New mechanical and robotic harvesting technologies to increase fruit production efficiency

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The purpose of this report is to communicate the findings of the project AP 01037 which aimed to investigate the latest developments and availability of mechanical and robotic harvesting technology by visiting key groups in the USA and Europe.

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1. MEDIA SUMMARY

The project ‘New mechanical and robotic technologies to increase fruit production efficiency’ has been completed. The project funded by Horticulture Australia Limited (HAL) and the Plant Royalty Trust Fund of Western Australia investigated the latest developments and availability of mechanical and robotic harvesting technology and has identified potential opportunities and benefits for the use of this technology in the Australian deciduous fruit industries. Advances in mechanical and robotic harvesting technology have the potential to significantly increase the harvest efficiency of labour further. The project also investigated mechanical harvesting options for other tree fruit crops such as citrus, olives and berries and new developments in sensor technology and for non-destructive fruit quality assessment.

The key outcomes of the project are:

- The project identified new developments and opportunities for the mechanised harvesting of deciduous fruit in three main areas: mechanical harvesting aids, mechanical bulk harvesting and robotic selective harvesting of individual fruits.
  - New developments in mechanical harvesting aids provide the most immediate opportunities to improve harvest efficiency in quality fresh fruit production. The Dutch designed Pluk-O-Trak was particularly impressive because of its high harvest rates, extremely low fruit bruising and damage, versatility for different orchard and operations, low running costs, quietness of operation, ease of maintenance and suitability to pickers.
  - Robotic bulk harvesting is a medium term proposition which needs further improvement for use on apples but has immediate application for cherries and possibly pears and plums. The main limitations for fresh apples are the detachment of stalks in some varieties, non-uniformity of fruit maturity on the tree and the potential for bruising in delicate varieties. The system is suited to narrow inclined canopies, which are used widely in the Australian fruit industry.
  - Robotic selective harvesting of individual fruits is an exciting longer term proposition. The advances in orchard production systems, mechanical, artificial intelligence and sensor technology since the first prototypes were developed in France in the 1990’s now make robotic harvesters an achievable and commercially viable proposition.

- It is important for the Australian industry to keep up to date with new developments in mechanical and robotic harvesting and advances in other technologies such as the non-destructive assessment of fruit quality occurring around the world. One way of achieving this is for the deciduous fruit industry to send a representative to the next International Symposium on Fruit, Nut and Vegetable Production Engineering in Montpellier, France in April 2005.
2. TECHNICAL SUMMARY

World production of deciduous tree fruits is increasing rapidly leading to more competition on export markets. The Australian fruit industry can improve its competitiveness by adopting more efficient fruit production and harvesting systems.

Producing fruit for the fresh market is high cost and labour intensive. Harvesting is the most labour intensive operation in fruit production accounting for up to 60% of the total labour requirement. Labour costs in Australia are several times that of our major competitors in Chile and South Africa.

The availability and quantity of sufficient labour for hand harvesting is a major concern to many growers. Fruit harvest is a very seasonal activity and the uncertainty of stable, skilled harvest labour at the right time is a major problem. The shortage, stability and cost of labour for hand harvesting, declining fruit prices and increasing competition from lower cost world producers have been the driving force behind development in mechanised harvesting. The ‘shake and catch’ bulk-harvesting systems developed in the 1980’s and 1990’s were unsuitable for fresh market fruits because of excessive fruit damage and lack of uniformity in fruit maturity on the trees. Advances in mechanical harvesting have thus been based mainly on mechanical aids, which have significantly improved the efficiency of hand harvesting.

In the 1990’s, major breakthroughs in mechanical harvesting technology, computers, image technology and advances in tree design and fruit production systems stimulated the development of a new generation of robotic harvesters. These harvesters were more suitable for fresh market fruit by delivering higher fruit removal efficiencies and less fruit damage. The leaders in this new technology are in the USA, Europe and Japan.

The HAL-VC funded project investigated the latest developments and availability of mechanical and robotic harvesting technology by visiting key groups in the USA, France and Italy. The scoping study identified potential opportunities and benefits of this technology for the Australian deciduous fruit industries. Mechanical harvesting of other tree fruit crops such as citrus, olives and berries and new developments in sensor technology and non-destructive testing of fruit quality were also investigated.

The major findings of the investigation and opportunities for the industry were:

- Currently only one group in the world is working on mechanical and robotic harvesting of fresh apples. Donald Peterson’s small group at the USDA ARS in Kearneysville, West Virginia has developed a robotic bulk harvester for apples trained to narrow inclined trellises and cherries on free standing trees.
- The French MAGALI project which developed a robotic system to selectively harvest individual apple fruits was suspended in 1996/97. At the time the operation of the prototype was considered very reliable but did not meet all the stringent criteria for commercially viability.
Mechanical harvesting aids are the most successful and widely used technology for increasing the efficiency of hand harvesting. One of the best examples is the Dutch designed ‘Pluk-O-Trak’, which is very popular throughout the premium apple-growing region of Europe.

There are significant opportunities for all three mechanical harvesting technologies:
- New mechanical harvesting aids provide the most immediate and positive impact in the industry, particularly for apples. The Pluk-O-Trak provides the best and most immediate option for high harvest productivity of quality fruit, particularly apples. Harvest rates are high and fruit bruising and damage extremely low. Other advantages include versatility for different orchard and operations, low running costs, quietness of operation, ease of maintenance and suitability to pickers.
- Robotic bulk harvesting is a medium term proposition which needs further improvement for use on apples but has immediate application for cherries and possibly pears and plums.
- Robotic harvesting of individual fruits is at the cutting edge of orchard and artificial intelligence technology and is an exciting longer-term proposition. The advances in orchard, mechanical, artificial intelligence and sensor technology now make robotic harvesting an achievable and commercially viable proposition. It would need higher investment in research and development, has greater capital costs and has potentially greater impact for larger orchard businesses. A commercial viable machine could be developed in three years.

Opportunities in the new technologies in fruit production and processing include the developments in sensors and measurement systems for the fruit and vegetables. For example, the technology being developed in the GLOVE project by groups in France, Belgium, Italy and Germany with EU funding. The instrumented glove is designed to non-destructively and rapidly assess fruit sugar levels (NIR), firmness (acoustic resonance) and size of fruit in the field.
3. INTRODUCTION

Deciduous tree fruit production is expanding in Australia and is a major export earner. The demand for fresh fruit is increasing in world markets as the standard of living increases. World production of deciduous tree fruits is increasing rapidly leading to more competition on export markets. Adoption of more efficient fruit production and harvesting systems is one way for the Australian industry to remain competitive and increase market share on the world stage.

Producing fruit for the fresh market is high cost and labour intensive. Harvesting is the most labour intensive operation in fruit production accounting for up to 60% of the total labour requirement. Factors, which influence the amount of labour needed to hand-harvest fruit crops include the type of fruit, production system and yield. Labour costs in Australia can be several times greater than our competitors such as Chile and South Africa.

The availability and quantity of sufficient labour for hand harvesting is a major concern to many growers. Fruit harvest is a very seasonal activity and orchards are mostly located long distances away from main population centers and sources of labour. In Australia hand harvest labour comes from a number of sources including local residents, backpackers from other countries, new migrants and refugees depending on the location and state. The uncertainty of stable, skilled harvest labour is a major frustration for orchardists.

The shortage, stability and cost of labour for hand harvesting, declining fruit prices and increasing competition from lower cost world producers have been the driving force behind development in mechanised harvesting over the years. The research effort and interest in commercial development of mechanical harvesting has been dependent on the labour relations’ climate, particularly in the USA and Europe. In the USA concerns about future shortages of immigrant labour are stimulating interest in mechanical harvesting, particularly in the northeast apple and cherry producing areas. The French and European governments suspended the work on harvest robotics in 1996 because of the declining employment situation in Europe.

Until recently, advances in mechanical harvesting have been based mainly on mechanical harvesting aids to improve the efficiency of hand harvesting. There are many examples of these including cherry pickers and picking platforms, which have been widely adopted throughout the major deciduous fruit growing countries of the world. The ‘shake and catch’ bulk harvesters, which were developed in the 1980’s and 1990’s have not been suitable for fresh market fruits. The major limitations to this technology are excessive fruit damage and lack of uniformity in fruit maturity on the trees. Bulk harvesting, however, has enabled the tart cherry and prune industries in the USA to survive by increasing the labour efficiency of hand harvesting more than 10 times.
Major breakthroughs in mechanical harvesting technology, computers, image technology and their compatibility with modern tree design and fruit production systems stimulated the development of a new generation of robotic harvesters in the 1990’s. These new bulk harvesters were more suitable for fresh market fruit by delivering higher fruit removal efficiencies and less fruit damage than the ‘shake-catch’ systems. Intelligent systems have also been designed to selectively pick individual fruit based on skin colour thereby improving the uniformity of maturity of harvested fruit.

The leaders in the development of new technology for mechanised fruit harvesting are in the USA, Europe and Japan. The key groups include the MAGALI apple project in France (partners: CEMAGREF, Pellenc SA, Sagem), the USDA ARS at Kearneysville in West Virginia, the Iwate University at Marioka in Japan and companies in the Netherlands and Italy developing and producing improved mechanical harvesting aids.

The aim of this project was to investigate the latest developments and availability of mechanical and robotic harvesting technology by visiting key groups in the USA, France and Italy. This scoping study identifies potential opportunities and benefits of this technology for the Australian deciduous fruit industries. Although deciduous fruits are the focus of the study mechanical harvesting of other tree fruit crops such as citrus, olives, berries and nuts are also discussed. New developments in sensor technology and non-destructive testing of fruit quality are also covered.
4. LITERATURE

4.1 Scope
In this report mechanical harvesting of deciduous tree fruits are grouped into three main methods:
(1) mechanical harvesting aids
(2) bulk harvesting
(3) selective harvesting of individual fruits.

Mechanical harvesting aids such as hydro-ladders, cherry pickers and platforms increase the efficiency of hand harvesting. There are many different mechanical harvesting aids which have wide commercial use in the world’s fruit industries (Sansavini, 1990).

Mechanical bulk harvesting and selective harvesting of individual fruits includes the use of computer technology and robotics. These methods have been tried in a wide range of fruit crops, but have only been commercially successful on a small proportion, primarily for processing. Fruit crops in which mechanical harvesting has been tried include apples (fresh and processed), oranges, peaches (fresh and processed), plums, prunes, cherries (tart and sweet), berries, olives and nuts. Mechanical harvesting has been most successful in tart cherries and prunes, two fruit crops that have a very high-labour requirement. In the USA more than 80% of these crops are machine harvested. Adequate harvest labour is not available and without mechanisation the industries would not be viable. The cost of hand harvesting makes it no longer economically feasible.

Mechanical harvesting fruit for the fresh market has been more difficult. The commercial ‘shake-catch’ harvesters up to the early 1980’s caused excessive damage and fruit quality did not meet the higher standards needed for fresh market fruit or even for processing. In the USA only 5% of the apple crop is harvested mechanically all for processing. Cling peaches for processing and plums for fresh market have been mechanically harvested but in both cases the lack of uniformity of fruit maturity on the tree has been the major drawback. Excessive damage has been the main drawback for mechanically harvesting sweet cherries and pears for the fresh market and pears for processing.

Since the late 1980’s most research effort and commercial development in mechanical harvesting has taken place in the USA, France, Spain, Italy, Japan, Israel, Chile, New Zealand and Australia. Major breakthroughs have come with improvements in mechanical design, the use of computer and image technology and the design of modern production systems compatible with mechanical harvesters.

4.2 Mechanical Bulk Harvesting
4.2.1 Mechanical
The ‘shake-catch’ harvester was the main system used in the 1970’s and 1980’s. In this system the mechanical harvester was designed to adapt to excising freestanding trees. These harvesters increases labour productivity by 5 to 15% depending on crop. However they were not successful commercially for fresh market fruit for two main reasons:
excessive fruit damage and non-uniform fruit maturity. The method was more successful for processing products such as tart cherries and Cider apples.

Improvements in tree design and compatibility with mechanical design for fruit removal and catching increased fruit removal and reduced fruit damage. The Tatura Trellis (Y-trellis) system developed in Australia used a narrow inclined fruiting canopy and harvester with an inclined catching surface and limb shaker (Gould et al., 1986). The Lincoln Canopy (T-trellis) developed in New Zealand used a limb impactor to remove the fruit (Lang, 1989). A rotating drum shaker was developed in the USA and New Zealand for use on the Lincoln canopy system for apples. An over the row continuously moving shake-catcher and rod press harvester were developed in the USA (Peterson et al., 1994). All have only limited commercial use.

*Over the row ‘shake-catch’ harvester for apples*
*(Photograph courtesy of USDA ARS)*
4.2.2 Mechanical/Computerised/Robotic Harvesting

Major breakthroughs in mechanical bulk harvesting have come with improvements in harvesting techniques based on the use of computer and image technology and their compatibility with modern fruit production systems, particularly narrow inclined trellises.

In the USA at the USDA-ARS at Kearneysville, WV (Peterson and Millar, 1999) and Cornell University, NY researchers (Robinson et al, 1990) have developed a robotic bulk harvesting system for apples. The system combines improved mechanical harvesting technology with an intelligent control system that identifies the fruiting pattern, determines locations and automatically positions and actuates a rapid displacement mechanism on limbs to remove the fruit. The system has been successful on a range of fresh apple varieties grown on semi dwarfing rootstocks trained on inclined Y-trellis. The unique catching system and fruit removal mechanism results in high removal rates. However stem removals, bruising, skin punctures and uniformity of maturity are still a concern for the fresh market. The system has been tested semi commercially on fresh cherries in Washington (Peterson and Wolford, 2000) and on citrus. At Kearneysville, Peterson and Millar are currently working on several improvements to the system (Personal comm.).
4.3 Robotic Selective Harvesting of Individual fruits

Intelligent robotic systems have been developed to selectively pick individual fruits.

The MAGALI project in France was one of the leaders in this area for apples in the 1990’s (Grand Esnon et al., 1987). The project was a partnership between the government research agency CEMAGREF (Center National du Machinisme Agricole du Genie Rural des Eaux Forets) and two private companies PALLENC S.A. and SAGEM. The systems was based on fruit detection and recognition machine vision systems, robotic control arm mechanical picking devices, optimum machine architecture for orchard structure and self-guidance in the orchard alleys. Although the prototype was very reliable it did not meet all the stringent criteria need by industry needed for commercial viability. The project was suspended in 1996/97. The system was designed to adapt to the traditional tree structures and growing systems at the time. This limited fruit removal rates and the overall success of the system for apples. The limited commercial success was due to the high capital cost and low capacity of the systems. Intact stems, bruising and stem punctures were commercially acceptable. In addition the system was able to selectively pick fruit on colour and maturity.

CEMAGREF and PALLENC S.A continued their work with the robotic harvester up to 1998 on the Eureka CITRUS project for oranges with other Spanish R&D institutions and companies (Rabatel et al., 1992). There were significant improvements in fruit removal rates and harvest efficiency (Bourley, pers. Com., 2001).

In Japan researchers at Iwate University are conducting work on the robotic harvesting of Fuji apples (Kataoka et al., 1999). They have developed a robotic harvesting hand for apples. The Chilean apple industry is also experimenting with mechanical harvesting systems for apples.

4.4 Mechanical Harvesting Aids

Mechanical harvesting aids are the most widely used forms of mechanical harvesting deciduous fruits for the fresh market. A wide range of harvesting aids are available including light weight step ladders, cherry pickers, hydro-ladders and picking platforms. There are varying degrees of sophistication, harvesting efficiencies and suitability to different tree growing systems.

Two systems, which are gaining most popularity in the premium apple producing regions of the world, are the self-propelled harvesting platforms and the Pluk-O-Trak.

The picking platform was developed in Italy for flat hedgerow systems. It is now used around the word on a range of deciduous fruits. The Pluk-O-Trak system was developed in Holland for apples and is now used on a range of other fruit including stone fruit, pears and oranges (Sanders, pers. com., 2001).
5. FINDINGS

5.1 Overview
Currently there is only one group in the world actively working on mechanical and robotic harvesting of fresh apples. Donald Peterson’s small group at the USDA-ARS in Kearneysville, West Virginia, USA has developed a robotic bulk harvesting system for apples trained to narrow inclined trellises. The system is used semi-commercially on sweet cherries in Washington State. The French MAGALI project which developed a robotic harvester for selectively harvesting individual apple fruits was suspended in 1996/97. Although the operation of the prototype was very reliable it did not meet all the stringent criteria for commercial viability. Advances in tree design, canopy and crop management and mechanical, robotic and sensing technology in recent years has lead to interest in reactivating a similar project on robotic harvesting of individual fruits. There is also a small project developing a robotic hand for harvesting Fuji apples at Iwate University in Japan which was not investigate in this study.

Mechanical harvesting aids are the most widely used form of mechanically harvesting fresh fruit around the world. The most impressive harvesting aid now in use is the Dutch designed ‘Pluk-O-Trak’. Several hundred of these machines are in operation throughout Europe including South Tyrol, the premium apple-growing region of Italy. In Europe there has been decline in the use of harvesting platforms as tree heights are reduced with the use of dwarfing rootstocks.

Designers of mechanical and robotic harvesting systems for fresh apples are faced with several specific engineering and agronomic challenges. Apples are more prone to bruising and damage than many other fruits, stems are easily detached from the fruit during harvest, and fruit maturity on the tree is not uniform. Tree designs and orchard management must also be compatible with the harvesting system.

Nevertheless significant improvements in robotic bulk harvesting and robotic selective harvesting of individual fruits are possible. This would make them commercially viable in the apple and other deciduous fruit industries. Industry adoption of new and improved mechanical harvesting aids such as the Pluk-O-Trak would make a significant contribution to industry by improving harvesting efficiency and fruit quality in premium apple varieties.

5.2. Robotic Bulk Harvesting
Donald Peterson’s group at the USDA-ARS in Kearneysville, W.Va., USA has developed a robotic bulk harvesting system for apples trained to narrow inclined trellises. I worked with him during the Empire and Jonagold apple harvest of in September 2001.

In the past mechanical harvesting of apples has been limited because of low removal rates, excessive fruit damage, stem detachment and the non-uniform fruit maturity. However recent improvements in tree design and compatibility with improved
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mechanical design for fruit removal and catching has increased fruit removal and reduced fruit damage.

Peterson’s bulk harvesting system has made major improvements in three main areas:

(1) **The tree training system.**
The tree training system is a critical part of the system. The Y-trellis is the most compatible with this mechanical robotic harvesting concept. Growing apples on semi-dwarfing rootstocks on a narrow inclined trellis has several advantages for the bulk harvesting system. Tree height is contained and fruit in the canopy are not positioned vertically above one another so that they can drop freely without impacting during the harvest operation. The narrow canopy is managed so that the laterals do not cross over one another and fruit is positioned to the sides or below the branches to facilitate effective removal and collection on the catching surface. The canopy management also enables the image system to clearly identify the fruit position in the canopy. Single leaders or multiple parallel leaders are acceptable. Fruiting laterals are also kept relatively short to assist in fruit detachment and minimising fruit movement caused through the pendulum effect of the impactor. The most compatible variety and rootstock combination on this training system for the bulk harvester is still to be determined.

(2) **The impactor, fruit catching and bin filling system**
The impactor mechanism has been designed to rapidly move the fruiting laterals away from the fruit at the point of attachment of the stalks so that the fruit falls freely and vertically downward during the fruit detachment operation and is not thrown into or out of the canopy. The positioning of the impactor is also a critical part of this operation. The harvesting operation removes fruit first from the top of the canopy and works down to the bottom so that falling fruit does not impact with fruit moving up the catching surface.

The fruit-catching surface is inclined so that it can be positioned as close to the canopy as possible and padded to reduce bruising. The harvested fruit is moved up the catching surface onto a sorting belt where field grading can be carried as the fruit is conveyed to the bin filler. The unique bin filling system is designed to minimise fruit damage and fill bins evenly.

(3) **The control system.**
The movement, positioning and activation of the Rapid Displacement system, which displaces the limbs to remove the apples, was conceived to be controlled by three systems: imaging, decision making and motion control. Although the image system was successful in locating apples, finding the leaders was more difficult. In practice positioning and activation of the RDA by the human operator with joystick-hydraulic controls was more effective than the image control. Two other improvements being investigated are (a) a simple imaging system to capture the image with the human operator determining the location of the RDA for detachment with a mouse or pressure sensitive screen, and (b) the fully automatic system.
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Robotic bulk harvester for apples
(Photographs courtesy of USDA ARS)

Rapid displacement system on the bulk harvester for apples
The system is being trialed on a number of varieties (Empire, Rubinstar Jonagold, Pink Lady™, Crimson Gala, Starkspur McIntosh, Starkspur Dixie Red Delicious, Ace Spur Delicious, Spur Gold Blush, Sun Crisp, Stark brae Star and Sun Fuji) grown on M9, M26, M7 and B9 dwarfing rootstocks. The results have been encouraging. The system is only compatible with fruit grown on a well-managed inclined trellis system with narrow canopies, such as Y or Tatura trellis. The Danish partner in the project has developed the image system. The image system was not used in the 2001 harvest due to previous season problems with light control and incompatible tree pruning management. It will be used again in next year’s harvest. The system has high fruit removal rates. Fruit damage and bruising is minor on more robust varieties but unacceptable on sensitive varieties such as Pink Lady™. However, two limitations remain to be overcome before the system is commercially viable for fresh apples: stem removal and non-uniform fruit maturity.

Stem removal can be up to 50% dependent on variety. The detachment of stems from the fruit does not damage the skin and has not been found to be an infection point for post-harvest breakdown during storage and handling. Stem pulls will detract from the appearance and marketability of the fruit.

Non-uniform fruit maturity on the tree is a problem because bulk harvesting is not able to selectively pick fruit. The variability of fruit maturity on the tree can be reduced with improved tree design and crop management techniques. For example, low vigor (dwarfing) rootstocks, tree training, and canopy management systems, which improve light distribution in the tree, lead to more uniform fruit development and maturation. Dormancy-breaking chemicals that concentrate the flowering period and improved chemical and hand thinning practices will also increase the uniformity of fruit development. Chemical manipulation of fruit maturity and blush colour may also improve the uniformity of maturity. For example, in sweet cherries, ethaphon is applied to the crop to improve uniformity of maturity and reduce detachment force for harvesting. Ethaphon has the same effect in apples but is not used because it reduces storage life. Other chemicals such as Apogee and Retain could be tried on apples.

At the present stage of development Peterson’s robotic bulk harvester has achieved semi-commercial success with sweet cherries in Washington State and may have more potential on plums and pears than apples. The robotic bulk harvester has been trialed commercially on sweet cherries (cvs Bing, Lapin and Van) in Washington state. Growers have been very encouraged by the results from these during the last two seasons. The harvester has been used on freestanding trees trained for adoption to the harvester. Ethaphon is applied before harvest to loosen the stalk attachment and removal rates greater than 95% have been achieved. Reject rates are within 1-2% of hand-picked fruit. The cost of harvesting has been very much reduced. All the stalks are removed during the harvest operation. However, market research shows that there is a good demand for these stalk-less cherries packed in clear plastic clamshell punnets. Stalk-less cherries are also easier to pack. Sweetness of the cherries is increased and acidity reduced by the application of ethaphon. Calcium chloride, which is applied in some years to reduce the
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risk of splitting from rain before harvest, can block the effect of ethephon reducing removal rates slightly.

Pears and plums are well adapted to growing on inclined trellis systems (eg Tatura trellis and Open Tatura trellis) which would make them very suitable to this harvest system. Uniform maturity in plums may be achieved easier than in apples and they are much less prone to bruising. Stalk-less plums are common during hand harvesting and provided the skin is not damaged post harvest deterioration is not a problem. In initial trials, stalks were very rarely removed from pears during mechanical harvesting although they can be broken.

The three wheel, all wheel-drive bulk harvester is supported by a 15KW power unit. The harvester is valued at about US$ 50,000. The engineering drawings and specification are available from Donald Peterson.

5.3 Robotic Selective Harvesting of Individual Fruits
Lespinase and Savilla in France first raised the concept of robotic harvesting of individual apples in the early 1980’s. The first robotic harvester was developed for fresh market apples (MAGALI project, France) and oranges (EURIKA project, France/Spain) in the 1990’s. The MAGALI project partners were CEMAGREF (Centre National du Machinisme Agricole du Genie Rural des Eaux Forests) and two private companies Pellenc and Sagem. Work was suspended in 1996 when it was concluded that there was no adequate solution for the robotic harvesting of apples. The operation of the prototype was very reliable but the design was unable to meet the following industry criteria for commercially viability:

- A capacity of 800 kg/hr of apples for a 4 arm machine.
- A removal rate of 80% of apples for adapted orchards (flat hedgerow trees).
- More than 90% of fruit harvested with stems attached.
- Less than 5% of fruit falling on the ground.
- Less than 5% of fruit bruised in the most fragile variety.

The MAGALI prototype (11 March 1994) was an automatic guided platform with two robotic arms for picking fruit. It was self-propelled with a controlled hydraulic steering system and four wide low pressure driving wheels. An optical, computerised control system was used to locate the fruit in the canopy and guide the robotic picking arms. Fruit was picked at 20-30 fruit/min and placed in a soft-receiving tray. There was a uniquely gentle bin filling system and automatic removal of bins when full. The computer and controller were held in a protected space.

The principles of operation of the robotic apple harvester were:

(1) Vision
The automatic vision system provided excellent images of the location of the fruit in the tree canopy for directing the robotic arm. Lighting was essential and allows for night
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harvesting. The only limitation was the cross over of branches in the hedgerow system that interfered with the direct line of vision needed to locate the fruit and achieve at least 80% crop removal.

(2) Fruit selection
The system was capable of recognising very subtle differences in colour. Therefore it was possible to select fruit based on background colour for uniform maturity. With new developments in sensors for non-destructive quality testing it may also now be possible to improve the selective picking of using technology such as Near Infra Red (NIR) for fruit sugar content and acoustic impulse response for fruit firmness or stiffness which are correlated with maturity.

(3) Picking the fruit
The robotic picking arm imposes a suction action, which grips the fruit. It then imparts a lifting and twisting action simulating hand picking to remove the fruit from the tree. The stalk remains attached to the apple.

(4) Putting down the fruit
A unique bin filling action was designed to minimise fruit bruising.

First prototype of MAGALI robotic harvester for apples
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*MAGALI robotic harvester prototype 1994*
*(Photographs courtesy of PELLENC s.a.)*

Robotic arms harvesting apples
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Picking the fruit

Automatic bin filling system
In 1996/97, Pellenc was approached by Australian researchers (Prof Bob Demison and Dr Malcolm Good, University of Melbourne and Mr David Pullar, Private Consultant) to see if there was interest in developing a joint project in Australia. However Pellenc’s view was that they would only be interested in reactivating the project when new breakthroughs in technology were made. In particular they needed to be convinced that improvements in tree designs would allow much better location of fruit in the canopy for access by the vision system and the robotic arm.

I met with Antoine Bourely, the former leader of the MAGALI project and now manager of automation at Pellenc’s factory in Pertuis, France. We discussed the reasons for the original project not meeting the industry criteria and whether the advances in technology since then are encouraging enough for Pellenc to be interested in a reactivated project. The conclusion was positive and we covered the following critical areas:

(1) **Tree design**
Tree design and accessibility of fruit to the robotic arm is seen as the major limiting factor in apple removal rates. The original prototype was designed to work on excising hedgerow plantings, which limited removal rates to 70%. The high proportion of crossover branches in these training systems interfered with the robot’s direct line of vision to the fruit necessary for the arm to locate the fruit.
The recent advances in apple production systems which grow varieties on low vigour (dwarfing) rootstocks (M9, M26) and use training systems with narrower canopies (slender spindle, tatura trellis), and pruning management to provide better accessibility to the fruit, would allow higher removal rates exceeding 80%.

(2) Harvest rate
At the time the project was suspended a prototype was being developed which had the capacity to harvest at 800kg/hr using 2 arms on each side of the machine (ie 200kg/hr/arm). Today this could be vastly improved again with new robotic technology and changing the design to a single sided harvester with 4 arms to harvest one side of the row at a time.

(3) Loss of fruit
Fruit loss from the dropping of fruit during harvest, although considered too high by the industry was probably no greater than hand harvesting. There were no hand-harvested controls in the trials. The main reason for fruit loss was the high proportion of apples in bunches. This would now be overcome by improved chemical and hand-thinning management to reduce the number of bunches. In Western Australia for example, crops in most high quality apple varieties are thinned to singles or doubles and are not grown in bunches. This would reduce fruit losses even further.

(4) Fruit without stems
In the prototype a small percentage of stems were detached from the fruit during picking. This was considered to be no more than with hand harvesting. The removal of stems did not result in post harvest or storage problems and was regarded as mainly cosmetic. The action of the robotic arm, which simulates the lift and twist of the picking could be improved if necessary.

(5) Bruising
Bruising was not considered a major problem. A small amount of damage occurred but where in the system it occurred was not determined. It was unlikely that the fruit was bruised in the picking action but occurred during subsequent handling and bin filling. Advances in protection of fruit during harvest, handling and bin filling would achieve lower levels of bruising.

Tree design to allow for harvest of more than 80% of the crop are now considered achievable and would overcome their main concern. Antoine Bourely is confident that all the other limitations could be overcome with the advances that have been made in technology. Pellenc would be very interested in reactivating a joint project once they have been persuaded that the tree design would meet their criteria.

The designers are confident that a commercial robotic harvester for fresh market apples could be developed within three years given the advances in technology. In a joint project with a southern-hemisphere country, such as Australia, with counter seasonal production, the development time could be reduced further. We estimated that to achieve these objectives a new project would need three full time engineers. Pellenc would
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provide the design supervision. The Pellenc Company expanded rapidly through the late
1990’s and now has considerably engineering design, manufacturing and operational
capability and capacity. Pellenc’s core business is in grape and olive harvesters and they
have offices and factories in France, USA, South America and Australia. What is needed
for a new project to be successful is agronomic expertise to provide the link between the
design engineers and compatible tree designs.

It was estimated that the prototype, developed to a more advanced stage for oranges, was
valued at 1,000,000 Fr (AU$ 250,000).

5.4 Mechanical Harvesting Aids
Mechanical harvesting aids are the most widely used form of mechanically harvesting
fruit around the world. They increase the productivity and efficiency of hand harvesting
by different rates depending on their degree of sophistication. Mechanical harvesting
aids include ladders, hydra-ladders, cherry pickers, bin trailers, harvesting platforms and
specialised machines such as the ‘Pluk-O-Trak’.

5.4.1 Cherry pickers, platforms and bin trailers
In Western Australia as in other states, cherry pickers are used extensively for harvesting
and other orchard operations such as fruit hand thinning and pruning. They are needed to
harvest tall trees, many of which can be up to 4.5m high, and where a large percentage of
the crop cannot be reached from the ground. In recent years self-propelled elevating
harvest platforms have been introduced. They have become very popular in many
deciduous fruit orchard businesses. If operated to their potential harvesting platforms
have higher harvest efficiency than cherry pickers. Platforms carry several pickers and
are able to harvest at a faster rate. However the efficiency of picking is governed by the
slowest picker on the platform. The main harvesting platform used in Western Australian
orchards is the Marchessi, which is imported from Italy. Cherry picker and platforms are
both very versatile and are used for other important orchard operations such as hand
thinning of fruit and pruning.

Harvesting platforms were developed in Europe for use in hedgerow systems for apples
and pears. Italy is the major manufacturer. In Europe there has been a decline in the use
of harvesting platforms as the height of orchard trees have declined with the adoption
dwarfing rootstocks. This allows more fruit to be picked from the ground in ‘pedestrian’
style apple orchards. Picking fruit directly into bins located on a bin trailer moving along
by the side of pickers is popular in parts of Italy. However fruit bruising is a problem
with this method if fruit is not placed carefully into the bins. Harvest rates of
180kg/hr/person can be achieved with this system. I visited a large orchard in Ferrara,
Italy where a picking crew of 10 were harvesting Fuji apples grown on M9 into a long
line of bins on an orchard trailer. On taller trees where all fruit cannot be reached from
the ground harvest platforms are still used to pick the tops of trees. There is also a trend
in Europe back to taller trees, up to about 3m, which will probably see a return to
platforms or other mechanical aids in the future.
5.4.2 Pluk-O-Trak

The most impressive harvesting aid I saw in Europe was the ‘Pluk-O-Trak’. In Italy the machine was operating in two orchards harvesting Braeburn apples for the fresh export market and Morganduft apples for processing. The Pluk-O-Trak is manufactures in the Netherlands by Munckhof. Several hundred machines are now being used throughout Europe and other parts of the world (Table 1). Two hundred have recently been sold in South Tyrol, the premium apple growing region and the Verona region in Italy. There are also several hundred in the Loire valley fruit-growing region in France. The ‘Pluk-O-Trak’ is being used to harvest a range of fruit for the fresh market including apples, pears, prunes, apricots and oranges.

<table>
<thead>
<tr>
<th>Country</th>
<th>France</th>
<th>Spain</th>
<th>Italy</th>
<th>Holland</th>
<th>Denmark</th>
<th>Switzerland</th>
<th>Portugal</th>
<th>Argentina</th>
</tr>
</thead>
<tbody>
<tr>
<td>No machines in operation</td>
<td>683</td>
<td>576</td>
<td>255</td>
<td>195</td>
<td>42</td>
<td>26</td>
<td>19</td>
<td>14</td>
</tr>
</tbody>
</table>

* Figures from N. Sanders of Munckhof (per. com. 2002)

The unique feature of the Pluk-O-Trak is the 6 to 8 conveyor chutes, which can be positioned close to the picker and fruit in canopy for ease of picking. The picking conveyors can be adjusted in all directions to minimize the distance to the picker and the crop. Harvest rates are high, 250kg/hr/person. Two models are available accommodating
New mechanical and robotic harvesting technologies for fruit

6 or 8 people and harvest at rates per machine up to 3t/hr. The machine can reach tops of trees from 3.25 to 4.25m high and be accommodated in very narrow rows from 3 to 6m wide. Fruit bruising and damage is extremely low as there is no fruit to fruit contact during picking until the fruit is placed into the bin by a very gentle and efficient bin filling mechanism. The machine can be fitted with a bin trailer with up to 14 bins. The full bins are easily and quickly discharged (less than 1 min by one person) and replaced with empty bins for continuous harvesting. Other possibilities are filling standard cartons and trays and pre-grading in the orchard. The machine is self-propelled with a small motor (11hp), which is very quiet and efficient on fuel. Other features are adjustable speed and automatic steering. Many of the mechanical adjustments can be converted to hydraulic control. The Pluk-O-Trak is also very versatile and can be used for pruning and hand thinning fruit operations. It is suitable for large or small orchards. The capital cost in Italy was between Lr 36 mill (AU$ 36,000) and Lr 60 mill (Au $60,000) depending on the size and modification with hydraulic controls (excludes the price of bin trailers). The growers on whose orchards I saw the small and large machines operating were both very pleased with the performance citing higher productivity, less damage, higher fruit pack-outs and happier pickers as the main reasons.

Pluk-O-Traks have been used in Australia. I know of only one that is in current use in Stanthorpe, Queensland. The grower is very pleased with its performance on his Royal Gala and Pink Lady™ orchard. The manufacturer has two agents in Australia (Western Australia and South Australia). In recent years the manufacturer has supplied Pluk-O-Trak machines to producers of a range of fruit crops around the world.

‘Pluk-O-Trak’ harvesting Morganduft apples for processing in north Italy
New mechanical and robotic harvesting technologies for fruit

‘Pluk-O-Trak’ harvesting Golden Delicious apples in France
(Photographs courtesy of Munckhof)


5.5. **Harvesters for other fruits, olives and berries.**

The focus of this project was harvesting technologies for deciduous fruits for the fresh market, particularly apples. However, while reviewing the literature and on the study I was able to report the mechanical harvesting of some other crops.

The mechanical harvesting of citrus is well developed, particularly for processing. Peterson (1998) and Korvan Industries in the USA have developed double-spiked-drum canopy shakers for the commercial harvesting of oranges in high-density groves for processing. The ‘Pluk-O-Trak’ is used extensively in Spain for harvesting fresh market oranges. The EURIKA citrus project had developed robotic harvesting of oranges to a very successful degree before the project was terminated in the late 1990’s.

Various mechanical harvesting techniques are being tried and developed for olives including trunk shakers, combs, canopy beaters and straddle harvesters. Korvan Industries were trialing a modified double-spiked-drum canopy shaker they had developed for citrus in California when I was there in September 2001. The system showed promise but its operation in the established groves with large old olive trees was difficult. Pellenc manufactures a trunk-shaker harvester system for olives, which is very popular throughout Spain. As with the early development of mechanical harvesting for apples and other fruits the success with olive harvesters is more likely to come when trees are resigned to be more compatible with the harvest system rather than trying to adopt the
harvester to the present tree designs. Prof. Tombesi and his colleagues in Italy have taken this approach and are developing new production and canopy management systems for olives that will be more compatible with mechanical harvesters in the future.

Mechanical harvesters for ‘highbush’ blueberries and blackberries have been developed and are in commercial use in the USA (Peterson et al, 1996 and 1997)

5.6 Other technologies
Technology, particularly in sensors for use in non-destructive fruit quality assessment and fruit grading is advancing rapidly around the world. One example I visited was the Giqual group at CEMAGREF in France, which develops measurement systems and sensors for the fruit and vegetable and food industry generally. They specialise in vision, NIR spectrometry and data processing for decision making. One of their present projects is the GLOVE, an instrumented glove to non-destructively and rapidly assess fruit sugar levels, firmness and size by pickers in the field. This is being developed in cooperation with groups in Belgium, Italy and Germany with EU funding. Giqual has developed other technologies to rapidly assess product quality in the apple, potato, table grape and cereal industries.

A valuable forum which present and discuss the latest developments in these and other areas such as mechanical harvesting is the International Symposium on Fruit, Nut and Vegetable Production Engineering. The last symposium, the 6th was held in Potsdam, Germany in September 2001 and the next will be hosted by CEMAGREF in Montpellier, France in April 2005.

*The instrumented ‘GLOVE’*
*(Photograph courtesy of CEMAGREF)*
6 DISCUSSION AND OPPORTUNITIES

There are exciting opportunities for Australia in each of the three areas of mechanical and robotic harvesting of deciduous fruit. The adoption of new mechanical harvesting aids such as the Pluk-O-Trak would have an immediate and positive impact in the industry, particularly for apples. Robotic bulk harvesting is a medium term proposition, which still needs improvement for apples. Bulk harvesting of cherries, pears and plums where seems to have more potential at this stage. Robotic selective harvesting of individual fruits is at the cutting edge of orchard and artificial intelligence technology. It is a longer-term proposition, probably up to three years to commercial application and requires more investment in research and development. The higher capital cost may limit its use to larger orchard businesses. However its development would have a more profound impact on the apple industry than other harvesting systems.

The Australian deciduous fruit industry should consider investing in each of these areas. Each provides applications and efficiencies for different sectors of the industry. Mechanised and robotic harvesting will have major impacts on the productivity, efficiency and viability of deciduous fruit production in the future.

Mechanical harvesting aids

The Pluk-O-Trak provides the best and most immediate option to improve harvest efficiency in quality fruit production, particularly apples. This machine has wide application from small to large orchards. Other advantages of the system includes its compatibility with different orchard designs and dimensions, its versatility for other orchard operations (pruning and hand thinning of fruit), low running costs, quietness of operation, ease of maintenance and picker comfort. The machine is commercially available for immediate adoption. The Pluk-O-Trak has been used in orchards, mainly in Europe for over 20 years undergoing continuous improvements. It is manufactured by a reputable company in the Netherlands (Monckhof) which specialises in orchard machinery. The company has two manufacturing plants located in Holland and the USA.

The Pluk-O-Trak needs to be demonstrated to growers in Australian orchards and compared to the performance of other currently used mechanical harvesting aids such as platforms and cherry pickers. There are two agents for the Dutch company in Australia and Monckhof would be keen to introduce a machine for trial in the Australian market.

Although there are two Pluk-O-Traks currently in Australia both are older models and neither are self-propelled. The machine in Queensland is the only one in current use and information and performance data could be collected during the harvest season.

Robotic bulk harvesting

The main limitations for the robotic bulk harvesting of fresh apples in the short term are the detachment of stalks in some varieties, non-uniformity of fruit maturity on the tree and the potential for bruising in delicate varieties. Further research and development is required. The system is also limited to narrow inclined canopies.
New mechanical and robotic harvesting technologies for fruit

The bulk harvesting system however, has immediate application for cherries and potentially for pears and plums. Many of our production systems for these fruits, particularly in Western Australia, are on inclined canopies, which are compatible with Peterson’s robotic bulk harvester.

Three approaches are suggested:
(1) continue discussions with Donald Peterson and update on his work with fresh apples,
(2) assess the interest within the deciduous fruit industry for robotic bulk harvesting with a view to:
   ♦ testing the harvesting system in Australia on suitable cherry, plum and pear orchards.
   ♦ joint research and development with the USDA-ARS program

The machine is valued at about US $50,000. Peterson is very keen to consider a joint project with Australia. The machine could be transported from the USA for trials or manufactured in Australia. Because of costs suggests it is preferable to build the machine in Australia.

Robotic selective harvesting of individual fruits
This is an exciting longer-term proposition. The advances in orchard, mechanical, artificial intelligence and sensor technology since the original MAGALI project was suspended in 1996 now makes robotic harvesting an achievable and commercially viable proposition. In addition there is a renewed interest in developing a robotic harvesting project. Possible interested partners are the Western Australian Department of Agriculture, Pellenc, CEMAGREF, the Australian apple industry, Universities in Australia, apple growers in the south of France and individual apple producers in Australia.

The robotic harvester is the most costly option requiring a larger investment in research and development. Time to commercialisation could be shortened to two to three years with cross hemisphere R&D. The total cost of the project would be around AU$450,00.

The technology would be more suited to the economics of large-scale production where productivity gains and labour savings would be greatest. Robotic harvesting also has the greatest potential to incorporate advances in sensor and other technologies, which could revolutionise deciduous fruit harvest and production.

Other advantages for Australia’s involvement in the project would include being at the cutting edge of technology and developing working relationships with research and development groups and commercial companies in Europe working on new technologies in the production and processing of horticultural crops.

I believe Australia would need to drive the interest in reactivating the project.
Other opportunities
A number of other opportunities were highlighted from the study tour to the USA and Europe. The main ones are:

(a) New technologies in food production and processing
The Giqual group at CEMAGREF, France develops measurement systems and sensors for the fruit and vegetable and food industry generally. They specialise in vision, NIR spectrometry and data processing for decision making. The GLOVE, an instrumented glove to non destructively and rapidly assess fruit sugar levels, firmness and size by pickers in the field is being develop by Giqual and groups in Belgium, Italy and Germany with EU funding. Giqual has developed other technologies to rapidly assess product quality in the apple, potato, table grape and cereal industries.

(b) The International Symposium on Fruit, Nut Vegetable Production Engineering
This is a forum to present and discuss latest developments in new technologies in food production and processing, such as mechanical harvesting, will be hosted by CEMAGREF in Montpellier in April 2005. The last symposium was held in Potsdam, Germany in September 2001. There would be benefits in attending this forum in the future.

(c) Mechanical harvesting of other crops
Information and contacts on commercially available harvesters for citrus, olives and berry crops. This information is available to the relevant industry contacts in Australia.
7 TECHNOLOGY TRANSFER

7.2 Industry meetings

• Hills Orchard Improvement group meeting, Lesmurdie Sports Club, Lesmurdie, Western Australia, 2002
• Donnybrook Orchard Improvement Group, Donnybrook Recreation Centre, Donnybrook, Western Australia, 2002

7.2 Publications

Articles are being prepared from the information collected in this project and presented in this report. The articles will cover the latest developments in and availability of mechanical and robotic harvesting systems for deciduous fruit crops. They will be published in industry newsletters and journals in 2003.
New mechanical and robotic harvesting technologies for fruit

8 RECOMMENDATIONS
The information collected by visiting key groups in the USA, France and Italy and
gathered from the literature and personal communication indicates there are exciting
opportunities for the Australia deciduous fruit industry in the three main areas of
mechanical harvesting aids, mechanical bulk harvesting and robotic selective harvesting.
There are further opportunities in advances made in sensor and non-destructive quality
assessment technology.

The following investments by the Australian deciduous fruit industry is recommended:

8.1 New harvesting and other technologies
It is important for the Australian industry to keep up to date with new developments in
mechanical and robotic harvesting and advances in other technologies such as the non-
destructive assessment of fruit quality occurring around the world. One way of achieving
this is for the deciduous fruit industry to send a representative to the next International
Symposium on Fruit, Nut and Vegetable Production Engineering in Montpellier, France
in April 2005.

8.2 Mechanical harvesting aids
The Pluk-O-Trak harvesting system is commercially available at comparable costs to
other harvesting aids such as platform pickers. It is suitable for use in small to large
orchards and its adoption would immediately improve harvest efficiencies in quality fruit
production and versatility with other orchard operations.

It is recommended that new improved Pluk-O-Trak models be introduced to Australia for
demonstration to growers and comparative trials.

8.3 Robotic bulk harvesting
Bulk harvesting systems have limitations for fresh apples at this stage. The USDA ARS
project is continuing to develop the system to overcome the problems with stalk
detachment, bruising and uniformity of fruit maturity in apples. Peterson’s bulk harvester
has immediate application to cherries and potential for plums, pears and processing
peaches.

It is recommended to:
(1) keep a watching brief on the USDA work on fresh market apples
(2) introduce or build a prototype of Peterson’s bulk harvester in Australia and develop
the system for use on cherries, plums, pears and processing peaches. The cost to build
the harvester in Australia would be about AUS$75,000.

8.4 Robotic selective harvesting
This is the most exciting proposition for mechanised harvesting. It uses cutting edge
technology and will revolutionise future orchard systems. It may be more suited to large
orchard operations because of the high investment cost and economies of scale. A new
R&D project will be needed to develop the concept to the commercial stage. Recent
advances in orchard, mechanical, artificial intelligence and sensor technology makes the development of a commercial robotic harvester within 3 years a realistic proposition.

Potential partners who have shown interest in developing and contributing to a new project include the Western Australian Department of Agriculture, Pellenc SA, CEMAGREF, the Australian apple industry, Universities in Australia, apple growers in the south of France and in Australia. The cost of a new project would be about AUS$450,000 over 3 years.

It is recommended that Australia drive the interest to develop and initiate a new project on the robotic harvesting of fresh market apples. The new project should include counter seasonal producers in Australia and France to speed up R&D. Pellenc should be consulted to be involved in the project because of their expertise developed in the MAGALI project and to clarify IP issues.
9 ACKNOWLEDGEMENTS
The following people are acknowledged for giving their time, information and ideas on mechanised and robotic harvesting: Donald Peterson, Scott Wolford, Piet Westerbeek, Rob Breukelman, Antoine Bourley, Bernard Bonicelli, Veronique Bellon-Maurel, Prof Sansavini, Alessio Martinelli, Prof Augustino Tombassi, Nico Sanders and Steffan Hermes.

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10 BIBLIOGRAPHY

10.1 Key References


10.2 Further Reading

New mechanical and robotic harvesting technologies for fruit


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12 VISIT ITINERARY
17 September to 2 October 2001

Mon 17 September  Fly Perth to Sydney to Los Angeles
               Drive to Fresno, California

Tue 18 September  Exeter, California
               KORVAN INDUSTRIES
               Olive harvesting -Ron Breukelman, design engineer,
               Don Dryer, Chairman of California Olive Commission
               Drive to San Francisco

Wed 19 September  Fly San Francisco to Washington DC
               Drive to Martinsburg, West Virginia

Thu 20 September  Kearneysville
               USDA ARS
               Bulk apple harvester
               Donald Peterson and Scott Wolford
               Harvest Empire and Star Jonagold apples

Fri 21 September  Kearneysville
               USDA ARS
               Meet researchers – IPM, biological control, transgenics, peach ripening
               genes.
               Visit commercial orchard

Sat 22 September  Drive to Washington DC
               Fly Washington DC to London

Sun 23 September  Fly London to Monpellier, France

Mon 24 September  Montpellier
               CEMAGREF
               Bernard Bonicelli - Agricultural engineering Lab, robotic harvester
               prototype
               Drive to Pertuis
               PELLENC
               Antoine Bourley - MAGALI project discussion, robotic harvester, visit
               factory (wine grape harvester, precision viticulture project, electronic
               secateurs etc)
               Return to Monpellier
New mechanical and robotic harvesting technologies for fruit

<table>
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<tr>
<th>Date</th>
<th>Activity</th>
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| Tue 25 September | Montpellier  
CEMAGREF  
Veronique Bellon-Maurel, sensing and information technologies for quality in food and agro- industries  
Pier Feuolli, biodegradable plastics for horticulture |
| Wed 26 September | Montpellier  
Report writing and travel arrangements |
| Thu 27 September | Drive Montpellier to Marsailles  
Fly Marsailles to Bologna, Italy via London |
| Fri 28 September | Bologna  
UNIVERSITY OF BOLOGNA  
Prof Sansevini and Dr Stefanne Mazzoni  
Visit high planting density pear trials  
Drive to Ferrara  
CIV  
Dr Alessio Martinelli  
Visit orchards harvesting Fuji apples and growing Pink Lady TM™, apple production on M9 rootstock  
Visit CIV’s apple, stone fruit and strawberry breeding property  
Return to Bologna |
| Sat 29 September | Drive to Peschiera on Lake Garda  
PLUK-O TRAK  
Steffan, Hermes  
Visit two orchards using the Pluk-O-Trak to harvest Braeburn and Morgenduft apples |
| Sun 30 September | Drive Lake Garda to Parugia |
| Mon 1 October | Perugia  
UNIVERSITY OF PARUGIA  
Prof Agustino Tombessi – olive harvesters and production systems |
| Tue 2 October | Drive Parugia to Rome  
Fly Rome to Perth via London |