Agriculture Spray Machinery Pattern Testing and Validation by the use of GIS and the use of a Dilution of Active Ingredient in Wastewater

AG. FILINTAS[1, 2], J. HATZOPOULOS[1], V. PARLANTZAS[2]
[1] Department of Environment,
University of the Aegean,
University Hill, GR81100 Mytilene, Lesvos island,
[2] Department of Agriculture Machinery & Irrigation,
T.E.I. of Larissa,
Periferiakos Larisas-Trikalon, 41110 Larissa,
GREECE.
filintas@teilar.gr, envm03092@env.aegean.gr

Abstract: - The scope of the present study is the spraying pattern testing, GIS modelling, validation and mapping of the application spray rate of field crop sprayer machinery in order to develop a method for the application of more accurate weed control with improved adjustments (pressure and volume of the chemical fluid, spraying boom height, spraying nozzles angle, calculation and selection of the appropriate forward speed of the tractor) and aiming to reduce environmental and economic costs associated with weed control. The spraying pattern testing, GIS modelling and mapping results provide an opportunity for the application of more accurate weed control technology in order to reduce environmental and agroeconomic costs associated with weed control.

Key-Words: - Agriculture Spray Machinery, Pattern testing and GIS mapping, Geographic Information Systems (GIS), Precision Agriculture, Wastewater

1 Introduction

In agricultural crop production, a very important issue is weed control.

Weeds compete with crop plants for moisture, nutrients and sunlight and can have a detrimental impact on crop yields and quality if uncontrolled. A number of studies have documented the yield loss of various cultures, associated with weed competition [1, 2, 3, 4, 5, 6].

When selective postemergence herbicides are unavailable or ineffective, hoeing of "in-row" weeds is required. However, in-row hand hoeing is costly, i.e., over five times more expensive than conventional cultivation [7], not always completely effective and it seems that agricultural spray machinery is the contemporary solution in modern cultivation systems. Although, considerable research is being done to investigate and improve the placement of the pesticides on plant and soil surfaces, less is being, or has been done, to assess or improve the accuracy of the application rate of agricultural sprayers machinery.

The spray characteristics of agricultural spray nozzles of sprayers machinery are important criteria in the application of pesticides because of their ultimate effect on the efficiency of the pesticide application process. Droplet size and velocity affect the structure of the spray deposits and the driftability of the droplets [8]. Furthermore, droplet size may influence the biological efficacy of the applied pesticide as well as environmental hazards. Accessional, the non-uniformity in weed populations has both temporal and spatial aspects that demand an accurate application with the harmonic combination of agricultural machinery (tractor and mounted sprayer machinery [9]. Also, the increasing use of expensive chemical pesticides in crop spraying machinery, raizes a concern for accurate metering, placement, testing and validation of the spray machinery, in order to reduce the serious distribution pattern errors which can occur in the field. The pressure and volume of the chemical fluid are very closely controlled in premarketing trials of the various manufactures of agricultural spray machinery, whereas this is by no means the case in practice by the farmers or even commercial spray personal. Moreover, since the ideal nozzle–pressure combination will maximise spray efficiency for depositing and transferring a lethal dose to the target, it will also minimise the off-target losses such as spray drift and user exposure.

The spray characteristics influencing the efficiency of the pesticide application process are the droplet size and velocity distribution, the volume distribution pattern, the entrained air characteristics, the spray structure and the structure of individual droplets [10].

The common agriculture spraying machinery relies on a metering principle that requires a proper initial adjustment of the desired application rate and a constant velocity of the spraying vehicle (autonomous or tractor with mounted sprayer machinery) for accurate application in the field [9]. Errors exist because usually farmers or even commercial sprayer personal don't precisely adjust the spray pattern (affected by pressure and volume of the chemical fluid, spraying height, spraying nozzles angle) and also, they don't select the appropriate forward speed of the tractor, and the delivery rate itself may not be set accurately.

An ADAS survey on the utilisation and performance of field crop sprayers in farm practice has shown that in 46% of the operations tested, there were errors greater than 10% between the intended and actual spray volume rates [11], that lead to reduced efficiency of spraying pattern (loss of target, reduced accuracy of the chemical fluid (herbicides, pesticides, etc) application, increased costs) of field crop sprayer machinery.

Regarding GIS it is considered that GIS provides a means of taking many different kinds of information, processing it into compatible data sets, combining it, querying and displaying the results on a map [9, 12]. In conjunction with GIS the Geostatistical methods were developed to create mathematical models of spatial correlation structures [13, 12] with a variogram as the quantitative measure of spatial correlation [9, 12]. Advances in electronics and computers generated new techniques to maximize the farmer's profit and to protect the environment. The value of spatial information for understanding spraying accuracy and application pattern issues and improving decision-making and machinery adjustments is increasingly recognized. As pressures on environment (agricultural land, soil and irrigation water resources) continue to mount, the ability to test, validate, decide and accurately adjust common farmers' field crop sprayer machinery becomes daily more essential.

A Geographic Information System (GIS) is a powerful information tool at the disposal of agriculture engineers and decision-makers.

2 Problem Formulation – Materials and Methods

In spraying procedure of field crop sprayer machinery with chemical materials for plant protection, the objective is to achieve an even distribution of active ingredient. This means that forward speed of the tractor or of the autonomous sprayer vehicle must remain constant or the application rate must be controlled so that it is independent of variation in forward speed.

From the above mentioned a question is arised upon the present article:

Is the reduced efficiency of spraying pattern (loss of target, reduced accuracy of the chemical fluid application, increased agricultural and environmental costs) of field crop sprayer machinery and the consequent environmental pollution through leaching in agricultural land, soil and water resources important and how can be investigated, tested and depicted through GIS modeling in conjunction with field tests, the spraying pattern efficiency?

To answer the above question, a methodology was developed and validated in a test field in the Technological Educational Institute of Larissa, in Greece at the farming period of year 2008, with a tractor mounted sprayer machinery.

2.1 Materials

The test rig used in this research was composed of manometers, volume cylinders, digital timer, GPS (Global Positioning System) devices, weight balance and a laptop computer.

Also, it was used a field crop sprayer machinery (Berthood model 500L) mounted on an International 453 tractor (Fig. 1).

The spray unit consisted of an insulated spray liquid tank with a volume of 500 L, a fluid level control system, a hydraulic mixing system, a vertical in-line dual-mebrane pump, a pressure regulator valve, a pressure gauge (resolution: 0.01 bar) and a spray boom with 14 hollow cone type nozzles.

System operating pressure ranges from 0.01 to 15.03 bar (0.2 to 218 PSI).

The relative agricultural machinery used (tractor and field crop sprayer) technical data are shown in Table 1.

The agricultural field of the farm that was chosen for the experiment had a uniplanar field surface and the boom of the field crop sprayer machinery was carefully levelled because if the boom extends outward over a uniplanar or an inclining field surface, the overlap decreases to the point of leaving unsprayed gaps between nozzles.

Table 1. Agricultural machinery (tractor and field crop sprayer) technical data.

TRACTOR	
Model	International 453
Tractor's weight	2070 kg
Total tractor width-rear tire outside to outside	1.78 m
Tractor's free height	0.5 m
Mounting System (MS)	3 point MS
PTO	540 rpm

FIELD CROP SPRAYER	
Model	Berthood 500L
Sprayer's weight	150 kg
Spray tank volume	500 L
Boom Length	7 m
Manual boom fold	Yes
Number of nozzles	14
Type of nozzles	hollow cone 65^{o}
Operating pressure range	0.01 to 15.03 bar
Pressure gauge resolution	0.01 bar
Fluid mixing system	hydraulic
Power intake	mechanical from PTO

2.2 Methodology

Measuring protocol: Prior to the field measurements, the volume discharge rate of each nozzle was tested at a pressure of 2.0 bar in the laboratory. For the measurements, the whole set of 14 nozzles were selected for each nozzle–pressure combination to be tested. All measurements were performed spraying water with a temperature of 20 ^{o}C in the laboratory. Environmental conditions are kept constant at a temperature of 20 ^{o}C and a relative humidity of 60–70%. Also, prior to the final on the move measurements, the boom of the field crop sprayer machinery was charged while the spray rig was stationary, blowing out water and the volume discharge rate of each nozzle was tested at a pressure of 2.0 bar in the field. Then the mixture was prepared using a dilution of active ingredient in wastewater instead of water in order to save water and simultaneously supply nutritients. Two nozzle (boom) height treatments were investigated, the first (treatment A) was 50cm spraying height and the second (treatment B) was 55cm spraying height. The nozzle (boom) height is an important factor which affects the amount of overlap actually achieved and consequently the spray pattern efficiency. Nozzle height is measured from the nozzle tip to the top of the target. Thus, for preplant and preemergence applications, the soil surface is the target but, for postemergence applications, it's measured from the top of the weed to get an accurate height. Both our treatments were preplant applications, so the soil surface was the target. The calculated target application rate of the boom sprayer was 300 Lt ha^{-1} (intended rate). The appropriate forward spraying speed was calculated and selected from the available speeds of the tractor in order to correspond in full charge of the PTO (Power Take Of) at 540 rpm, in the lowest possible engine rounds for fuel economy. The leveled boom of the field crop sprayer machinery was fully charged and then the tractor with the mounted crop sprayer passed through the sampling locations network layout (78 samples), with the previously selected forward spraying speed.

Data processing and Map development: The difference of GIS from other kinds of computer mapping systems is that the attribute data and spatial information are always linked and processed jointly in GIS [9]. So, by use of methods of laboratory test and nozzle volume discharge tests, field rate tests in sampling locations layout, GPS verification, Geographic Information Systems and computer data processing, the treatments spraying patterns of the sprayer machinery were modeled and mapped in digital form in EGSA87 for spatial evaluation and analysis in order to export conclusions of spray patterns efficiencies aiming to achieve an even distribution of active ingredient for more accurate application weed control and reduce the associated environmental and agroeconomical costs.

The scope of the present study is the spraying pattern testing, GIS modelling, validation and mapping of the application rate of field crop sprayer machinery in order to provide an opportunity for the application of more accurate weed control with improved adjustments (pressure and volume of the chemical fluid, spraying height, spraying nozzles angle, calculation and selection of the appropriate forward speed of the tractor) and aiming to reduce environmental and economic costs associated with weed control.

3 Problem Solution - Results and discussion

In comparing spray patterns, it is important to understand regional conditions (environmental conditions and farming practices) when assessing their global suitability. The nozzles results data obtained were statistically processed by means of analysis of basic statistics and one sample t-test using the SPSS ver.13.0 statistical package [14]. The basic statistics of the experiments nozzles results and of the treatments spraying flow rate results are shown in Table 2. The manufacturer's data of the hollow cone nozzles shows that for a pressure of 2.0 bar the nominal volume discharge rate is 50 Lt hr^{-1}. The measured mean volume discharge rate of the nozzles (Fig. 1) was found 59.15 Lt hr^{-1} (Table 2) with a deviation from mean from -19.36% to +14.79%. According to the statistical one sample t-test [14] that was performed, the nozzles results were significantly different for 95% and also for 90% confidence Interval (Table 3) from the nominal volume discharge rate, so it was used the measured mean volume discharge of the nozzles as nominal volume discharge rate in the initial calculations of the sprayers application flow rate and of the forward spraying speed.

Fig. 1: a) The sprayer (boom) machine mounted on the tractor. b) Detail of the sprayer machine. c) Detail of the boom with the nozzles discharge.

The results of the initial spray pattern geostatistical analysis and GIS mapping for the experimental treatments appear in figures 2.A.(b) and B.(b). In Fig. 2 A.(c) and B.(c) are shown the classiified (10 classes) GIS maps. In Fig. 2 A.(d) and B.(d) are depicted the defined interval classification results of the spray pattern GIS mapping for the two treatments. The defined classes show errors greater than 5%, 7.5%, 10% and 15% between the intended and actual spray flow rates in the spray pattern. In Fig. 2 A.(e) and B.(e) are depicted the five classes defined interval classification results of the spray pattern GIS maps which represent errors greater than 1% and 5% between the intended and actual spray flow rates in the spray pattern. Finally, in Fig. 2 A.(f) and B.(f) are depicted the spray pattern efficiency, with the actual spray flow rates areas which have errors up to 5% above (green lines) or bellow (solid green) of the intended (target application rate of 300 Lt ha^{-1}) spray flow rates.

Table 2. Basic Statistics of the experiments results.

Statistic	Nozzles' volume discharge rate	Treatm. A Spraying flow rate (at 50cm height)	Treatm.B Spraying flow rate (at 55cm height)
N Valid	14	78	78
Mean	59.15	279.45	284.51
Std. Error of Mean	1.95	4.64	4.57
Median	59.83	289.26	294.73
Mode*	47.70	177.32	231.98
Std. Deviation	7.30	40.94	40.40
Variance	53.32	1676.27	1631.82
Skewness	-0.19	-0.45	-0.28
Kurtosis	-1.70	-0.52	-0.98
Range	20.20	157.30	145.66
Minimum	47.70	177.32	193.58
Maximum	67.90	334.62	339.24
Percentiles: 25	52.25	252.68	248.49
50	59.83	289.26	294.73
75	66.57	322.45	328.38

*Multiple modes exist. The smallest value is shown

Table 3. Nozzles flow rate measurements t-test results for 95 and 90% confidence interval.

Test Value	t	df	Sig. (2-tailed)
50	4.6897	13	0.0004
50	4.6897	13	0.0004

Mean Difference	Percent	Confidence Interval of the Difference Lower	Upper
9.1521	95%	4.936	13.3682
9.1521	90%	5.696	12.6082

The rest areas of the spray pattern in red color, represent errors greater than 5% which is considered acceptable. The results of the measured values of the spraying patterns showed that the mean application rates were 279.45 and 284.51 Lt ha^{-1} for treatment A and B accordingly and both treatments were significantly different (A treatment had a p=0.00003 and B treatment had a p=0.00112) from the intended (target application rate of 300 Lt ha^{-1}) flow rate.

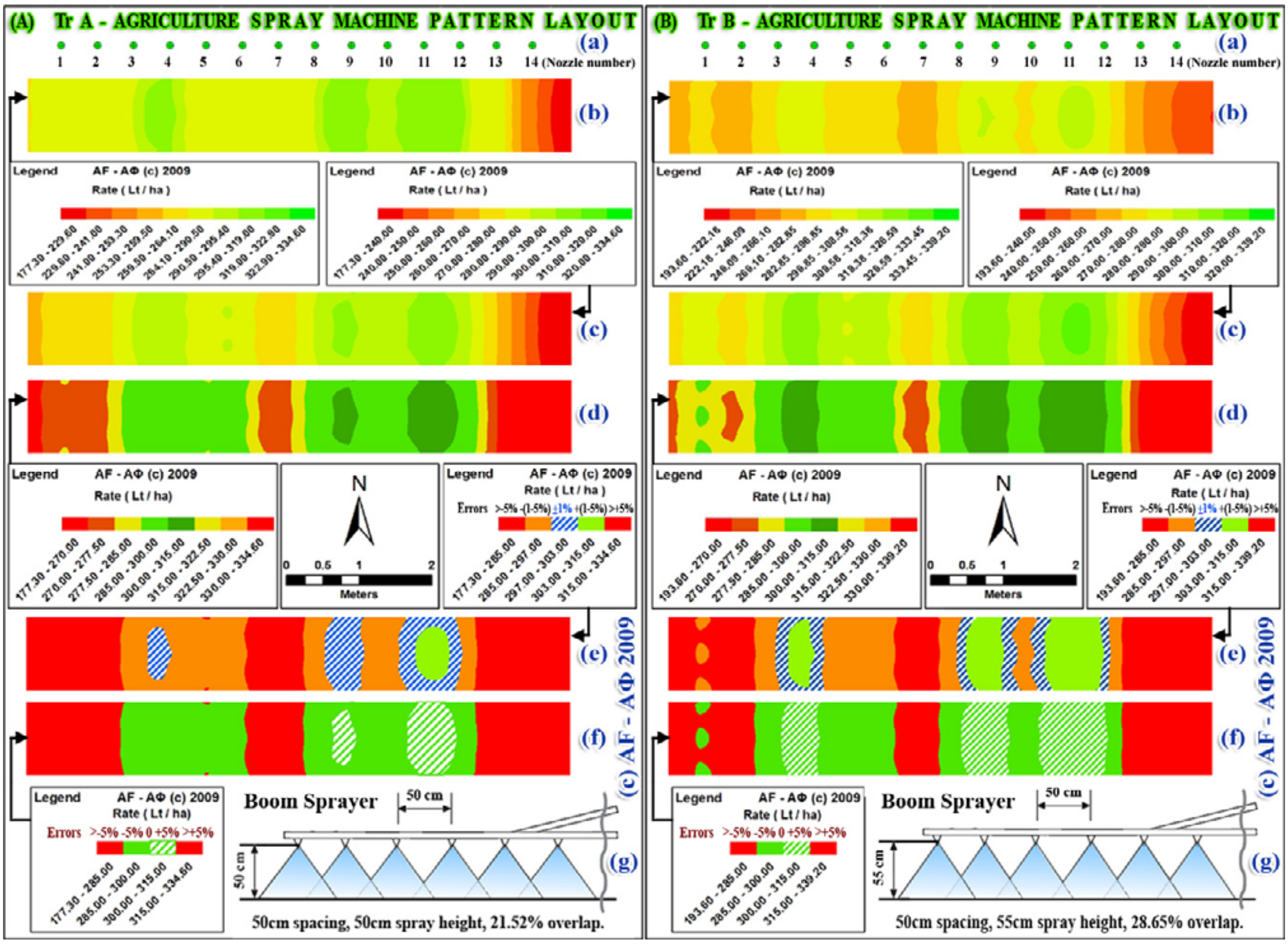

Fig. 2: Agriculture spray machinery pattern layout GIS maps of: A) treatment A (a, b, c, d, e and f) and B) treatment B (a, b, c, d, e and f).

Moreover, the analysis of the spraying pattern measured and predicted data of the test field, indicated that the spray (boom) height variation did not significantly change (significance level 0,05) the field applied application rate, of the spray dilution of active ingredient in wastewater (p=0.438). Also, the geostatistical analysis of the spraying pattern GIS maps (Fig. 2.A and 2.B) and data (Fig. 3.a, b), of predicted vs measured data, resulted in relatively resembling values of MPE and RMSSE (Table 4). However, the treatment B had a mean application rate closer to the calculated target application rate (300 Lt ha^{-1}), a better Mean Prediction Error (Table 4) and a better spray pattern efficiency in comparison with the treatment A (Fig. B.(f) and A.(f)). The regression model of the B treatment spraying pattern data and map ($Y_{Predicted}$=predicted flow rate Kg ha^{-1}) is shown in the equation (2):

$$\mathbf{Y_{Predicted} = 0.186\ X_{Measured} + 23.505} \qquad (2)$$

where $X_{Measured}$ is the measured spray application rate in Kg ha^{-1}.

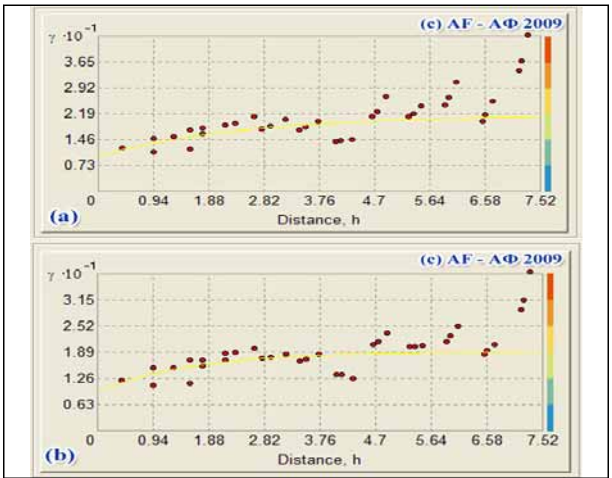

Fig. 3: Geostatistical variogram of spraying pattern for: a) Treatment A. b) Treatment B.

From the above mentioned we concluded that the methods which were used to derive the treatments spraying pattern classified GIS maps, lead to a high accuracy resulting depiction of the sprayer application flow rate patterns.

Table 4. Geostatistical analysis and crossvalidation results of the spraying pattern (treatments A and B).

S N	Treat-ment	Mean application rate (Lt ha^{-1})	MPE(1)	RMSSE(2)
1	A	279.45	0.01453	0.9841
2	B	284.51	0.01225	0.9713

(1) MPE = Mean Prediction Error
(2) RMSSE = Root Mean Square Standardized Error

4 Conclusion

The results of the measured values of the spraying patterns showed that the mean application rates were 279.45 and 284.51 Lt ha^{-1} for treatment A and B accordingly and both treatments were significantly different (A treatment had a p=0.00003 and B treatment had a p=0.00112) from the intended (target application rate of 300 Lt ha^{-1}) flow rate. Moreover, the analysis of the spraying pattern measured and predicted data of the test field, indicated that the spray (boom) height variation did not significantly change the field applied application flow rate (p=0.438). Also the nozzles' volume discharge rate variation seemed that it was the primary factor affecting the spray pattern variability. The overall accuracy attainable by a control system is dependent on the accuracy of its constituent parts, and current trends towards increased speed and reduced volumes in spraying will increase the need for more accurate instrumentation. Spraying pattern testing, GIS modelling and mapping provide an opportunity for improvements in the equipment aiming at an application of more accurate delivery weed control technology, in order to reduce the variability of the spray pattern and the environmental and agroeconomical costs associated with weed control.

Acknowledgements: This research project is co-financed by E.U.-European Social Fund (80%) and the Greek Ministry of Development-GSRT (20%).

References:

[1] Hodgson, J.M., *The nature, ecology, and control of Canada thistle.* In: Tech. Bull. 1386, U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C. 1968.

[2] Roberts, H.A., Hewson, R.T., Ricketts, M.A., Weed competition in drilled summer lettuce, *Hortic. Res.* Vol.17, 1977, pp.39–45.

[3] Monaco, T.J., Grayson, A.S., Sanders, D.C., Influence of four weed species on the growth, yield, and quality of direct seeded tomatoes (*Lycopersicon esculentum*), *Weed Sci.*, Vol.29 No.4, 1981, pp.394–397.

[4] Lanini, W.T., Le Strange, M., Low-input management of weeds in vegetable fields, *Calif. Agric.*, Vol.45, No. 1, 1991, pp.11–13.

[5] Shrefler, J.W., Stall, W.M., Dusky, J.A., Spiny amaranth (*Amaranthus spinosus* L.) a serious competitor to crisphead lettuce (*Lactuca sativa* L.), *Hortic. Sci.*, Vol.31, 1996, pp.347–348.

[6] Heisel, T., Andreasen, C., Christensen, S., Sugar beet yield response to competition from *Sinapis arvensis* or *Lolium perenne* growing at three different distances from the beet and removed at various times during early growth, *Weed Res.*, Vol.42, 2002, pp.406–413.

[7] Chandler, J.M., Cooke, F.T., *Economics of cotton losses caused by weeds.* In: McWhorter, C.G., Abernathy, J.R. (Eds.), Weeds of Cotton: Characterization and Control. The Cotton Foundation, Memphis, TN, 1992, pp. 85–116.

[8] Taylor W.A., Womac A.R., Miller P.C.H, Taylor B.P., An attempt to relate drop size to drift risk, In: *Proceedings of the International Conference on Pesticide Application for Drift Management*, 2004, pp 210–223.

[9] Filintas T.Ag., *Land Use Systems with emphasis on Agricultural Machinery, Irrigation and Nitrates Pollution, with the use of Satellite Remote Sensing, Geographic Information Systems and Models, in Watershed level in Central Greece.* MSc Thesis, Department of Environment, University of the Aegean, Mytilene, Greece, 2005.

[10] Miller P.C.H., Butler Ellis M.C., Effects of formulation on spray nozzle performance for applications from ground-based boom sprayers, *Crop Protection*, Vol.19, 2000, pp.609–615.

[11] Rutherford I., An ADAS survey on the utilisation and performance of field crop sprayers, In: *Proceedings of the Br. Crop Protection Conference*, 1976, pp.357-363.

[12] Hatzopoulos N.J., *Topographic Mapping, Covering the Wider Field of Geospatial Information Science & Technology (GIS&T),* ISBN-10:1581129866, ISBN-13: 97815811 29861, Universal Publishers, 2008, p.740.

[13] Isaaks E.H. and Srivastava R.M., *Applied Geostatistics,* Oxford University Press, New York, 1989.

[14] Norusis, MJ, *SPSS 13.0 Guide to Data Analysis,* Englewood Cliffs: Prentice Hall, USA, 2005.