FINAL PROJECT REPORT
WTFRC Project Number:

Project Title: Mechanization Research

Is there more than one PI? ☐ **Yes** ☒ **No**
If so, please complete the Co-PI info.

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Budget History:

Item	**Year 1: 20,000**	**Year 2:**	**Year 3:**
Salaries			
Benefits			
Wages			
Benefits			
Equipment			
Supplies			
Travel			
Miscellaneous	$3407.65		
Total	$3407.65		

(Attach final report to this form and send to Kathy@treefruitresearch.com)

Mechanization Research

Part 1

Image Processing/ Non-contact Sensing

Image processing could be used for scouting for pests and diseases that are not visible to naked eye in the visible spectrum. Near Infrared cameras and thermal infrared wavelengths could be deployed to capture images that could be processed and analyzed to provide information on topics such as water stress, thermal or heat stress, fruit size and count, disease problems such as fungal and bacterial infections (that cause lesions that alter the temperature of the tissues/cells in the affected areas), pests and insects that are difficult to detect but could be identified by thermal images because of their different temperature profiles. Water stress could be identified 3-5 days before the trees start wilting (using crop water stress estimate model and spectral reflectance imagery), chemical and nutrient mapping could be done using multispectral imagery and could be beneficial in targeted fruit picking. Monochrome (grayscale) image analysis and thresholding techniques could be used to estimate fruit and leaf counts in the trees. This could be used as feedback control routines in harvesting/pruning/thinning robots. Sunburn and heat stress could be detected using thermal imagers, accurate yield estimation and fruit size and count estimation is possible by image processing. The cost of this package is budgeted as follows:

Imaging hardware: Camera, frame grabber, filters, etc.,: $5000
Software: Matrox imaging library, visual C++ developer module: $2000
Thermal imaging system: $10,000

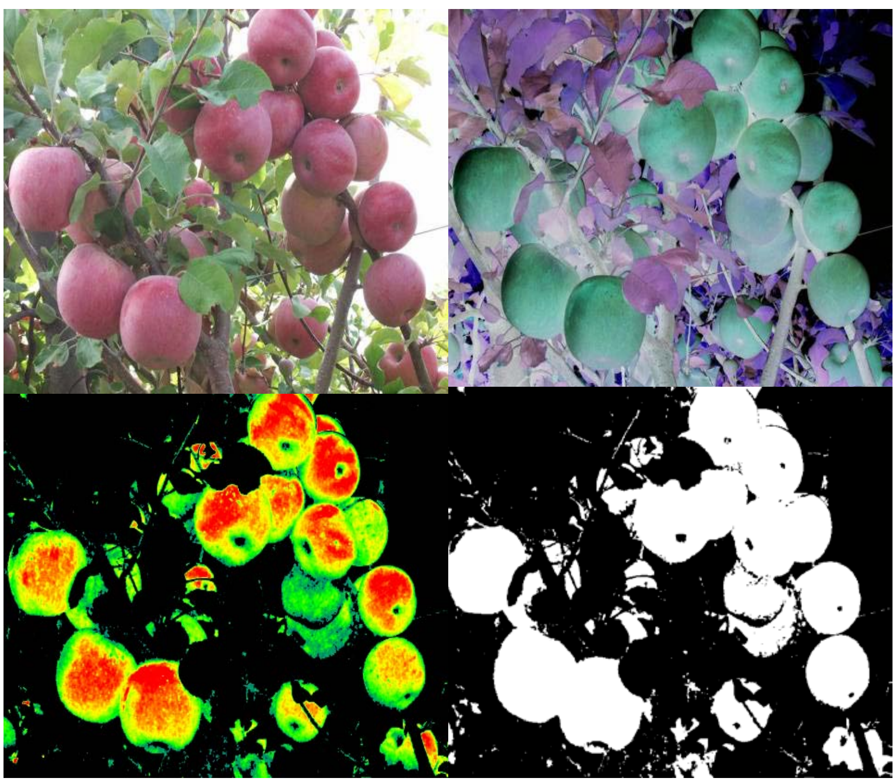


Fig 1. Images for yield prediction and heat stress identification.

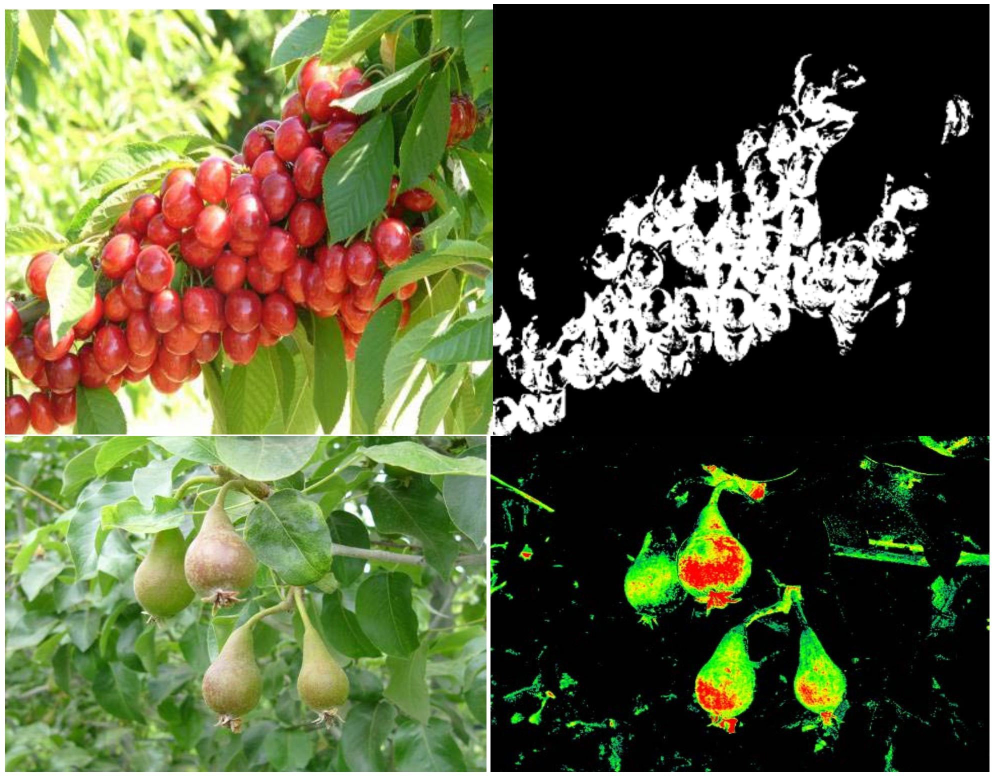


Fig 2. Cherry fruit count estimation and pear heat stress from image analysis.

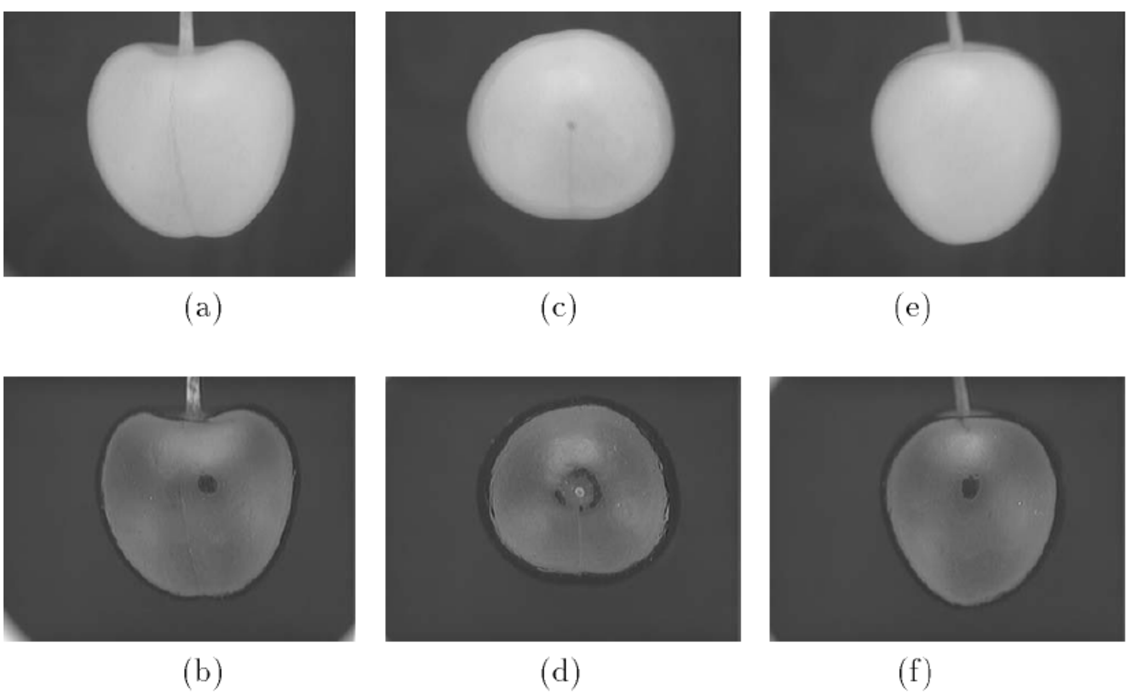


Fig 3. Bruised and pitted cherries identified by an infrared image.

Part 2

Summary of Different Types of Sprayers used in Orchards

In the foreseeable future most pest control products, will continue to be applied through conventional hydraulic nozzles. Whatever the type of spray equipment the end requirement is the same, to break-up the liquid into appropriate sized droplets and to put them where they are needed (Young, 1985). The nozzle regulates the spray flow, droplet size and spray pattern. Flow rate is affected mechanically by orifice size and spray pressure. Whilst nozzle type, orifice size, pressure, and spray angle can define the droplet size range. In addition factors such as viscosity, liquid density, surface tension, and climatic conditions affect the spray characteristics. The complexity of the spray droplet spectrum produced by commercial spray nozzles and other devices along with the complexity of the natural system has been and remains a major difficulty, which has hindered spray research (Himel, 1963).

Studies were conducted to determine the spray drift potential and coverage from different sprayers used to apply chemicals in orchard trees. Traditional PTO driven air-blast sprayer was compared with the modified version of the air-blast sprayer (with wooden doughnuts at the fan intake) and new technology tower sprayers in the Mid-Columbia orchards. A fluorescent tracer was used to quantify the spray deposition on the targets. Meteorological measurements were recorded during the experiments. Leaves were sampled from the trees in rows 1-8 downwind from the spray swath. Nylon screens were positioned on wooden poles at 3 different heights of 1m, 2m and 3m. The poles were located at lateral distances of 15m, 30m, and 50 m along a line perpendicular and downwind from the spray swath. It was found that the traditional airblast sprayer had better spray coverage but higher drift potential than the other sprayers that were tested. The tower sprayers and the modified airblast sprayer with plywood donuts and air-induction nozzles had lower drift potential than the traditional airblast sprayer. The following summary describes the principle of each sprayer type along with its pros and cons.

Summary of Experiments:

Airblast Sprayer:

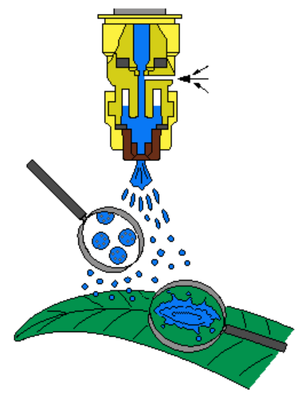
Creates a broad droplet spectrum ranging from <50 to 500 microns and larger depending on size of nozzle and pressure. Provides good penetration and spray coverage. Drift is a major problem as droplets <100 microns tend to drift. Coverage at top of trees is not good as it sprays from ground upwards, has a low profile relative to the leaves. Uses high-velocity, large volume air stream to carry the droplets. Velocity is important for getting the spray to the top of the trees or across a field. Most airstreams lose 75 percent of their velocity in the first 25 feet from the sprayer. It was also found that the maximum air velocity at different distances and heights from the sprayer was linearly related to fan speed. Air-stream velocity at any location was reduced by the increase in sprayer travel speed. Laser and ultrasonic tree detectors can control the sprayers to spray only on trees and not in spaces between trees.

The effect of the air stream on spray droplet size is proportional to the velocity difference between the liquid spray and the air stream. The greater the velocity difference, the greater the atomization. The spray droplet break-up will be minimal if the nozzle injects the spray into the air stream moving in the same direction as the air. Likewise, if the spray is injected into the air stream directly against the air flow, the atomization will be maximum.

The major function of the air stream is to move the pesticide into the tree canopy and uniformly deposit it on the fruit and foliage and on other parts of the tree or crop. Air stream characteristics that influence the coverage include air volume (cubic feet per minute: CFM) and velocity (feet per minute: FPM). These are influenced by fan type, size; speed, volute design, etc. Several factors are involved in an air-delivery sprayer's performance. Most of these factors interact rather than act independently.

The hollow cone nozzles used in the airblast sprayers produce a spray pattern with the liquid concentrated on the outside of a conical pattern. Cone nozzles are used mainly to apply insecticides, fungicides, or growth regulators where penetration and complete coverage of foliage is needed. Working pressures range from 50-400 psi. Hollow cones are ideal for low-volume applications, and solid cones are used to apply high volumes. Spray drift is high due to the small, light-weight droplets produced. The low profile and radial airflow pattern and largely unidirectional airflow results in non-uniform spray coverage in different sections of the canopy, especially with concentrate applications.

Air Induction Nozzles:



New nozzle technology such as air induction nozzles produces larger droplets than conventional hydraulic cone nozzles. Large droplets normally roll off the leaf but air inclusion nozzles create air bubbles within the larger droplets which then collapse on contact with the leaf, dissipating the energy and dispersing the liquid.

Air inclusion, air induction or venturi nozzles where an internal venturi creates negative pressure inside the nozzle body. Air is drawn into the nozzle through holes in the nozzle side, mixing with the spray liquid. The emitted spray contains large droplets filled with air bubbles and virtually no fine, drift-prone droplets. The droplets explode on impact with leaves and produce similar coverage to conventional, finer sprays. Air-induction nozzles provided less drift potential with larger droplets; however, spray coverage was lower than that of the conventional nozzles. The biological efficacy of the air-induction nozzles needs further investigation.

Wooden Donut Airflow Restrictions:

Airblast sprayers are generally used with the same settings (except changing from dilute to concentrate sprays) from dormant season to the post-harvest clean up applications, irrespective of changes in canopy volume or density. Tractor speed, air-stream velocity and volume are maintained at same levels throughout the season irrespective of the canopy geometry and density. This results in a highly inefficient application leading to extensive drift, especially during dormant spray season. Wooden donuts were fabricated such that they had areas of ½, 2/3rd area of the airblast fan. The donuts significantly reduce the air stream velocity from the airblast sprayer. Droplets released into this lower speed air stream are not further atomized, thus formation of small sized (<100 microns) drift prone droplets are prevented. Depending on the growth stages of the trees through the season, fabrication of 3 donuts such as 2/3 fan area, ½ fan area, and ¼ fan area is suggested to match the dormant spraying, pre-bloom, and fruit setting stages, respectively. Excellent low cost drift control option, biological efficacy needs to be evaluated.

The radial airspeeds from airblast sprayer were measured with and without plywood donuts to restrict the fan's airflow. The donuts reduced drift and enabled the spray output to be lowered to match the different growth stages of the canopy while maintaining the same tractor speed. The percentage reductions in the airspeeds were measured at different engine RPMs with and without the plywood donut restrictions. The donuts reduced the airspeed outputs by 40% (Table 1). Since the effect of air-stream on droplet size is proportional to velocity difference between spray and air-stream, the droplets from the sprayer with donuts were larger than the ones without the donuts and produced less spray cloud with lower drift potential.

Table 1. % Reduction in wind speed from airblast sprayer with plywood donut

Engine Speed	**1000 rpm**	**1250 rpm**	**1500 rpm**	**1750 rpm**	**2000 rpm**
Right side	38.19	45.59	41.49	45.05	49.10
Left side	39.16	46.53	41.25	45.02	49.09

Electrostatic Sprayers:

Electrostatic sprayer systems give the pesticide a positive electric charge as it leaves the nozzles. Plants naturally have a negative charge, so the positively charged pesticide is attracted to the plants. The spray is directed horizontally through or above the crop (depending on the pesticide being applied). The advantages are pesticide adheres to foliage well, so less pesticide is needed per acre. Coverage is more even than with other types of equipment, minimizes the likelihood of drift.
The Limitation is that its useful only for application to foliage, and the electrostatic sprayers don't have enough penetration for the spray droplets to reach the inner parts of the trees and trunks. This could be achieved by air-assisted charged particle nozzle systems. The following table shows the effect of having the electrostatic charging system switched on versus turned off, and the spray coverage in the first two rows in an high density apple orchard (9 ft row spacing) during dormant season. There was a significant difference in the second row between electrostatic on vs. off. However, since electrostatic sprayers work best with leaves on for foliar coverage, more tests are needed to see the penetration and spray coverage in full mature canopy stages.

Table 2. Spray coverage analysis from electrostatic sprayer.

	Electrostatic ON				**Electrostatic OFF**			
	East (Right side)		West (Left side)		East (Right side)		West (Left side)	
	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2	Row 1	Row 2
Deposition (ul/cm2)	**2.10**	**0.46**	**6.20**	**0.50**	**2.00**	**0.26**	**5.10**	**0.21**

Hardi Tower Sprayer:

Air-assisted sprayers direct the spray towards the trees and have high profile, thus they help in adequate penetration of tree canopies. However, the air volume and speed are two critical factors governing deposition, excessive or lack of enough air can result in inefficient and inadequate spray coverage and will result in off-target drift. Airflow should be adjusted to facilitate spray penetration inside tree canopies and prevent rattling of leaves and spray drift.

The Hardi sprayer uses a centrifugal fan with 10 spouts and equally sized air hoses. This sprayer has great potential in getting better coverage and reduced drift for trees up to 14 feet tall and row spacing from 8 to 14 feet, and capable of applying 20-350 GPA. It has an adjustable swivel or turnable hitch, heavy-duty self-priming pump, hydraulic spray controls, a 4 gallon clean water tank, and a remote tank drain.

It has air-assisted hydraulic nozzles, the air-flow from the centrifugal fan is evenly distributed through the hoses providing a uniform conical air flow. The key is low speed but high volume of air to transport and deliver the droplets on to the targets, thus providing a uniform coverage with less drift. Spray coverage is not compromised as it uses hydraulic cone nozzles similar to airblast sprayers that create droplets with broad spectrum (25-500 microns) depending on the pressure. Drift is controlled as it uses low velocity but large volume of air to carry the droplets.

Proptec Tower Sprayer:

Rotary atomizers create smaller, more uniform droplets, which would normally drift. When used in conjunction with a tower and cross flow fan design the smaller droplets are actually directed into the canopy. This type of sprayer, referred to as controlled droplet application, produces 95-98% of its droplets all of the same size. The size produced depends on the speed of the fan. Advantages include less water, resulting in better timeliness and a more targeted spray. Horizontal penetration into the canopy is preferential to vertical penetration from an air blast sprayer.

Horizontal penetration into the canopy is preferential to vertical penetration from an air blast sprayer.
The droplets may be carried to the target by gravity or by an air stream created by a fan. The limitations are that gravity type may not penetrate foliage well, not suitable for use in hilly terrain and windy conditions, and trees with limbs overlapping the row spacing. High rotational speed fans require narrow cord blades and the airflow is highly constricted downwind of the fan which substantially reduces the swath

width. The larger droplets from rotary atomizers pass straight through the air stream radially, and do not become entrained, thereby reducing dose efficiency on foliage. High rotational speeds, especially with larger fans, are noisy, may also create mechanical problems, and high rotational speed gearing is expensive.

The obvious advantages of this technology are reduced volume per hectare, reduced sprayer refill times, reduced spray time per hectare, and reduced overall cost for equipment, fuel and labor.

Accutec Sprayer:

Uses air-shear nozzles that use high-speed air to breakup the spray liquid into droplets rather than orifice nozzles and pressure, and creates droplets of 50 microns for excellent spray coverage on both sides of leaves. Air speeds of 170 to 400 miles per hour are required. Drift is a problem with the tower-less option as it sprays from the ground upwards (similar to airblast sprayer) but with the use of mast tower, spraying is done horizontally that will minimize drift. Uses a low pressure tank thus enabling use of precise rate controllers for chemical and time savings. Refill time is greatly reduced as air is used as the carrier instead of water predominantly. Uphill or downhill spraying problems are solved using the rate controller. Proper overlap of spray pattern is needed with the tower sprayer for complete coverage of the trees, thus nozzle angle and deflector orientation are important factors while performing calibration to match the tree geometry. Uses non-clogging stainless steel air-shear nozzles, thus is relatively maintenance free and can spray viscous formulations and suspension of high-concentrate solutions.

Advantages are trees can be sprayed at higher speed (3-3.5 mph with Accutec vs. 1.7 to 2.3 mph with regular airblast) and it uses less water and uses air as carrier (low volume spraying), so the refill time and chemical costs are lower.

Cropland Sprayer:

This sprayer is built around multiple, independent fans (4-8+) that are light weight (they are made of plastic), powered off tractor hydraulics, and have pressurized hydraulic cone nozzles arrayed around the outside of the fan. So, the air delivery of the system is separate from droplet generation, unlike the Proptec/Accutec units that are discussed above. This sprayer has achieved 30% market share in Australian and New Zealand orchards and vineyards in less than a decade, according to the Australian scientists who collaborated in its development.

The 5 blades have a very broad cord, which increases towards the blade tip to increase Reynolds number and maximize the total blade area. Blade pitch is fixed and set to give consistent airflow over the full length of the blade, especially near the Hub and for maximum swath. They operate at a lower speed of 1500-3000 rpm. The sprayer has a 50 cm diameter, direct blast axial flow fan and a series of hollow cone nozzles. Has higher efficiency and provides uniform coverage with improved penetration to inner canopy sites and under-leaf surfaces. The advantages are that it has low power requirement, uses large air volumes at low velocity, multi-directional, rotating turbulent airflow, without ducting and bending of the air stream, and has good profile relative to the crop canopy. Since this sprayer uses hydraulic cone nozzles, spray coverage is not compromised.

Results from Spray Coverage/Drift Measurement Experiments: The following charts show the comparison between different sprayers that were tested for their spray coverage and drift potential in the Mid-Columbia orchards. A water soluble fluorescent tracer (Fluorescein, 15 ppm) and was used to quantify the spray deposition on the targets. Leaves were removed from pre-defined zones of trees in rows 1-8 downwind from the spray swath (figure 1). Nylon screens of 56% porosity and known area (8"x8") were used as drift collectors. The screens were framed and mounted on wooden poles at 3 different elevations of 1m, 2m, and 3m, and at transverse distances of 15m, 30m, and 50m downwind from the spray swath. 100 GPA was used for concentrated spray trials and 200 GPA was used for dilute (dormant season) spray trials. Samples were analyzed using a spectrofluorimeter (Model LS50B, Perkin-Elmer, Fremont, CA). Meteorological recorders (15 Channel HOBO Weather Station, Onset Computer Corp, Bourne, MA) were used to record temperature, solar radiation, relative humidity, wind speed and wind direction. The following sprayers were used in the study.

1) A traditional 500-gallon PTO driven air-blast sprayer (Air-O-Fan, Reedley, CA) with hydraulic cone nozzles (45 swirl plate, 120 PSI);
2) Modified version of the same air-blast sprayer with restricted airflow intake using plywood doughnuts of ½ and 2/3rd fan area;
3) Airblast with air-induction nozzles (Teejet flatfan AI110025, AI11003, AI11004, AI10002);
4) Two new technology tower sprayers (Proptec tower sprayer, Blueline, Moxee, WA, and Hardi Arrow tower sprayer, Hardi, Fresno, CA).

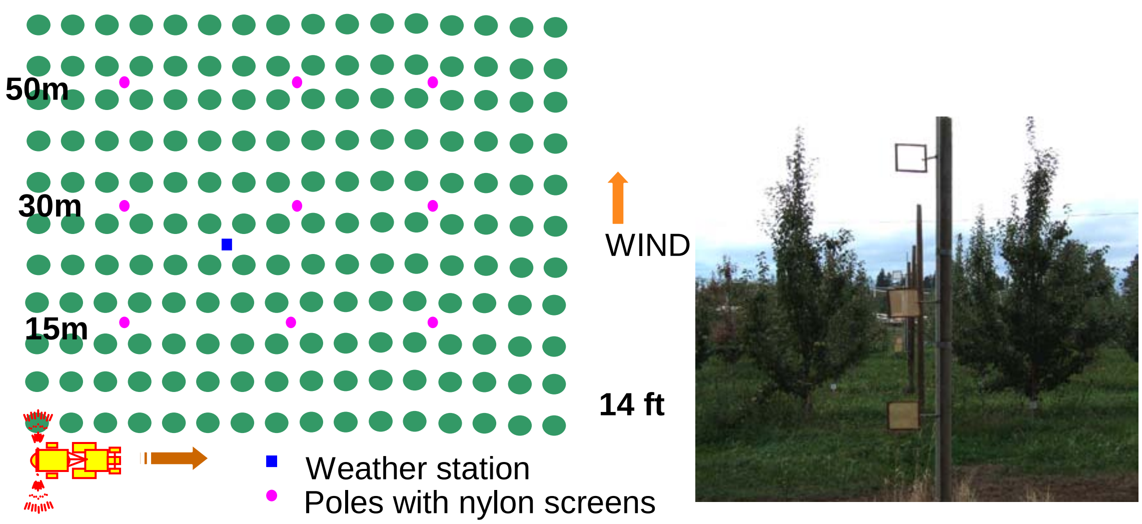


Fig 4. Orchard layout with drift collectors.

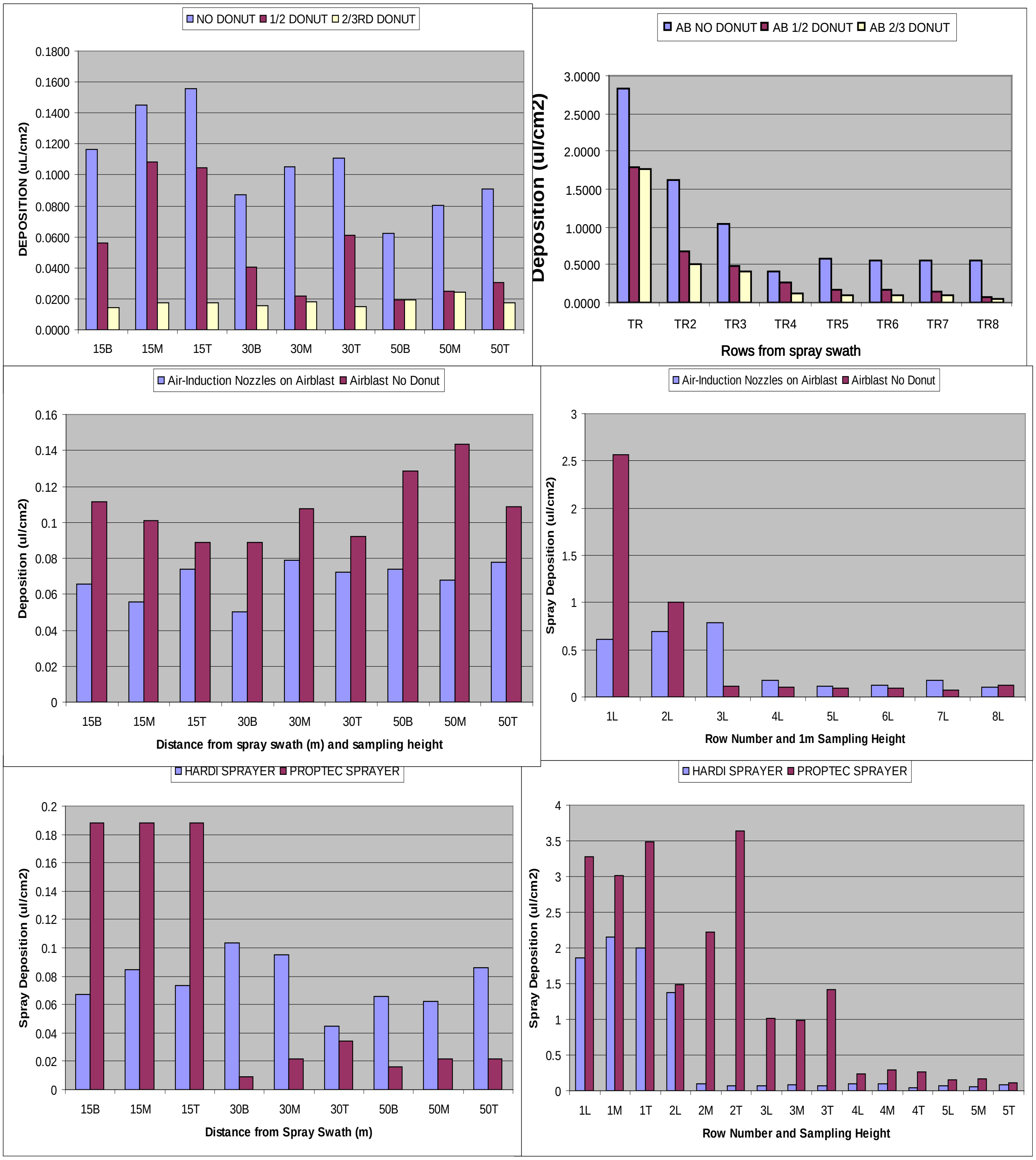


Fig 5. (Top Row): Drift potential and spray coverage from airblast sprayer with and without plywood donuts. B,M and T are 1m, 2m and 3m sampling heights, respectively.
(Middle Row): Drift potential and spray coverage of air-induction and cone nozzles on an airblast.
(Bottom Row): Drift potential and spray coverage from Hardi and Proptec tower sprayers.

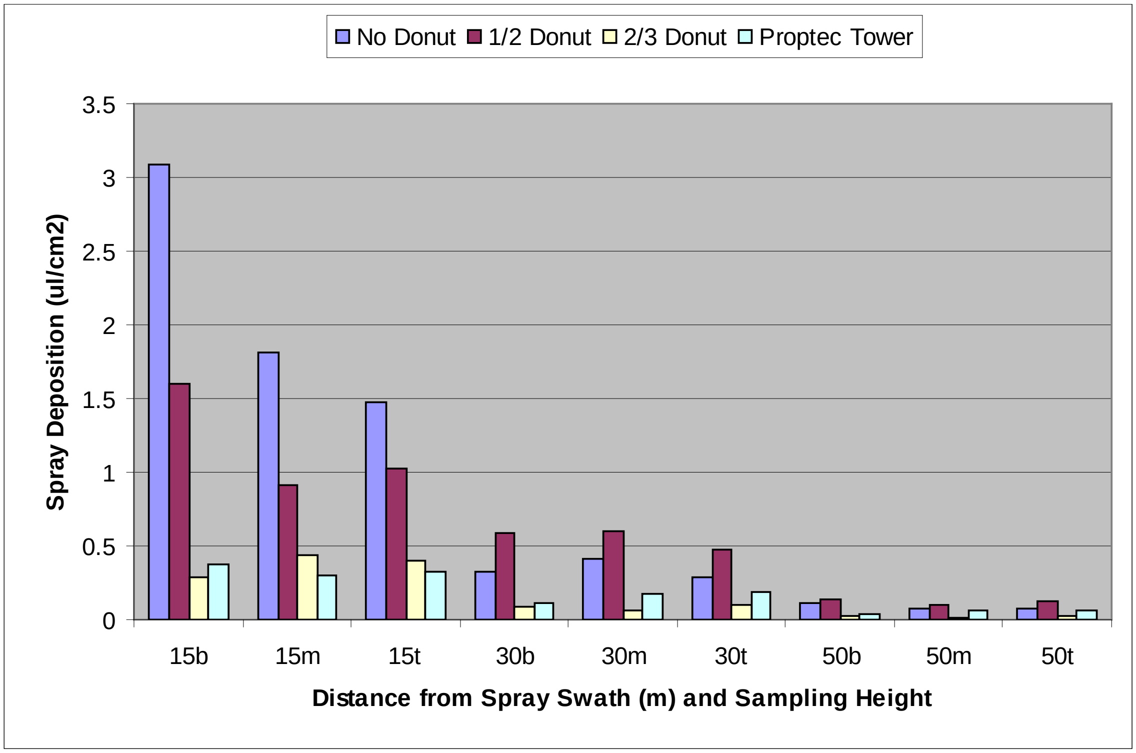


Fig 6. Dormant spray drift potential from airblast and tower sprayers.
B,M and T are 1m, 2m and 3m sampling heights, respectively.

CONCLUSIONS: This research focused on controlling pesticide drift from different sprayers at the initial point of emission (the sprayers themselves) and not rely on controlling the movement of pesticides after their release into the environment. It was found that the traditional airblast sprayer with hydraulic cone nozzles had better spray coverage but higher drift potential than the other sprayers that were tested. The Proptec and Hardi tower sprayers and the modified air-blast sprayer (using air-induction nozzles and low cost plywood donuts) were better in terms of drift reduction. The tower sprayers (Proptec and Hardi) had nozzles oriented such that they sprayed horizontally whereas the airblast sprayer sprayed upwards into the air; hence the tower sprayers had low drift potential with improved and uniform spray coverage when compared to the airblast sprayer. During the dormant season, the Proptec tower sprayer had significantly low drift potential compared to the airblast sprayer. The use of plywood donuts also dropped the drift potential considerably. Both of the tower sprayers had similar and low drift potential but the coverage was slightly better for the Proptec sprayer. The Hardi used air-assisted hydraulic nozzles with low speed but high volume of air to transport and deliver the droplets, thus providing uniform coverage with less drift. Air-blast sprayers have low profile and are inefficient, however, spray drift from air-blast sprayers can be substantially reduced by proper calibration, new nozzle technologies and spray practices.