To solve this problem a number of parties have developed robotic vision systems to locate and count fruit while it is still on the tree. The basic idea is that a sensor array is towed up and down every row before harvest to record fruit distribution, so that it can be mapped. This information can then be used to apply fertiliser at a variable rate to replace the nutrients taken off the orchard by the crop. This technology is now well advanced and can detect 85-95% of the fruit on the tree in modern planting systems. The **Vision Robotics Scout** from California detects fruit by digital imagery analysis, Purdue University have a system that uses video detection and the **Volcani Institute in Israel** has done work on detecting green apples on a green background.

In the future these sensor arrays will also be able to detect: fruit size, colour and sugar levels, giving growers, packers and marketing agents, invaluable information for harvest planning and crop estimation.

Vision robotics scout – "Newton"

In a further development in harvest assist technologies, the **DBR** augmented harvest system for the apple industry handles the fruit from the time it is picked from the tree until it is placed in the bin.

The system is composed of two main components. The first is a vacuum-assisted tube that "sucks" in the apple from the picker's hand and transports it to a location just above the bin, where the fruit arrives with near-zero speed. The second element is an "elephant ear"-type revolving helix that places the fruit one by one in the bin.

By eliminating the filling up and subsequent emptying of the picking bag, the system increases harvest efficiency significantly, and by eliminating the dumping of entire bags in the bins, the system helps reduce fruit bruising. The components are modular and can be modified for use with a tractor or another type of orchard platform. This technology has the potential to be expanded to include over-the-row harvest platforms that can pre-sort fruit in the orchard to reduce transport, storage and grading costs when the fruit leaves the orchard.

DBR harvest system

6e. Remote sensor technology available

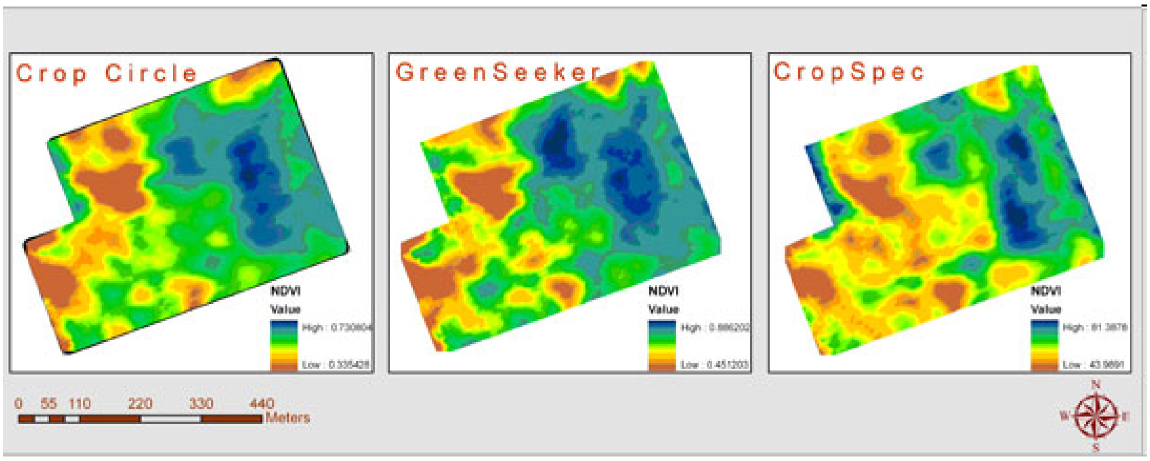
Remote sensing can be carried out by satellite, aircraft, and ground based sensors.

- Satellite sensors are hampered by clouds, low resolution, expense and long turn around times.

- Aircraft imagery is also affected by weather and, while not as expensive, still takes some time to process the data and get the results back to the grower.

- Ground based sensors are the most readily available to growers and can be adapted to work on-the-go, saving time and giving immediate feed-back.

Ground based sensors like **Greenseeker /Weedseeker** from Ntech, **CropCircle** from Holland Scientific , and the **Yarra N-Sensor** are infra red sensors calibrated to measure the wavelength of the light reflected off a leaf surface to give an indication of the chlorophyll content of the leaf. This number is expressed as an NDVI (normalised difference vegetative index) and is used in algorithms to indicate characteristics of the crop such as biomass and nitrogen content.



NDVI maps from different sensors

This index coupled with GPS coordinates enable a map to be drawn to show areas of high and low greenery. Fertiliser and growth regulator rates can then be adjusted accordingly. As more research is done the sensors will be able to detect other factors such as pest and disease presence enabling variable rate spray application.

Leaves reflect light in the 400-750 nm range as visible light and in the 750-1000 nm range as near infrared light. Photosynthesis requires mostly 450nm and 680nm light, known as blue-red light. Biomass and other crop factors are detected above 750 nm, in the near infrared range.

Other sensors used include: thermal imaging cameras that measure the temperature of the canopy and are useful in detecting plant stress caused by drought: infrared sensors (Lidar etc.) and ultrasound sensors that are used for measuring canopy size and position.


Sensor array

Sensor networks are also being used to combine information from many locations to produce an overall picture for management decisions. These include irrigation monitoring, frost protection, sap flow meters and pest traps.

Pennsylvania State and Washington State Universities have developed an electronic bucket trap that will automatically count moths caught and transmit the data via a wifi network to a database. This information could be very valuable in determining first moth flights and high population areas.

6f. Variable rate application

Once maps have been drawn from relevant data, application maps can be created. These are sent to tractor mounted controllers that will vary the rate of a chosen product according to parameters set by management.

For orchard applications equipment is available off the shelf for this purpose. Fertiliser spreaders with variable rate controllers have been used in agriculture for a number of years and can easily be adapted or orchard use. Suppliers include, **KRM Bogballe**, **Kuhn** and **Amazone.**

KRM Bogballe variable rate spreader

Orchard sprayers have already been commercialised for variable rate application, but further modification needs to be done if individual products need to be varied.

Herbicide machines that only spray green weeds are widely used in the amenity sector and can be bought off the shelf today.

Variable rate applications can be combined with autonomous tractors, so that no driver is required and work carried out is monitored by surveillance cameras. What is required are on-the-go technologies that are able to respond to variability in orchards and apply variable rate solutions to create more uniform yields in terms of quantity and quality.

6g. Comprehensive Automation for Specialty Crops (CASC)

Much of the work described above is being pursued by CASC, which is a matching grant program funded by the USDA-SCRI and industry to develop comprehensive automation strategies and technologies for the specialty crop industry, with an initial focus on apples and nursery trees. They are a multi-disciplinary, multi-institutional group comprised of engineers, scientists, extension educators, growers, and industry representatives in universities, government labs, and companies spanning five states, representing some 70% of all US apple production.

Their goals are:

- To develop information, mobility, and manipulation technologies that will provide the infrastructure for the deployment of sensors and tools that will enhance crop monitoring, foster better and quicker decision-making, reduce labour stress, and increase fruit quality and yields.

- To develop systems to automatically detect plant stress and disease and insect infestations; systems to inventory nursery trees (including calliper information) and crop load; and to integrate this data into information management databases that allow growers to quickly and efficiently assess fruit, tree, and farm conditions.

- To accelerate technology adoption by determining the return on investment of the technologies developed and the barriers to adoption.

- To reduce the time from technology development to adoption through a nationwide extension and outreach program.

We would do well to keep an eye on their developments which can be followed at www.cascrop.com

6h. Recommendations re applications

To reduce variability in our orchards I recommend that the following actions need to be taken.

1. **Get the basics right** before exploring new technologies. Ensure that management systems are robust and all traditional management practices are world class in terms of site selection, soil preparation, planting systems, plant material and nutrition programs.

2. **Soil mapping**. Start with soil mapping and use these maps to carry out targeted soil sampling, identifying management zones that need special attention.

3. **Yield mapping**. Overall yield, on an orchard by orchard basis, is relatively easy to measure and is standard practice in the fruit industry. GPS logging technology is now more affordable and it is now feasible to geotag every bin that is harvested. This can be done with a simple bar-code scanner used by courier companies. At the very least bins should be allocated on a row by row basis.

4. **Canopy mapping.** The idea here is to generate maps of canopy density and leaf greenness. This can be done with satellite imagery, but I suggest that growers make use of ground based sensor technology that is most readily available to growers and can be adapted to work on-the-go, saving time and giving immediate feed-back to apply variable rate nutrients and sprays. This data can also be collected during routine operations and used at a later date.

5. **To act on the data** gathered, variable rate applications of spray, fertiliser or herbicide need to be made using VRA machinery. This can be purchased, hired or manufactured on the farm depending on the level of accuracy required. Computer controllers that are user friendly and reliable will be required for this equipment.

There is still so much that we can do to improve our yields and quality. If we can take more time to measure the relevant factors, we can react by amalgamating the layers of information and produce a plan of action. Even if we do not employ all the technology available, we can still take some steps towards precision farming that will pay dividends in the future.

The tools are out there and more are being developed. We cannot afford not to embrace them if we are to survive.

> *"It is not the strongest that survive, nor the most intelligent, but the ones most responsive to change" – Charles Darwin*

7. Actions taken since my Nuffield Study Tour

So far I have negotiated a soil mapping contractor to do trial work in orchards and sought out suppliers of sensors in the UK to measure variations in leaf chlorophyll.

This harvest we have been monitoring yields and quality more accurately to begin to build up a database of information.

I have also conducted numerous tests on sprayers to ascertain and improve the precision of application to successfully reduce the cost and improve the efficacy of pesticide applications.

I look forward to extending these opportunities for the benefit of the industry.

Douglas Hutton Squire NSch

26 Bridgewood Road
Woodbridge
Suffolk
IP12 4HA

tel : 01394 610569 home
tel : 07702959592 mobile
email : dhuttonsquire@hotmail.com
web : www.fastltd.co.uk

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Dr. Arnold Schumann
www.crec.ifas.ufl.edu/academics/faculty/schumann/schumann_arnold.htm

Keith Hollingsworth www.chemicalcontainers.com/homepage.asp

Lowell Zelinski www.precisionaginc.com/lowells_bio.shtml

Prof Patrick Brown http://ucce.ucdavis.edu/seeker/personinfonew.cfm?index=246

Dr. Fran Pierce http://cpas.wsu.edu/staff/francispierce.html

Dr. Qin Zhang http://cpas.wsu.edu/staff/qinzhang.html

Karen Lewis
www.cascrop.com/index.php?option=com_content&view=article&id=1392:karen-lewis&catid=110:project-members&Itemid=282

Tom Auvil
www.treefruitresearch.com/component/option,com_qcontacts/catid,40/id,13/view,contact/

Tory Schmidt
www.treefruitresearch.com/component/option,com_qcontacts/catid,40/id,15/view,contact/

Dave Fraser
www.simplot.com/agricultural/grower_solutions/agtech.cfm?content=tech&pg=specialists&id=WA

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