RHEA PROJECT ACHIEVEMENT: AN INNOVATIVE SPRAY CONCEPT FOR PESTICIDE APPLICATION TO TREE CROPS EQUIPPING A FLEET OF AUTONOMOUS ROBOTS.

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Abstract

The new Community rules on the reduction of risks to the environment and food safety require a breakthrough innovation in all sectors especially in agriculture where there is a strong pressure due to the remarkable use of pesticides and herbicides. In this context, it's a necessary reinterpretation of the classic management methods to a new modern agricultural concept the "integrated agronomic approach" for a targeted individual care and aware of the plant, of the biotic and environmental components that interacting.

The operating units of "agricultural mechanics and mechanization" of Pisa and Florence have the task of establishing the actuators in the final three specific contexts: wheat, corn and olives. In the first case, the robot will perform chemical weed control, while in the corn case will be used only mechanical and thermal physical tools. For the third scenario we worked on the design and testing of an automatic unit for the pesticides application sprayed on crops, especially olive trees and woody crops for biomass energy production.

The objective of the Unit of Florence is the realization of a sprayer with distribution based on the geometry in intensive and super-intensive olive trees. A complex air assisted sprayer has been designed and realized as concentration of the latest innovation of the international research integrated in the RHEA robot system.

The semi-mounted sprayer applied to small autonomous tractor equipped with many typologies of sensor is able to recognize the presence, shape and thickness of the various horizontal bands of the canopy by adjusting the activation, the amount, the type of spraying. Moreover, is possible, separately on each band, to control the direction of air diffusors and the airblast flow rate in relation to the presence or thickness of the canopy. An innovative device system to control dose application proportionally to the canopy band thickness has been applied by an high frequency solenoid valve driven by variable duty cycle controller.

New RHEA spray concept, has the aims to follow the rules imposed by the European Union to reduce pollution caused by then distribution of pesticides.

Key words: Precision agriculture, pesticide reduction, automation, robotization.

1. Introduction

The sustainable use of PPP (Plant Protection Products) (Brown, 1971; Raisgl and Felber, 1991; Vieri & Spugnoli, 1996).] and the need of a renewed integrated system of agricultural knowledge and management in course of evolution by the Precision Agriculture approach (Vieri & Spugnoli, 1997; Pérez et al., 2011) moved the design of the EU FP7 RHEA Project (Robot fleets Highly for Effective Agriculture and forestry management) the purpose of which to demonstrate an integrated system of: a) field and crops monitoring by sensors proximal

GMU (ground mobile units) and remote UAV (unmanned aerial vehicle), b) computer assisted management and control task, c) a fleet of robot operating in field.

The system consist of six integrated modules: Mission Manager (MM), Perception System (PS), Communication and location System (CS), Actuation System (AC) divided into High Level and Low Level Decision, Mobile Units (MUs) and the Base Station and Graphic User Interfaces (GUI) [RHEA, 2010; Gonzales et al., 2011].

The report is related the third scenery considered in the RHEA Project that involve the application of sprayed chemicals to the woody crops canopy. The other two are chemical and physical, mechanical and thermal, effective weed management in field crops.

A lot of work has been done on spray chemical optimization and especially since the 1980s to adapt the spraying techniques to the crops (Brown,1971, Vieri M. *et al.*, 1990, 1993, 1998abc, 2002).

Advances in sensors, actuators and in electronic controllers have facilitated the boarding of electronics in sprayers for tree and bush crops.

First step is the interruption of liquid flow rate when no foliage was detected (Solanalles et al. 2006; Gil et al., 2006); further developments were achieved with the control on the different vertical bands of canopy (Llorens et al., 2010; Giles et al., 1989; Koch & Weisser, 2000; Doruchowscki & Holownicki, 2000)

The next step was matching the sprayed flow rate proportional to the canopy width using ultrasound sensors (Escola et al, 2002) and later the laser LIDAR (Light Detection And Ranging) (Tombo et al., 2002, Walklate et al, 2002, Sanz et al., 2004)

The spray jet, the dose and air energy applied, shall be adequate to the morphological features of the treated canopy (Shmidt and Koch, 1995; Holownicki et al., 2000; Walklate et al, 2000 and 2002; Pergher et al, 2002). Other important researches were devoted to the appropriate sprayer scheme in order to better fit the treatment in variable weather condition (Doruchowski et al., 2011); Hoçevar et al. (2010) investigated on a variable inclination and positioning of the spray diffusors to better fit air spray jet onto the canopy.

Latest studies taken into account the georeferenced 3D prescription maps application to make an optimized Variable Rate Treatment (Tombo et al., 2002; Wei et al., 2004; Escolà et al., 2007; Palacin et al., 2007; Zhenget al., 2009; Sanz et al., 2011; Moorthy et al., 2008; Llorens et al., 2011); even on Olive tree crops (Moorthy, 2011). It also permits to have the traceability of applied dose on each step of the plant.

2. Material and methods

The primitive configuration of the RHEA ground mobile units taken into consideration very small vehicles with 200-400 kg mass and less than 15 kW power, operating at a forward speed of 1.5 m/s and with only one arm.

In particular, for canopy treatment, this is really feasible only for spot spraying e.g. in the insects control, but not appropriate for other diseases like mushroom etc. In these cases arise at least two problems: one is the dosage that, even in a modern intensive tree plant with an average of 5000 m^2 of canopy volume per hectare, requires not less than 100-200 l/ha; second it is the necessity of air assist device to well put the chemical sprayed droplets inside the canopy and the inappropriate use of only one manipulator (spray diffusor) that at the prescribed forward speed produce an unacceptable unequal sinusoidal application.

On these and other consideration the RHEA Consortium approved a more suitable ground mobile unit (GMI) with these specifications: 4x4 wheel drive, CVT transmission, 37.3 kW gross power, 10% of which available as electric power , with a mass of 1600 kg, 3 hitch points lift and standard 52 rad/s p.t.o. That make it possible to adopt a ready to common use and innovative air assisted sprayer.

Another important choice of has been the Olive intensive plant for the final demonstration; this decision it is due to the fact that Olive crop is quite assimilable to both modern Orchard Crops and Woody Tree Crops as mentioned in the RHEA Project Proposal; plantation scheme is 4.0 m inter-row and 1.5 distance on the row to reach a foliar wall as flat and regular as possible.

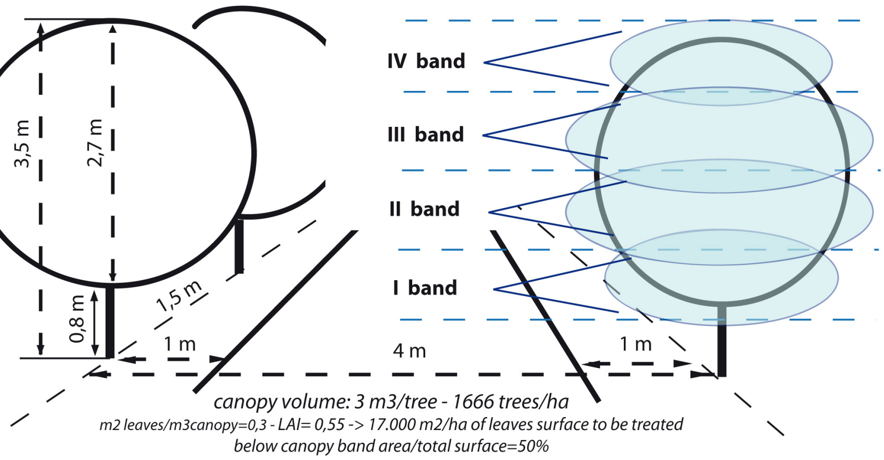


Fig. 1 : demonstration woody perennial plant and definition of the4 horizontal bands

On these aims we investigated different solutions in terms of spraying and air vector devices:

- The Proptec Rotary Sprayer module with centrifugal pulverization. Changing the rotating plates pulverization varies from 50 up to 110 micron ; flow rate is variable from 0 up to 24 L/min ad air flow rate from 0 up to 800 m^3/h according with fan rotational speed (up to a max 5500 rpm). Each module is oil hydraulically driven and requires a power of 5 kW.
- The Sardi fan module is similar to that of Proptec but adopts 6 hydraulic nozzles on each module. Each of these is oil hydraulically driven and requires a power of 5 kW and produces a flow rate less than 800 m^3/h. A single side apparatus with empty tank 300 L and 4 modules weights approximately 300 kg and requires a power of 25 kW quite similar to the Proptec.
- The Tangential cross-flow fan requires a very low power and we can assume to create a device with 3 modules correspondent to the low-medium-high band of the canopy on each module can be mounted 3 pressure nozzle. Each module requires an oil hydraulic motor of 5 kW (total 15 kW) and 5 kW more needed for the hydraulic pump of the chemical plant. A single side apparatus with empty tank 300 L weights approximately 300-400 kg. The poor flow rate (5000 m^3/h) makes this apparatus appropriate for close crop and tiny canopy.
- The Oktopus spraying technique is composed by multiple indipendent spraying modules with a central fan and a hydraulic pump driven by the mechanical pto. This kind of sprayer developed by UF and NOBILI since 1995 is designed with the aim to adopt multiple independent spraying modules to control separately liquid (dose and droplets size) and airblast vector (intensity and direction) in the different bands of the canopy. Droplet size and flow are variable adopting different nozzle type and different hydraulic pressure. The equipment requires 15 kW of power and has a mass of about 300 kg with an empty tank of 300 L capacity.

Where also analyzed:
- the equipment configuration: single side or double side and number of modules;
- the device system (DS) and the control system or Low Level Actuation System (LLAS);

- the controlled main parameters: spray cloud features, liquid flow rate, air flow rate and airjet variable direction.

Where finally defined rules for each devices to better fit optimum spray features on each vertical bands of the canopy

3. Results

The final decision on Woody Perennial Crops treatment Device System, has been oriented toward a complete sprayer double side with eight separate spraying modules on the four vertical bands of the parallel canopy wall.

The equipment presents the following main features:

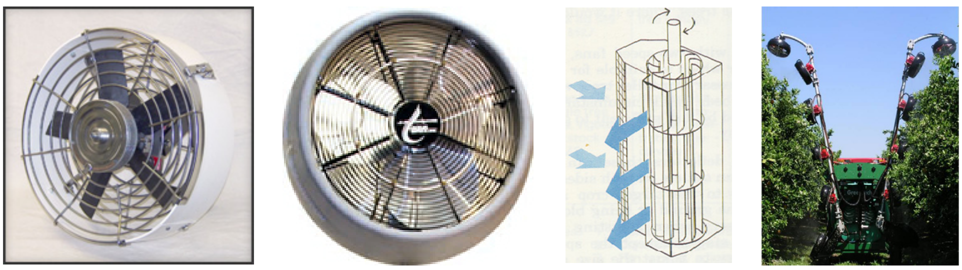
- maximum height of the vertical boom 2.5 m;
- total band to be treated 2.7 m (3.0-3.5 m crop top);
- total equipment weight (empty tank) 400 kg;
- tank: 300 L;
- hydraulic pump with max 100 L /min - 25 bar, max 5 kW from rotating mechanical p.t.o.;
- fan max 15 kW from rotating mechanic p.t.o.;
- the equipment is semi-loaded as it is coupled at the 3 hitch point lift but is floating and resting on its wheels when is spraying.

The new designed device is characterized by following features.

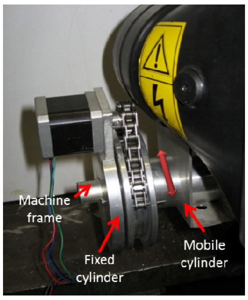
- 8 ultrasonic sensors to reach data on canopy width of each vertical band;
- the variable control of the flow rate at each module to adapt dosage at the canopy thickness on each band:
    - 100% canopy thickness =100% dose,
    - 50% canopy thickness = 70% dose,
    - <50% canopy thickness = 30% dose,
    - absence of canopy = 0 dose.

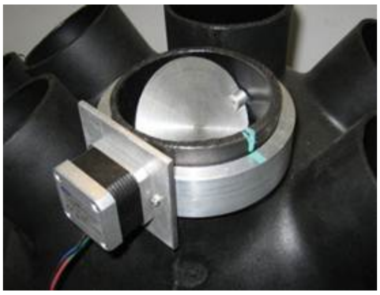
  Two solutions has been developed and tested: a) intermittent spray nozzle driven by frequency and duty cycle electronic controller; b) dual nozzles on each module with 70% and 30% of needed flow rate on each band with full canopy thickness;
- the airblast flow rate control on each module by butterfly valves (step motor controlled) on each of the 8 air pipe;
- the main fan air flow rate control actuated by a mail butterfly valve (step motor controlled) on the fan inlet manifold;
- the variable inclination (step motor controlled) of the 4 terminal modules (top and bottom) to improve the deposition in these sensitive areas of the canopy.

The entire equipment with the whole system of Devices (DS) it is controlled by the LLAS that consist in the PLC and related algorithms. All controlled in turn by the HLDMS and upstream from the MM of the RHEA system.

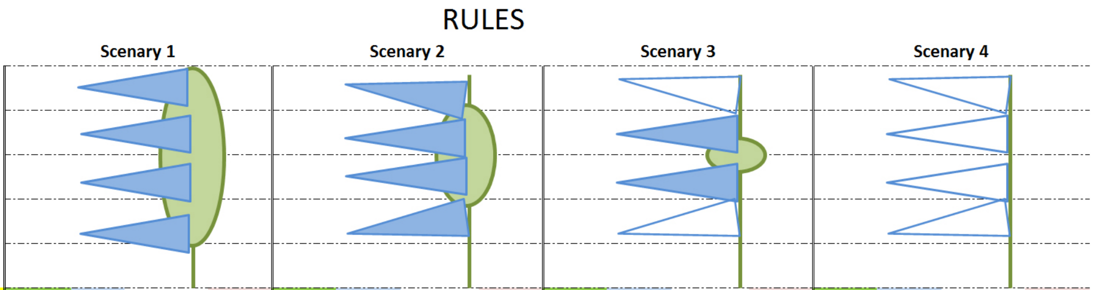


Figg. 2,3,4,5 : Spraying and air vector devices solutions: Proptec, Sardi, Tangential cross-flow fan






Figg. 6, 7, 8 : Fan air flow rate control, actuated by a mail butterfly valve; the variable inclination, step motor controlled.



	Scenary 1				Scenary 2				Scenary 3				Scenary 4			
spray module & ultrasonic sensor	canopy	spray	inclination	air	canopy	spray	inclination	air	canopy	spray	inclination	air	canopy	spray	inclination	air
1	ok	yes	0°	yes	no	yes	-15°	yes	no	no	-15°	no	no	no	-15°	no
2	ok	yes	0°	yes	ok	yes	0°	yes	no	yes	0°	yes	no	no	0°	no
3	ok	yes	0°	yes	ok	yes	0°	yes	no	yes	0°	yes	no	no	0°	no
4	ok	yes	0°	yes	no	yes	+15°	yes	no	no	+15°	no	no	no	+15°	no

Fig. 9 : Rules on module 1-4 direction and single airblast control on each bands

4 Conclusion

The RHEA robot airblast sprayer for precision tree crops treatment represent an unique innovative integrated system that includes all suggestions derived from advanced researches.

The entire spray robot module has both remote and proximal controls; remote to control tractor and proximal to control spraying. This choice has a double aim to have an innovative sprayer that can be used and tested as independent autonomous equipment also with normal tractors.

The spraying configuration provides 8 different vertical bands of independent treatment with separate controls of chemical dose applied and air flow direction and rate. It consists in 30 controls devices (8 butterfly valve at the air conveyor; 1 main butterfly valve at the manifold fan inlet; 4 actuator to control upper and lower outlet diffusor inclination; 16 solenoid valve; 1 pressure valve), 8 controller and 1 PLC, 12 sensors (1 for forward speed ; 1 for liquid pressure, 8 Ultrasound Sensors, 1 for tank level, 1 for pressure).

The 8 US sensors could be replaced by on board LIDAR or by a remote control directly send by the HLDMS (High Level Decision Making System) that could use the LIDAR on the scouting Aerial Unmanned Vehicle to provide a 3D prescription map able to command the different operating system of the air sprayer in the different vertical bands.

The expected chemical dosage saving is ranging from 50 and 70% of the conventional rate of application maintaining the quality of deposition on the foliage.

The next two years of tests will give data on technical and operative characteristic of this complex system.

Acknoledgements

Special thanks are due to NOBILI Agricultural Equipment of Molinella (Bo) for the precious support. And also to our colleague Sig. Giancarlo Cosi for the special commitment and passion to develop the RHEA air sprayer prototype devices.

References:

- Brown A.W.A. & Pal R. (1971). Insecticide resistance in arthropods. World Heath Organization Monograph Series 38. Geneva (second edition from 1958).
- Chen Y. (2010). Development of an Intelligent Sprayer to Optimize Pesticide Applications in Nurseries and Orchards. Dissertation for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University.
- Doruchowski G. & Holownicki R. (2000). Environmentally friendly spray techniques for tree crops. Crop Protection 19, 617-622.
- Doruchowski G, Swiechowski W., Godin A. & Holownicki R. (2011). Automatically controlled sprayer to implement spray drift reducing application strategies in orchards. Journal of Fruit and Ornamental Plant Research. 19 (1) 2011: 175-182.
- Escolà F., Solanalles F., Planas S. & Rossell J.R. (2002). Electronic control system for proportional spray application to the canopy volume in tree crops. Proceedings of EurAgEng Conference. Paper 02-AE-010. Budapest,Hungary.
- Escolà A., Camp F., Solanalles F., Llorens J., Planas S., Rosell J.R., Gràcia F., Gil E. & Val L. (2007). Variable dose rate sprayer prototype for dose adjustment in tree crops according to canopy characteristics measured with ultrasonic and laser LIDAR sensors. Proceedings ECPA-6th European Conference on Precision Agriculture pp 563-571.
- Gil E., Escolà F., Rosell J.R., Planas S. & Val.L. (2006). Variable rate application of plant protection products in vineyard using ultrasonic sensors. Crop Protection 26, 1287-1297.
- Gonzalez-de-Santos P., Vieri M., Ribeiro A., Raffaelli M., Emmi L., Fontanelli M., Rimediotti M., Frasconi C., Sarri D. & Peruzzi A. (2011). The RHEA project: a fleet of autonomous robots for precision chemical and non chemical weed management in arable crops and on-canopy spraying in tree crops. Proceeding Convegno di Medio Termine dell'Associazione Italiana di Ingegneria Agraria, Belgirate, 22-24 settembre 2011.
- Hoçevar M., Sirok B., Jeicic V., Godesa M., Lesnik M. & Stainko D. (2010). Design testing of and automated system for targeted spraying in orchards. Journ. Of Plant Deseases and protection 117(2) 71-79.
- Jeon H.Y., Zhu H., Derksen R., Ozkan E. & Krause C. (2011). Evaluation of ultrasonic sensor for variable-rate spray application. Computers and electronics in Agricolture 75, 213-221.
- Holownicki R., Doruchowski G. Godyn A. & Swiechowski W. (2000). Effects of air jet adjustment on spray losses in orchards. Aspects of Applied Biology 57 Pesticide Application, 293-300.
- Koch H. & Weisser P. (2000). Sensor equipped orchard spraying efficacy , saving and drift reduction. Aspects of Applied Biology 57, 357-362.
- Llorens J., Gil E., Llop J. & Escolà F. (2010). Variable rate dosing in precision viticulture. Use of electronic devices to improve application efficiency. Crop Protection 29 (3), 239-248.
- Llorens J., Gil E., Llop J. & Meritxell Q. (2011). Georeferred LIDAR 3D vine plantation map generation. Sensors 11, 6237-6256.
- Moorthy, I.; Miller, J.; Hu, B. & Chen, J.; Li, Q. (2008). Retrieving crown leaf area index from an individual tree using ground-based lidar data. Can. J. Rem. Sens., 34, 320-332.

- Moorty I., Miller J.R., Berni J.A.J, Zaro-tejada P., Hu B. & Chen J. (2011). Field characterization in Olive (Olea Europaea L.): tree crown architecture using terrestrial laser scanner data. Agric.Forest Meteorol. 151, 204-214.
- Palacin J., Palleia T., Tresanchez M., Sanz R., Llorenz J., Ribes-Dasi M. Masip J., Arnò J., Escolà A. & Rossel J.R. (2007). Real time tree-foliage surface estimation using a groung laser scanner IEEE Trans. Intrum. Meas. 56, 1377-1383.
- Pérez-Ruiz M., Aguera J., Gil J.A., Slaughter D.C. 2011. Optimisation of agrochemical application in olive groves based on positioning sensors. Precision Agriculture 12, 564-575.
- Pegher G., Balsari P., Cerruto E. & Vieri M. (2002). The relationship between vertical spray pattern fron air assisted sprayers and foliar deposit in vine canopies. Aspects of Applied Biology 66, International Advances in Pesticide Application.
- Raisgl U., Felber H., 1991 - Comparison of different mist blower and volume rates for orchard spraying. B C P C Mono n .4 6 Air Assisted Spraying in Crop Protection.
- RHEA, (2010). http://www.rhea-project.eu/.
- Sanz-Cortiella R., Llorenz-Calveras J., Escolà A., Arnò-Satorra J., Ribes-Dasi M., Masip-Vilaalta J., Camp F., Gràcia-Aguilla F., Solanalles-Batlle F., Planas-DeMarti S., Pallejà-Cabré T., Palcin-Roca J., Gregorio-Lopez E., Del-Moral-Martinez I. & Rosell-Polo J.R. (2011). Innovative LIDAR 3D dynamic measurement system to estimate fruit-tree leaf area. Sensors. 11, 5769-5791.
- Schmidt K. & Koch H. (1995). Adjustment of airblast sprayer and distribution of pesticide deposits in orchard. Nachrichtenblatt des Deutches Pflanzenschultzdienstes 47, 161-167.
- Solanalles F., Escolà A., Planas S., Rossell J.r., Camp F. & Gràcia F. (2006). An electronic control system for pesticide application proportional to the canopy width of tree crops. Biosystem Engineering 95(4). 473-481.
- Tombo S.D., SalayaniM., WhitneyJ.D., Wheaton T.A. & Miller W.M. (2002). Investigation of laser and ultrasonic ranging sensors for measurement of citrus canopy volume. Applied Engineering in Agriculture 18 (3), 367-372.
- Vieri M. & Spugnoli P. (1990). An automatic dosing system for sprayers. Atti AgEng International Conference. Berlino, 24-27 ottobre 1990. Poster e paper n°4/12.
- Vieri M. & Cioni A.(1993). A software for periodical control of sprayers. Proceedings C.I.G.R. "Models, Computer Program And Expert Systems For Agricultural Mechanization". Firenze, 1-2 ottobre 1993.
- Vieri M. & Spugnoli P. (1996). Containing evaporation losses in pesticide application: mistblower set-up related to threshold meteorological conditions in Mediterranean Areas. Proceedings International Conference on Agricultural Engineering - AgEng 96 Madrid 23-26 sept.1996 pg.299.
- Vieri M. & Spugnoli P. (1997). An high pressure injection system for precision application of pesticide. BIOS Scientific Publishers Limited, Oxford 1997.
- Vieri M:, Venturi A. & Michelucci S. (1998). A Software Procedure to Control Spray and Airblast Set-up of Orchard and Pest Control Sprayers. International Conference “AgEng’98” Oslo 24-27 agosto 1998.
- Vieri M., Guidi S. & Tiribilli B. (1998). Spray distribution Control in Orchard Sprayers: Tests on New Apparatus Equipped with a Laser Detector.International Conference “AgEng’98” Oslo 24-27 agosto 1998.
- Vieri M. & Spugnoli P. (1998). Operational Risk Assessment of sprayers by hazard using multicriterion analysis. Journal of Agricultural Engineering Research. 71, 405-414.
- Vieri M. & Giorgetti R. (2002). Results of the comparative efficiency distribution trial on two sprayers (conventional GEO-diffuser and OKTOPUS-spraying modules) using different settings. Adv.Hort.Sci, XV, (2001), 1-9.
- Vieri M. (2003). Spray airjet characterisation by impulse measurement. 7th Workshop on “Spray application techniques in fruit growing”. Cuneo 25-27 june 2003. 149-156
- Vieri M. & Sarri D. (2010). Criteria for introducing mechanical operation of oil olives: results of a five year project in Central Italy. Advances in Horticultural Sciences. 2010. 24(1): 78-90

- Walklate P., Richardson G., Cross J. & Murray R. (2000). Relation between orchard tree crop structure and performance characteristics of an ari axial fan sprayer. Aspects of Applied Biology 57, Pesticide Application, 285-292.
- Walklate P., Cross J., Richardson G., Murray R. & Baker D. (2002). Comparison of different spray volume deposition models using LIDAR measuremetns of apple orchards. Biosystem Engineering 82(3). 253-267.
- Wei, J. & Salyani, M. (2004). Development of a laser scanner for measuring tree canopy characteristics: Phase 1. Prototype development. Trans. ASAE, 47, 2101-2107.
- Wei, J. & Salyani, M. (2005). Development of a laser scanner for measuring tree canopy characteristics: Phase 2. Foliage density measurement. Trans. ASAE, 48, 1595-1601.
- Zheng, G. & Moskal, (2009). L.M. Retrieving leaf area index (LAI) using remote sensing: Theories, methods and sensors. Sensors, 9, 2719-2745.