SZENT ISTVÁN UNIVERSITY

DOCTORAL (Ph.D.) THESIS

TECHNICAL SOLUTIONS FOR REDUCTION OF ENVIRONMENT DAMAGING EFFECTS OF SPRAYING

Zoltán Gulyás

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Ph.D. School

Name:	Ph.D. School of Environmental Sciences
Discipline:	Environmental Sciences
Leader:	Dr. György Heltai Professor, D.Sc. Szent István University Faculty of Agricultural and Environmental Sciences Institute of Environmental Sciences Department of Chemistry and Biochemistry
Supervisor:	Dr. Sándor Szoboszlay Associate Professor, Ph.D. Szent István University Faculty of Agricultural and Environmental Sciences Institute of Environmental and Landscape Management Department of Environmental Protection and Safety
Supervisor:	Dr. László Fenyvesi Professor, Ph.D. Szent István University Faculty of Mechanical Engineering Institute of Mechanics and Machinery External Department of Agricultural Engineering

....	....
Approval of School Leader (Dr. György Heltai)	Approval of Supervisor (Dr. Sándor Szoboszlay)
	....
	Approval of Supervisor (Dr. László Fenyvesi)

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LIST OF SYMBOLS, ABBREVIATIONS

ANOVA:	analysis of variance
BCPC:	British Crop Production Council
d_v:	volume mean drop diameter
d_{v10}:	10 % volume drop diameter
d_{v50}:	50 % volume drop diameter
d_{v90}:	90 % volume drop diameter
MGI:	Hungarian Institute of Agricultural Engineering
P-value:	by statistical tests: significance level
Figure Q-Q:	dot-diagram used for graphic testing (viewing) of data distribution (especially normality)
α:	concerning statistical tests: confidence interval

1. BACKGROUND OF WORK, OBJECTIVES

Plant protection is an essential element of plant production technology. On the one hand, it provides for security of growing, on the other hand, it allows for the production of proper quality crops in the amount necessary. It has an outstanding role in the success of growing, and chemical control has a special importance even due to its effects on the environment.

Taking the efficiency, quality, and the effects on environmental elements of chemical control into account the mechanization of plant protection has a key role. Plants grown can only be protected from the produce reducing, quality deteriorating effects of pests, pathogens, and furrow-weeds, if pesticides selected with proper expertise are spread over the soil or the plants in the optimal time in the "necessary and sufficient" quantity, in an accurate and appropriately even distribution. The conditions listed must also be met in order to have the least harmful effects on the natural environment and that created by man, as a result of using plant protecting agents.

A possible cause for failing to achieve the expected results are believed by the farmers and plant protection experts to be the inefficiency of the chemicals used. It is also an obvious reason that the spray liquid had not been appropriately spread over the target surface. The efficiency of spraying is generally low during procedures applied nowadays, as most of the spray spread out is not utilized. This greatly impairs treatment efficiency, and extraordinarily increases spraying costs as due to the unsatisfactory results the protection activities need to be repeated in many cases, and, moreover, the prices of plant protection products are also continuously on the rise. Besides efficiency issues another important factor is that chemicals by-passing surfaces to be protected charge and endanger the environment, in some cases seriously damaging, contaminating it.

The system, design of the sprayers, and the technical solutions on the machines (primarily the nozzles fixed on the spray booms) significantly influence how much the spray distributed becomes utilized or lost.

During the past years the requirements against the technology of spraying have become stricter throughout the world. The social and professional demand is becoming more and more expressed and urging to have the interventions done saving material (using reduced amounts of chemicals and water, that is using less spray liquid), and in an environmentally sound way without the working quality of spraying and the efficiency of the treatments becoming worse. Experts dealing with research development - after recognising the actuality and importance of the topic - have made great efforts jointly with the companies manufacturing/developing sprayers to elaborate technologies, machines, and technical solutions satisfying the requirements set up and to distribute them on a large scale.

The outstanding importance of the topic is supported by the fact that the control of the plant protecting machines' design and technical condition - especially that of new and used industrial size sprayers - in the European countries is performed according to regulations set up based on basically environment protection-related requirements, test methods set out in EN and ISO standards.

During the past decade as the measures on plant protection and plant protection activities have become effective the competent authorities in our country have also been putting increased emphasis on the qualification and control of new and in-use plant protection machines. At present, according to the law No. XLVI of the year 2008 on the food chain and authority control, and the FVM regulation No. 43/2010 (IV 23) on plant protection activities and regulating the execution of the law the new plant protection machines equipped with a tank with a volume larger than 5 dm^3 must be subjected to type qualification process before being put into trade. Machines subject to the legal measures are only allowed to be distributed in Hungary with a licence issued by MGI.

Machine owners must be prepared for the fact that the periodical inspection system of sprayers in use will soon mandatorily be introduced in Hungary according to the direction 2009/128/EC valid in the member states of the European Union, and according to the national regulations.

Based on the above it can be stated that the research, development, testing of the efficient, material-saving, environmentally sound spraying procedures, sprayers, technical solutions, and their introduction to the players of society, and their application on a wide range is an extremely actual task of great importance.

My research activity hypotheses were the following:

- Hypothesis No. 1: As a result of reducing operating pressure the size of the drops generated increases, and the particles formed by lower pressure drift in a smaller amount and to a lower distance.

- Hypothesis No. 2: Drift Guard and Air Induction flat fan nozzles produce larger drops than conventional flat fan nozzles, and the particles generated by them drift away less.

- Hypothesis No. 3: There is a detectable difference between the Air Induction flat fan nozzles with remarkably different technical layouts from the aspect of their drop-generating characteristics of outstanding importance for environment protection, and in respect of the degree of drift of the particles generated by them.

- Hypothesis No. 4: The size of the drops produced during the use of TwinFluid nozzles is changeable in accordance with the information given by the manufacturing company, therefore, the amount of the particles drifted and the distance of drift can be reduced.

The objective of my work was testing of the listed hypotheses. Accordingly, I set out the implementation of drop production inspections with a particle sizer and drift measurements in a wind tunnel as my research tasks. The results and consequences from these tests helped me clarify the following:

- how much the droplet size exactly increases due to the reduction of the operating pressure during the application of the TeeJet TP11004VP standard, DG11004VS Drift Guard, AIXR11004VP Air Induction Extended Range, and AI11004VS Air Induction flat fan nozzles used for field-spraying, and how much the amount of the drifted particles and the distance of drift decreases,

- how much the DG11004VS, the AIXR11004VP, and the AI11004VS nozzles increase the drop size, and decrease drift related to the TP11004VP nozzles,

- is there any significant difference between the technically rather different AIXR11004VP and AI11004VS Air Induction flat fan nozzles concerning their drop-generation characteristic values rather important in connection with the possible ambient effects, and in the degree of the drift of the generated drops,

- within the TwinFluid 042/TK-SS10 nozzle's operation applied on John Deere sprayers does the drop size significantly change in all cases due to the changes between the settings, and at the same time can the degree and distance of the drift of particles generated be reduced.

Furthermore, another objective of my research work was to draw up professional recommendations for practical experts based on my research achievements and consequences.

2. MATERIAL AND METHOD

As the most important criterion of selecting my test objects I kept in view to test the good quality products of any company well-known and acknowledged world-wide and manufacturing spraying nozzles, as the companies fulfilling the said requirements can be characterized by precise production processes, high-level research-development activities, and a strict quality insurance system.

Concerning hydraulic field-spraying the whole product range of the companies in the example were reviewed, and with the help of model aspect the nozzles were compared to each other based on several points, which may be considered as objects during the test.

I selected different type (conventional, Drift Guard, Air Induction Extended Range, and "classic" Air Induction) TeeJet made flat fan nozzles, and TwinFluid nozzle used on John Deere sprayers, which are also made up of TeeJet parts.

In the first step of my tests the drop-production of the selected technical solutions that is the distribution by size of the generated particles was inspected in laboratory conditions by different operation properties and different settings, using a laser particle sizer.

Then the degree and the distance of drift of the drops generated by the flat fan nozzles and the TwinFluid nozzle were identified in a wind tunnel, using the same operation parameters and settings as by the drop-production inspections by different wind velocities.

Those data were evaluated and analysed in all detail which have outstanding importance concerning the environmental effects of spraying.

2.1 Inspections of drop production

The main technical characteristics given by the manufacturer of the inspected TeeJet flat fan nozzles are given in table 1.

Table No. 1: Main factory technical parameters of the tested flat fan nozzles

Nozzle's exact name	Nozzle type	Spray angle (°)	Size*/ ISO-colour code**	Nozzle insert***	Op. pressure range (bar)	Optimum work height (cm)
TP11004 VP	TP/ standard	110	04/ red	polimer (VP)	2-4	50
DG11004 VS	DG/ Drift Guard	110	04/ red	stainless steel (VS)	2-5	50
AIXR11004 VP	AIXR/ Air Induction Extended Range	110	04/ red	polimer (VP)	1-6	50
AI11004 VS	AI/ Air Induction	110	04/ red	stainless steel (VS)	2-8	50

Notes:
*: "size 04" means that the nominal flow rate of the nozzle is 1.5 l/min by 2.8 bar operating pressure.
**: "red ISO-colour code" according to ISO 10625:2005 means: the nominal flow rate of the nozzle is 1.6 l/min by 3.0 bar operating pressure.
***: The nozzle insert material only affects the non-abrasiveness that is the duration of the nozzle.

The tested TwinFluid 042/TK-SS10 type technical solution used on John Deere sprayers is a complete TwinFluid nozzle consisting of the following TeeJet made partial units. Compact design nozzle holder (1 piece), 042 size calibrated insert (1 piece), individual nozzle cap (1 piece), O-ring (1 piece), TK-SS10 type deflector nozzle (1 piece).

Figure 1 shows the layout of the TwinFluid nozzle, and demonstrates the way of mounting them without the use of a tool on the nozzle holders equipped with a drop-preventing membrane valve.

Fig. No. 1:
TwinFluid nozzle mounting and fixing

Table 2 shows the major factory technical data related to the TwinFluid 042/TK-SS10 nozzle.

Table No. 2: Major factory technical parameters of the inspected TwinFluid 042/TK-SS10 nozzle

Pressure (bar)		Drop size*	Nominal flow rate (l/min)
Liquid	Air		
1.00	1.00	Very fine	0.30
2.00	1.25		0.60
2.50	1.50		0.68
1.50	1.00	Fine	0.51
2.50	1.25		0.75
3.50	1.50		0.95
1.50	0.75	Medium	0.59
2.00	1.00		0.67
4.00	1.50		1.05
1.50	0.50	Coarse	0.67
2.50	0.75		0.88
3.50	1.00		1.04

Note:
*: The drop sizes were given by the nozzle manufacturer according to those set out in the BCPC classification system, depending on the calibrated insert (042), and the liquid and air pressure.

The uninfluencable (determined) and adjustable parameters of the drop generation tests, the adjustment limits related to adjustable characteristics, and the drop generation characteristics definable by measurement are given in table No. 3.

Table No. 3: Characteristics groups and adjustment limits related to drop generation tests

Uninfluencable ambient parameters	Adjustable characteristics	Adjustment limits	Measurable characteristics
- ambient air characteristics: - temperature - relative humidity - air movement (velocity, direction) - liquid** temperature	Liquid** pressure (bar)	0.0-10.0	- d_{v10} (μm) - ratio of drops below 100 μm (%) - d_{v50} (μm) - d_{v90} (μm)
	Air pressure* (bar)	0.0-10.0	
	Mounting height (m)	0.0-1.0	

Notes:
*: Only refers to TwinFluid nozzle.
**: According to chapter 4.1 of the standard ISO 5682-1:1996: clean tap-water free of solid contamination (tap-water or mains water).

Among the determined characteristics the ambient air temperature and relative humidity were measured using a VIKING THERMO-HYGRO type, calibrated, digital gauge (measurement range: -10.0-50.0 °C, and 24-99 %; resolution: 0.1 °C, and 1 %). The temperature of the liquid used was determined using a LOMBIK mercury-in-glass, inner scale type, calibrated glass tube thermometer (measurement range: 0.0-50.0 °C; resolution: 0.1 °C).

The minimum and maximum values were recorded concerning all three parameters. Based on these the temperature was between 18.9 °C and 22.7 °C, relative humidity was between 41 % and 59 %, and the temperature of the liquid used was between 15.5 °C and 19.4 °C during the measurement of the flat fan nozzles, and the TwinFluid nozzle.

The values of the adjustable characteristics were determined based on the recommendations of the manufacturing company of the flat fan nozzles, and the TwinFluid nozzle, and my practical experience concerning field-spraying.

Settings concerning flat fan nozzles are shown in table No. 4, and those applied for TwinFluid nozzle are given in table No. 5.

Table No. 4: Drop production inspection settings of flat fan nozzles

Nozzle's exact name	Operating pressure (bar)	Spraying height (m)
TP11004VP	3.0 & 4.0	0.5
DG11004VS	3.0 & 4.0	0.5
AIXR11004VP	3.0 & 4.0	0.5
AI11004VS	3.0 & 4.0	0.5

The pressure by the test of the flat fan nozzles was set using a HBM PE 300A/20B type calibrated, digital remote-type pressure transmitter (measurement range: 0.0-20.0 bar; measurement accuracy: ±0.3 %; resolution: 0.1 bar), and the working height was checked using a calibrated steel measuring tape.

Table No. 5: TwinFluid 042/TK-SS10 nozzle drop production test settings

Setting No.	Pressure (bar)		Drop size*	Spray height (m)
	Liquid	Air		
1.	2.00	1.25	Very fine	0.5
2.	2.50	1.25	Fine	0.5
3.	1.50	0.75	Medium	0.5
4.	1.50	0.50	Coarse	0.5

Note:
*: See table No. 2.

In connection with the TwinFluid 042/TK-SS10 nozzle the liquid pressure was also adjusted using the above mentioned, calibrated digital remote-type pressure transmitter, and the air pressure was adjusted using a INGERSOLL-RAND R18-C4-F000 type, calibrated air-pressure gauge (measurement range: 0.0-10.0 bar; measurement accuracy: ±1 %; division: 0.1 bar), the tool and method for checking spraying height was the same as those given in connection with the flat fan nozzles.

The drop production characteristics of the flat fan nozzles and the TwinFluid nozzle were identified using a Malvern 2600 C type laser particle sizer operating on the principle of diffraction in the MGI's professional competent test laboratory with an accredited status. The major metrology characteristics of the measuring apparatus used according to the specification given in the user's manual delivered with the equipment and issued by the manufacturer: measurement range: 0.5-1800.0 µm; measurement accuracy: ±4 %; resolution: 0.1 µm.

Before the drop production inspection of the flat fan nozzles with different dimensions, as a first step, one nozzle (dripping preventing membrane valve, nozzle holder, nozzle cap, rubber gasket) used as an auxiliary for the test was mounted on a meter rack developed on my own. The orifice of the flat fan nozzles to be tested and mounted in the nozzle cap was located exactly above spray-fan, on the longitudinal centre point of the laser beam transmitted at right angle on the longitudinal axis of the fan. This provided for the spraying height generally spread in field spraying practice, and for the location appropriate for the measurements (Figure No. 2).

The TwinFluid nozzle was also mounted on the same nozzle holder equipped with dripping preventing membrane valve.

In the second step the points giving the symmetrical spray-fan edges (reference points) were set and apparently and permanently marked for each operating parameter for each flat fan nozzle, and for each setting in case of the TwinFluid nozzle. Based on those set out in the user's manual issued by the manufacturer the whole spray-fan was tested on the section between the reference points moving the nozzle with a velocity of 0.01 m s^{-1} along the horizontal track fixed to the meter rack elaborated for the measurement purpose. Concerning the flat fan nozzles the test was performed by two different operating pressure values for each nozzle, and in case of the TwinFluid nozzle repeated three times for each setting. The rounded average values of the parameters characterizing the drop production of the technical solutions identified by the measurement, and the relevant spreading values were given in numerical format.

Figure 2 shows the described test method.

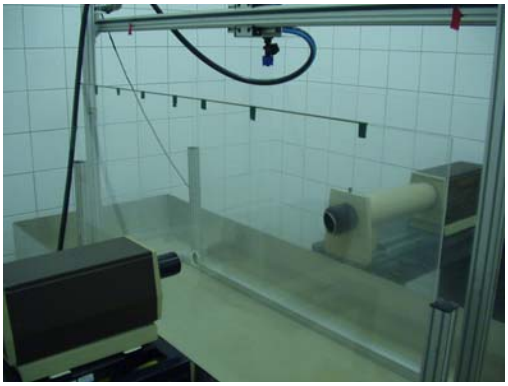

Figure No. 2:
Illustration of the drop production inspections performed using a laser particle sizer

From the test results d_{v10} and the ratio of drops smaller than 100 μm were assessed and analysed in detail as from the characteristics determined using the measurement these parameters have the greatest influence on the drift inclination of the particles, and in relation to this to the possible ambient influences of the spraying.

2.2 Drift measurements in a wind tunnel

The uninfluencable and adjustable parameters of the drift measurements, the adjustment limits, and the characteristic definable by the measurements are given in table No. 6.

Table No. 6: Parameter groups and adjustment limits characteristic of drift measurements

Uninfluencable ambient parameters	Adjustable characteristics	Adjustment limits	Characteristics definable by measurement
- ambient air characteristics: - temperature - relative humidity - laminar air-flow direction (wind direction) - liquid** temperature	Liquid** pressure (bar)	0.0-10.0	Relative coverage (%)
	Air pressure * (bar)	0.0-10.0	
	Wind velocity (m s^{-1})	0.0-10.0	
	Mounting height (m)	0.0-1.0	

Notes:
*: In case of TwinFluid nozzle.
**: See table No. 3.

The identification and recording of the determined parameters were performed the same way in all points described in connection with the inspections of drop production. The measured characteristics had the following values during the drift measurements: air temperature: 14.0-19.2 °C, relative humidity 35-46 %, temperature of liquid used: 13.7-18.1 °C.

During the tests when choosing, setting, and checking the pressure and mounting height values exactly the same procedure was followed as by those described in the subsection related to the inspections of drop production.

The wind velocity was set to 2.0, 4.0, and 6.0 m s^{-1} values using a calibrated multifunction measuring instrument type Testo 400 (measurement range: 0.4 – 60.0 m s^{-1}; measurement accuracy: ±0.2 %; resolution: 0.1 m s^{-1}).

Drift measurements were also performed among laboratory circumstances in a wind tunnel established and put into operation by the workers of the Department of Fluid Mechanics of Budapest University of Technology and Economics at the MGI headquarters. The measurement room length in the wind tunnel is 8 m, the width is 2 m, the height is 1.5 m, and the maximum speed of producible laminar air-flow (max. wind velocity) is 10.0 m s^{-1}.

The nozzle fixed on a special meter rack located in the wind tunnel and used as an auxiliary for the tests and identical to the one used for the inspections of drop production was mounted in a way that, on the one hand, the flat fan nozzles to be tested and mounted in the nozzle cap and the spray fan generated by the TwinFluid nozzle make an angle exactly 90° with the laminar air-flow direction (that is the longitudinal axis of the wind tunnel), and, on the other hand, the flat fan nozzles, and the TwinFluid nozzle's orifice is located exactly over the longitudinal centre line of the wind tunnel's floor. Along the longitudinal centre line of the measurement room, below the tested objects, and in a distance of 1, 2, 3, 4, 5, 6, and 7 m from them (measurement points) water-sensitive (WS) papers of 52 x 76 mm in size, that is a total of 8 pieces per measurement were fixed to the floor. Spraying was performed by the given three different wind velocities (the duration of spraying was 10 seconds in each case), then the totally dry water-sensitive papers (samples) were collected. The test layout used is shown in Figure 3.

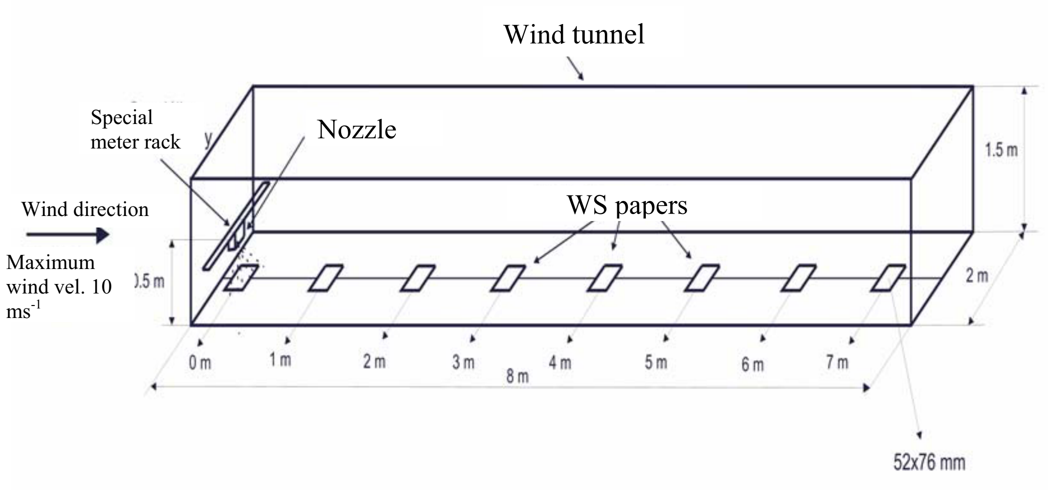

Figure No. 3:
Drift measurements in wind tunnel - illustration

For the appropriate magnification pictures of the samples were taken using a digital camera (resolution: 2260 dpi) with a stereo microscope inserted (type: Wild M7A, zoom range: 6X-31X), and then the pictures were recorded electronically.

Next, the relative coverage related to each sample (the % ratio of the part turning to blue due to water and the original yellow area) was identified using a Vision Development picture processing module belonging to the data collecting measurement controlling programme type National Instruments LabView v7.1. Concerning the flat fan nozzles the tests were performed at two different operating pressure values per nozzle, and in case of the TwinFluid nozzle they were repeated three times per setting. The results (rounded average values, and dispersion) were given and represented in numeric and graphic formats.

The total relative coverage (the sum of the 8 relative coverage values) related to the total measurement range was assessed and analysed in detail as the degree (amount) of the drift of the drops generated, that is the influence on organic and inorganic environment can be well characterized by this parameter. Besides, also due to the environmental relations special attention was given to the particles' drift distance.

The chosen and above described measurement methodology and assessment method do not provide exact qualitative data, at the same time, they are suitable for characterizing the drift of spray droplets, and the possible environmental effects of spraying, and to detect the conformation of and the differences between the tested objects within the framework of comparative tests.

2.3 Statistical analysis

The statistical analysis of the test results concerning the four different flat fan nozzles, and the TwinFluid nozzle operated by four different settings were all performed using Windows SPSS 14.0 software (SPSS Inc., Chicago, Illinois, USA).

The distribution of the data (the ratio of d_{v10} and the drops smaller than 100 μm) of inspections of drop production and drift measurements performed in a wind tunnel subjected to statistical analysis were tested using Kolmogorov-Smirnoff test (significance level: $P > 0.05$), and by the survey of Q-Q figures.

Differences between the results of inspections of drop production were identified concerning flat fan nozzles related to the nozzles and the operating pressure (as groups), in case of TwinFluid nozzle related to the settings (as groups), and the differences between the data of drift measurements were identified related to the wind velocity (also as groups)- besides those listed - using ANOVA.

Duncan and Scheffe Post Hoc Test was used to compare pairs of nozzles, and settings.

3. RESULTS

In respect of the statistical analyses performed the d_{v10} and the % ratio of drops smaller than 100 µm, and the results received concerning the total relative coverage recorded during the drift measurements did not differ in any of the cases (neither in connection with flat fan nozzles, nor in connection with the TwinFluid nozzle) from the normal distribution. The confidence interval concerning each statistical test was $\alpha = 0.05$.

3.1 Inspection of TeeJet TP11004VP, DG11004VS, AIXR11004VP and AI11004VS flat fan nozzles

3.1.1 Inspections of drop production

The operating pressure values used in the framework of testing the four flat fan nozzles, and the drop production characteristics identified by measurement are shown in table No. 7.

Table No. 7: The characteristics identified by inspections of the drops produced by the TP11004VP, DG11004VS, AIXR11004VP, and AI11004VS flat fan nozzles, related to the operating pressure

Nozzle's exact name	Press. (bar)	d_{v10} (µm)	d_{v50} (µm)	d_{v90} (µm)	< 100 µm drops ratio (%)
TP11004VP	3.0	55.7 ± 2.8	133.2 ± 7.8	231.1 ± 15.6	34.6 ± 3.3
DG11004VS		93.3 ± 3.9	211.0 ± 2.7	376.1 ± 1.6	13.0 ± 1.1
AIXR11004VP		117.1 ± 4.1	308.0 ± 16.7	643.1 ± 50.6	8.3 ± 0.5
AI11004VS		120.0 ± 4.5	329.0 ± 7.8	711.0 ± 9.4	8.0 ± 0.6
TP11004VP	4.0	50.2 ± 1.1	127.3 ± 6.6	230.1 ± 16.2	38.2 ± 2.8
DG11004VS		83.3 ± 6.5	195.5 ± 15.7	335.4 ± 30.7	16.8 ± 2.6
AIXR11004VP		100.0 ± 3.2	208.6 ± 10.0	331.0 ± 34.4	11.3 ± 0.6
AI11004VS		101.6 ± 2.3	269.4 ± 8.6	490.5 ± 37.7	10.8 ± 0.5

At an operating pressure of 3.0 bar d_{v10} was between 55.7 ± 2.8 µm – 120.0 ± 4.5 µm, and at an operating pressure of 4.0 bar it changed within the range between 50.2 ± 1.1 µm – 101.6 ± 2.3 µm depending on the nozzles (Table No. 7).

Based on the comparison of the four flat fan nozzles as groups using statistical methods a significant difference was found between the nozzles by both test pressure concerning dv_{10} (3.0 bar: $F_{3.8}$=175.969, P<0.001; 4.0 bar: $F_{3.8}$=118.073, P<0.001).

Based on the pairwise comparison in d_{v10} of the drops generated by the AIXR11004VP and the AI11004VS nozzles there were no significant differences by any of the pressure values (P>0.05). In case of the rest of the nozzle pairs (TP11004VP and DG11004VS, TP11004VP and AIXR11004VP, TP11004VP and AI11004VS, DG11004VS and AIXR11004VP, DG11004VS and AI11004VS) by both pressure values significantly different - characterised by d_{v10} value - drops were produced (P<0.05).

Furthermore, table No. 7 shows that by 3.0 bar pressure concerning the ratio of drops smaller than 100 µm values within the range 34.6 ± 3.3 % - 8.0 ± 0.6 % were recorded; by a pressure of 4.0 bar the recorded values were within the range 38.2 ± 2.8 % - 10.8 ± 0.5 %.

Based on the comparison of nozzles as groups, by both pressure values there was a significant difference between the nozzles even in the ratio of drops smaller than 100 µm (3.0 bar: $F_{3.8}$=151.962, P<0.001; 4.0 bar: $F_{3.8}$=134.707, P<0.001).

The pairwise comparison also resulted in data equivalent to results gained during the comparison of the d_{v10} values. There was no significant difference by any pressure value between the AIXR11004VP and AI11004VS nozzles concerning the frequency of appearance of drops smaller than 100 µm (P>0.05). The comparison of the rest of the nozzle pairs at 3.0 and 4.0 operating pressure values both resulted in significant differences even in the ratio of drops smaller than 100 µm (P<0.05).

3.1.2 Drift measurements in a wind tunnel

The results of the measurements performed by different wind velocity values and different operating pressure values are shown in Figures No. 4-9. Under the nozzle a 100 % coverage was identified for all three wind velocity values, and for all nozzles by both operating pressure values in case of all repetition.

The results gained by a wind velocity of 2.0 m s^{-1}, and by an operating pressure of 3.0, and 4.0 bar are shown in figures No. 4 and 5. Figures No. 4 and 5 show that in case of wind velocity of 2.0 m s^{-1} by an operating pressure of 3.0 and 4.0 bar in case of all four flat fan nozzles there was a detectable degree of relative coverage (≥ 1 %) up to a distance of 2 m from the nozzle.

For the TP-type nozzle at a pressure of 3.0 bar at 2 %, for the DG type at 4 %, and for the AIXR and AI nozzles 1 % relative coverage each was recorded for the given distance.

At 4.0 bar operating pressure, in a distance of 2 m the following values were recorded for the above order of the nozzles: 5 %, 3 %, 2 %, 1 %.

Results recorded by a wind velocity of 4.0 m s^{-1} are shown in figures No. 6 and 7.

Figure No. 6 shows that by a wind velocity of 4.0 m s^{-1} and a pressure of 3.0 bar in a distance of 7 m (measurement limit) from the nozzle 1 % relative coverage was registered for the TP nozzle. Concerning the DG nozzle the same coverage was at 6 m, and in case of the AIXR and the AI types it was at 4 m, each.

On a pressure of 4.0 bar (figure No. 7) concerning the TP and the DG nozzles no change was found related to the results gained by lower operating pressure in connection with the relation between the detectable level of relative coverage and the distance from the nozzle. At the same time, in case of the AIXR and the AI types 1 % coverage was recorded in a distance of 5 m each.

Data identified in case of a wind velocity of 6.0 m s^{-1} are shown on figures No. 8 and 9.

Figure No. 8 shows that by a wind velocity of 6.0 m s^{-1} and a pressure of 3.0 bar for each nozzle, except for the AI type, a detectable level of relative coverage was identified at the measurement limit (TP: 3 %, DG: 2 %, AIXR: 1 %). Concerning the AI nozzle the coverage level ≥ 1 % was recorded up to a distance of 6 m.

At a pressure of 4.0 bar (figure No. 9) the test of the TP nozzle showed a relative coverage of 4 %, while that of the DG and the AIXR nozzles showed that equal to the data recorded by lower operating pressure, while that of the AI type showed a relative coverage of 1 % in a distance of 7 m.

It is also readable from the figures that related to results gained by wind velocities 2.0 and 4.0 m s^{-1} the values identified at the different measurement points significantly increased by both operating pressure values in case of all tested flat fan nozzles.

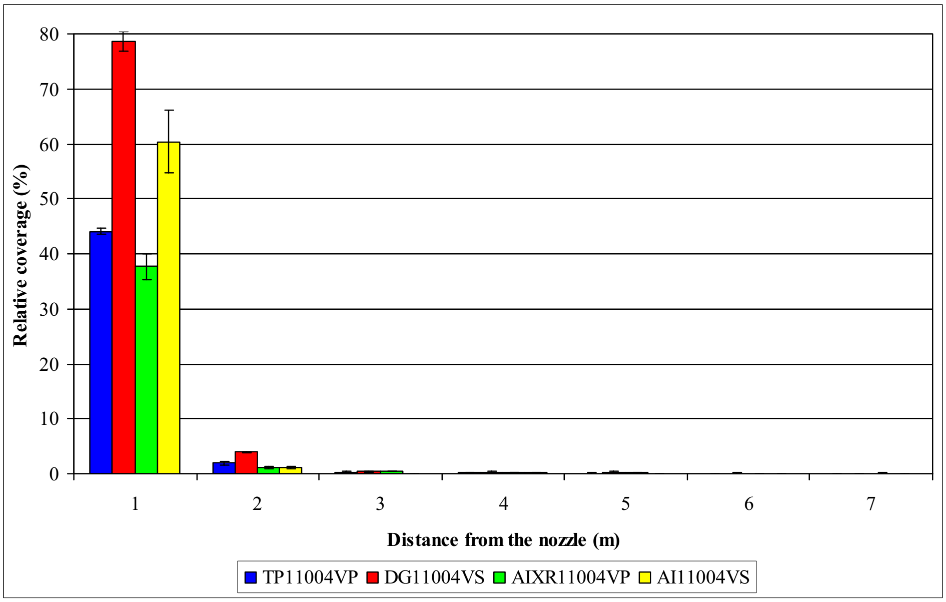

Figure No. 4:
Drift of drops produced by the flat fan nozzles TP11004VP, DG11004VS, AIXR11004VP, and AI11004VS in a wind tunnel by a wind velocity of 2.0 m s^{-1} and an operating pressure of 3.0 bar

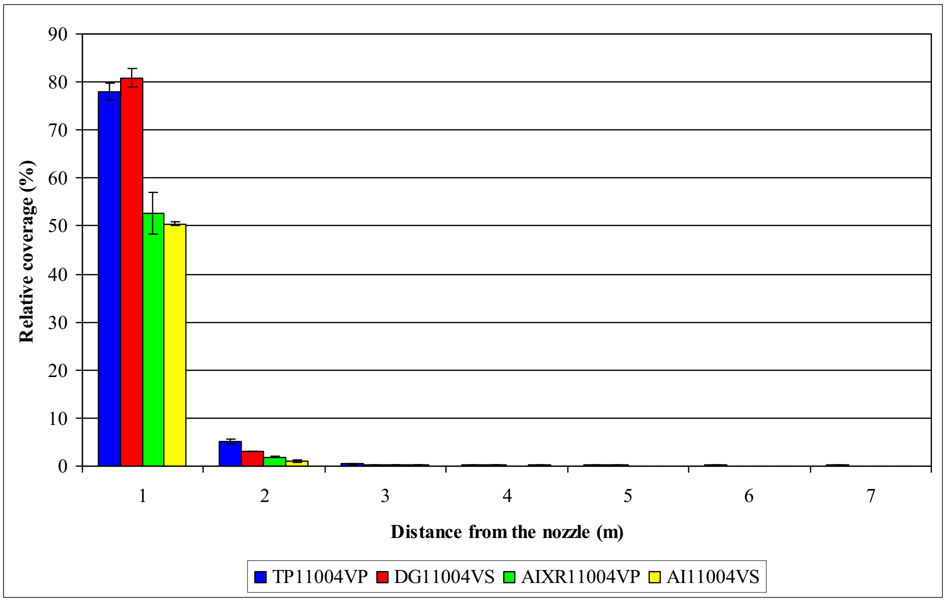

Figure No. 5:
Drift of droplets created by the flat fan nozzles TP11004VP, DG11004VS, AIXR11004VP, and AI11004VS in a wind tunnel by a wind velocity of 2.0 m s^{-1} and an operating pressure 4.0 bar

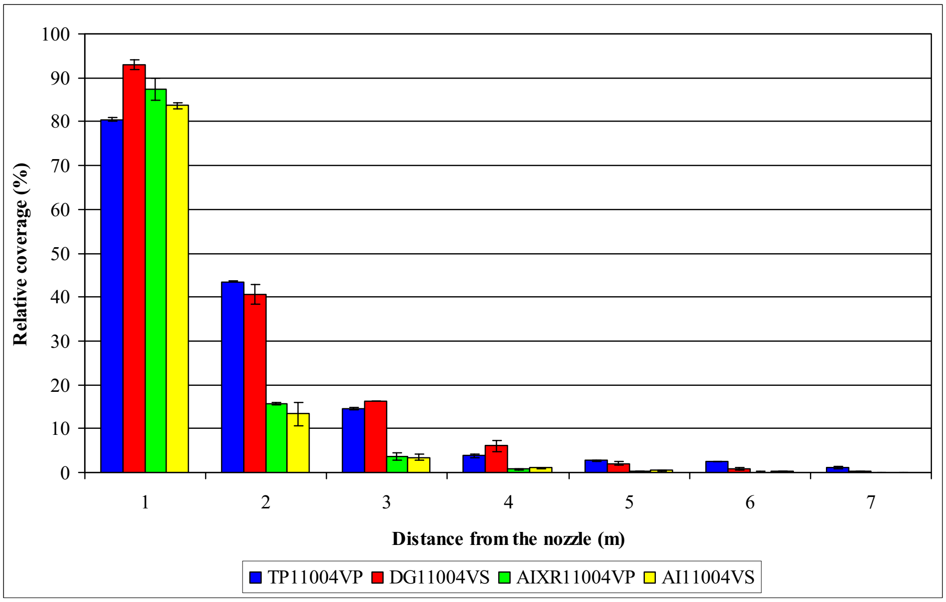

Figure No. 6:
Drift of particles produced by the flat fan nozzles TP11004VP, DG11004VS, AIXR11004VP, and AI11004VS in a wind tunnel by a wind velocity of 4.0 m s^{-1} and an operating pressure 3.0 bar

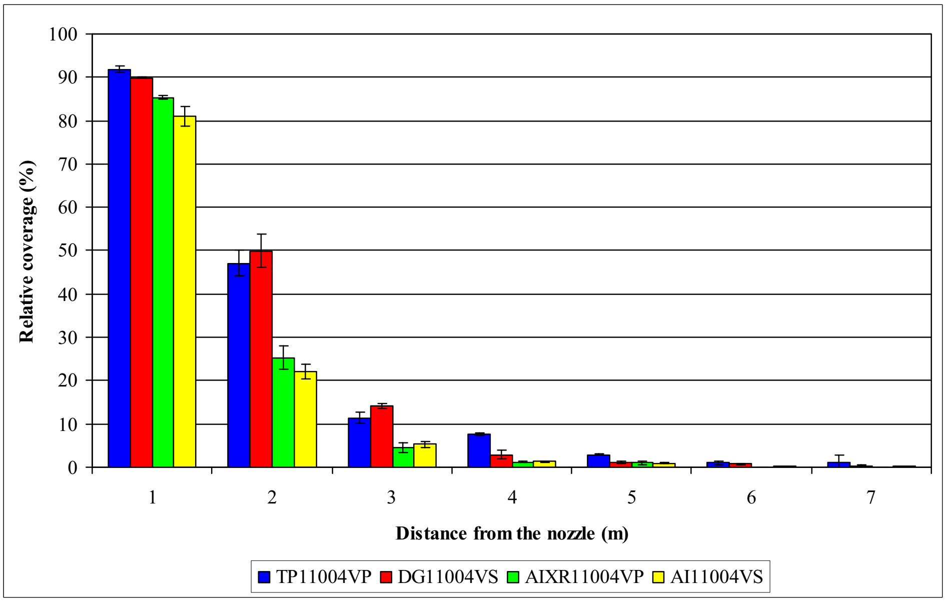

Figure No. 7:
Drift of drops generated by the flat fan nozzles TP11004VP, DG11004VS, AIXR11004VP, and AI11004VS in a wind tunnel by a wind velocity of 4.0 m s^{-1} and an operating pressure 4.0 bar

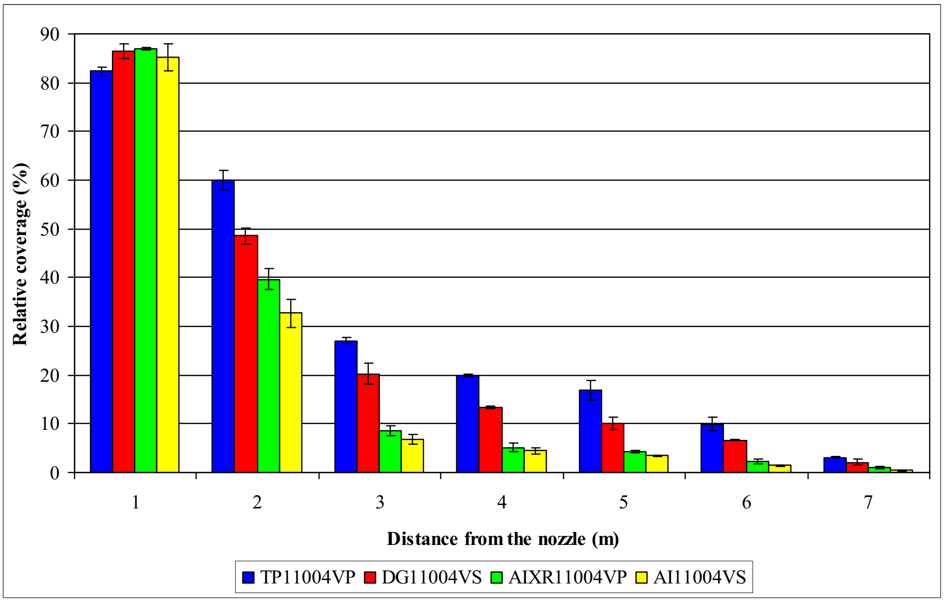

Figure No. 8:
Drift of droplets created by the flat fan nozzles TP11004VP, DG11004VS, AIXR11004VP, and AI11004VS in a wind tunnel by a wind velocity of 6.0 m s^{-1} and an operating pressure 3.0 bar

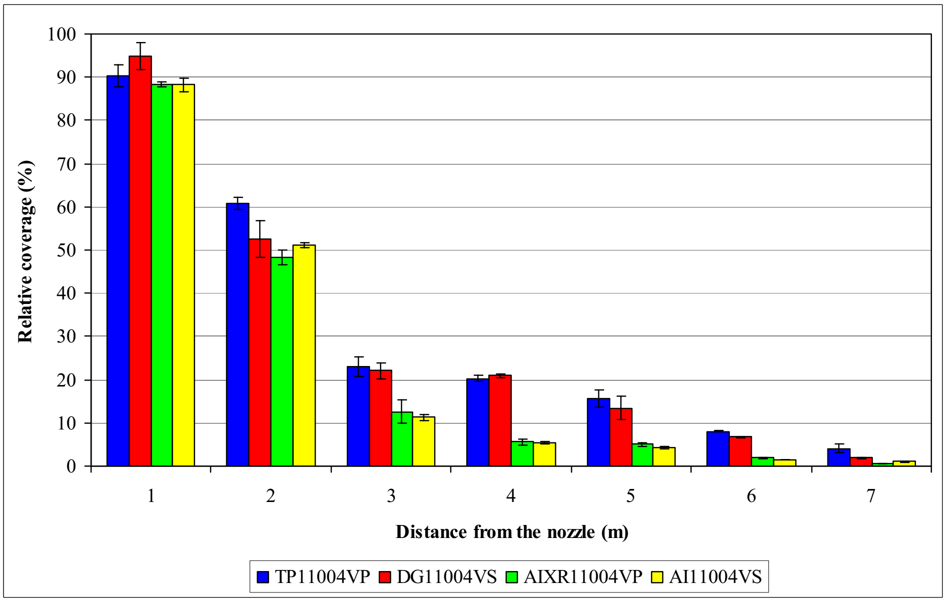

Figure No. 9:
Drift of particles generated by the flat fan nozzles TP11004VP, DG11004VS, AIXR11004VP, and AI11004VS in a wind tunnel by a wind velocity of 6.0 m s^{-1} and an operating pressure 4.0 bar

Concerning the total relative coverage related to the total measurement range the results gained as a function of the nozzles, the operating pressure, and the wind velocity are given in Table No. 8.

Table No. 8: Drift of the drops produced by the flat fan nozzles TP11004VP, DG11004VS, AIXR11004VP, and AI11004VS in a wind tunnel as a function of the operating pressure and the wind velocity

Nozzle's exact name	Pressure (bar)	Total relative coverage (%)		
		Wind velocity ($m\ s^{-1}$)		
		2.0	4.0	6.0
TP11004VP	3.0	147.0 ± 0.6	249.0 ± 0.4	319.0 ± 5.7
DG11004VS		184.0 ± 2.5	259.0 ± 1.5	288.0 ± 0.7
AIXR11004VP		140.0 ± 1.9	208.0 ± 3.1	248.0 ± 5.4
AI11004VS		162.0 ± 6.0	202.0 ± 2.4	234.0 ± 6.1
TP11004VP	4.0	184.0 ± 1.4	263.0 ± 3.6	322.0 ± 6.6
DG11004VS		184.0 ± 2.0	259.0 ± 5.0	312.0 ± 9.3
AIXR11004VP		155.0 ± 4.3	218.0 ± 3.9	262.0 ± 2.9
AI11004VS		152.0 ± 0.2	211.0 ± 2.3	263.0 ± 0.5

Table No. 8 shows that by an operating pressure of 3.0 bar the values of the total relative coverage fell between 140.0 ± 1.9 % - 184.0 ± 2.5 % by a wind velocity of 2.0 $m\ s^{-1}$, and by 4.0 $m\ s^{-1}$ within the range 202.0 ± 2.4 % - 259.0 ± 1.5 %, while by a wind velocity of 6.0 $m\ s^{-1}$ they changed between 234.0 ± 6.1 % - 319.0 ± 5.7 % depending on the nozzles.

By an operating pressure of 4.0 bar data were recorded within the following intervals depending on the wind velocity and the nozzles: 2.0 $m\ s^{-1}$: 152.0 ± 0.2 % - 184.0 ± 2.0 %, 4.0 $m\ s^{-1}$: 211.0 ± 2.3 % - 263.0 ± 3.6 %, 6.0 $m\ s^{-1}$: 262.0 ± 2.9 % - 322.0 ± 6.6 % (table No. 8).

The comparison as groups within the framework of a statistical analysis of the results of the four flat fan nozzles by an operating pressure of 3.0 bar showed significant differences for all three wind velocities between the total relative coverage values of the nozzles (2.0 $m\ s^{-1}$: $F_{3.8}$=89.808, P<0.001; 4.0 $m\ s^{-1}$: $F_{3.8}$=411.178, P<0.001, 6.0 $m\ s^{-1}$: $F_{3.8}$=139.984, P<0.001).

Based on the comparison of pairs in case of an operating pressure of 3.0 bar and a wind velocity of 2.0 $m\ s^{-1}$ all four flat fan nozzles produced a total relative coverage value significantly different from the others (P<0.05). By the same operating pressure and by higher wind velocity values (4.0 $m\ s^{-1}$ and 6.0 $m\ s^{-1}$), at the same time, there was no significant difference between the degree of drift of the drops - characterized by the total relative coverage - generated by the nozzles AIXR11004VP and AI11004VS (P>0.05).

The rest of the nozzle-pairs (TP11004VP and DG11004VS, TP11004VP and AIXR11004VP, TP11004VP and AI11004VS, DG11004VS and AIXR11004VP, DG11004VS and AI11004VS) could also be characterized by significantly different relative coverage levels by higher wind velocities (P<0.05).

Based on the analysis of the data of the tests performed by an operating pressure of 4.0 bar (as groups) showed significant differences between the nozzles concerning the given parameter (2.0 m s^{-1}: $F_{3.8}$=157.827, P<0.001; 4.0 m s^{-1}: $F_{3.8}$=152.147, P<0.001, 6.0 m s^{-1}: $F_{3.8}$=87.699, P<0.001).

The pairwise comparison of the data gained by an operating pressure of 4.0 bar produced the same results by all three wind velocities. The degree of the drift of the particles - characterized by total relative coverage - generated by the pairs TP11004VP and DG11004VS, and AIXR11004VP and AI11004VS showed no significant difference (P>0.05). Concerning the rest of the nozzle pairs significantly different total relative coverage values were identified (P<0.05).

3.2 Inspection of TwinFluid 042/TK-SS10 nozzle

3.2.1 Inspections of drop production

The test settings of the TwinFluid 042/TK-SS10 nozzle, and the drop production parameters identified by measurement are shown in table No. 9.

Table No. 9: Drop production characteristics of the TwinFluid 042/TK-SS10 nozzle identified by measurement as a function of the setting

Setting	Liquid pressure (bar)	Air pressure (bar)	d_{v10} (µm)	d_{v50} (µm)	d_{v90} (µm)	< 100 µm drops ratio (%)
1.	2.00	1.25	63.1 ± 3.4	161.3 ± 4.3	289.6 ± 22.5	25.7 ± 0.9
2.	2.50	1.25	59.5 ± 5.4	176.1 ± 10.3	351.6 ± 14.6	25.1 ± 2.8
3.	1.50	0.75	86.3 ± 9.4	256.1 ± 6.1	509.8 ± 18.1	13.9 ± 2.0
4.	1.50	0.50	97.4 ± 11.6	288.9 ± 28.0	564.6 ± 40.3	11.6 ± 2.1

Table No. 9 shos that the value of d_{v10} was between 63.1 ± 3.4 µm – 97.4 ± 11.6 µm depending on the settings.

Based on the comparison as groups within the framework of statistical analysis of the four settings significant difference was found between each setting for d_{v10} ($F_{3.8}$=15.113, P≤0.001).

The pairwiese comparison concerning d_{v10} characteristic of the drops generated by the settings 1 and 2, and 3 and 4 showed no significant difference (P>0.05). Concerning further setting-pairs (1 and 3, 1 and 4, 2 and 3, 2 and 4) no significantly different d_{v10} value was gained (P<0.05).

Concerning the rate of occurrence of drops smaller than 100 µm values between 11.6 ± 2.1 % - 25.7 ± 0.9 % were recorded depending on the settings (table No. 9).

Based on the comparison of settings as groups there was a significant difference between each setting even in the ratio of drops smaller than 100 µm ($F_{3.8}$=37.966, P<0.001).

Within the framework of comparing as pairs data also equal to the results received during the comparison of the d_{v10} values were gained. There was no significant difference between the settings 1 and 2, furthermore 3 and 4 concerning the rate of occurrence (P>0.05). At the same time, the comparison of the rest of the setting pairs resulted in significant differences even in the ratio of the drops smaller than 100 µm (P<0.05).

3.2.2 Drift measurements in a wind tunnel

Figures No. 10-12 show the results of the tests performed by different wind velocities. In case of all repeat 100 % relative coverage was identified concerning all three wind velocities and all used settings under the nozzle.

Based on figure No. 10 it can be stated that by a wind velocity of 2.0 m s^{-1} in case of setting No. 1 (liquid pressure: 2.0 bar, air pressure: 1.25 bar) and setting No. 2 (2.5 bar, 1.25 bar) detectable level of relative coverage was recorded up to a distance of 3 m from the nozzle. In the given distance relative coverage of 1 % was registered by setting No. 1 and 2 % by setting No. 2. Concerning settings No. 3 (1.5 bar, 0.75 bar) and No. 4 (1.5 bar, 0.5 bar) the distance proper for the above requirement was 4 m. In this distance a relative coverage of 1 % was identified for both settings.

Figure No. 11 shows that by a wind velocity of 4.0 m s^{-1} in case of all four settings a relative coverage of ≥ 1 % was recorded in a distance of 7 m from the nozzle. By settings No. 1 and 2 the detected value by the measurement limit was 4 % and 2 %, and by settings No. 3 and 4 it was 1 % each. By lower wind velocity concerning the distances 3 and 4 m mentioned in connection with the detectable coverage in case of setting No. 1 10 % and 13 %, for setting No. 2 11 % and 12 %, for setting No. 3 11 % and 7 %, and for setting No. 4 5 % relative coverage was identified for both distances given.

Figure No. 12 shows that by a wind velocity of 6.0 m s^{-1} the registered value within the measurement limit were 4 %, 5 %, 1 %, and 2 % in the order of the settings, and the relative coverage identified at the measurement points within the range 1-7 m further increased.

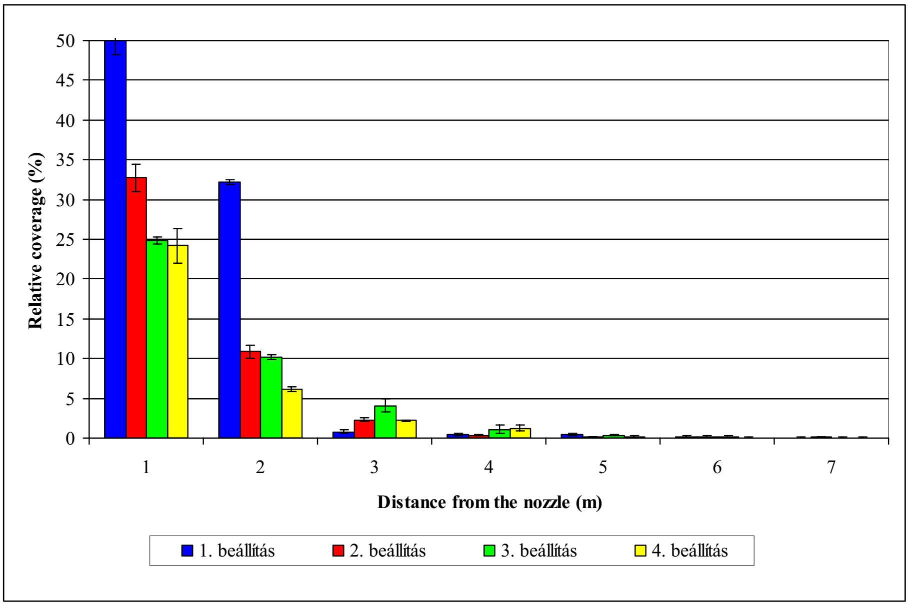

Figure No. 10:
Drift of the drops produced by the TwinFluid 042/TK-SS10 nozzle in a wind tunnel by a wind velocity of 2.0 m s^{-1}

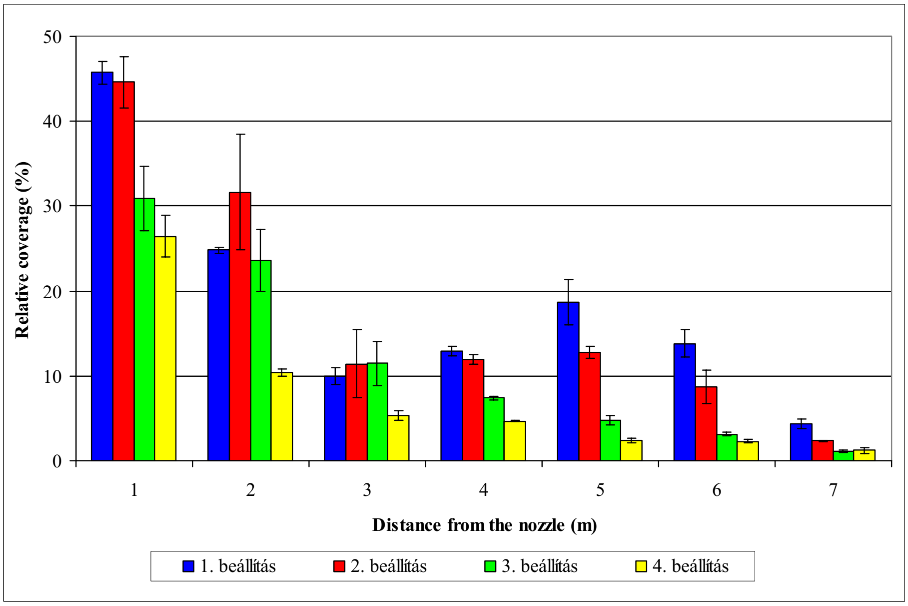

Figure No. 11:
Drift of the particles generated by the TwinFluid 042/TK-SS10 nozzle in a wind tunnel by a wind velocity of 4.0 m s^{-1}

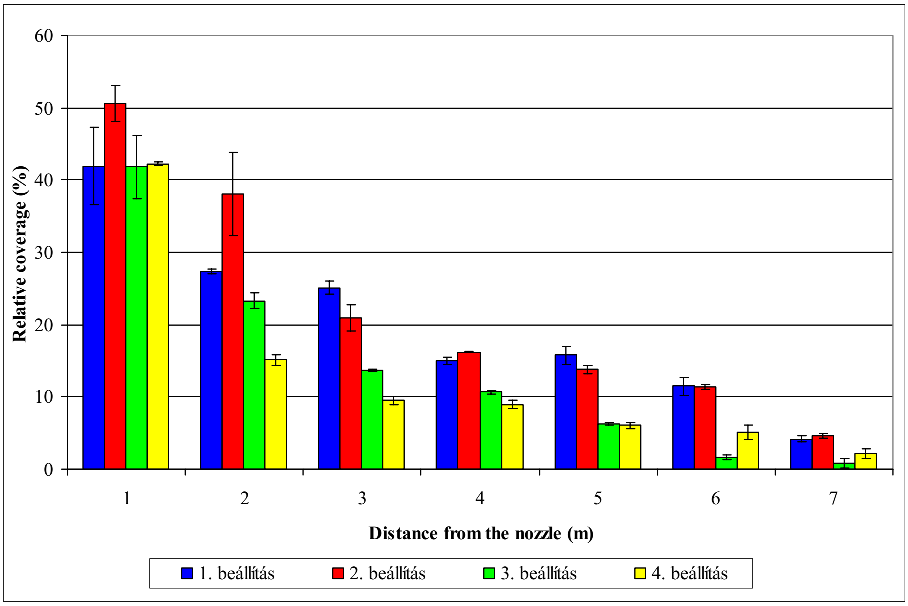

Figure No. 12:
Drift of the droplets created by the TwinFluid 042/TK-SS10 nozzle in a wind tunnel by a wind velocity of 6.0 m s^{-1}

Concerning the total relative coverage relating to the total measurement range, by three different wind velocities the data recorded depending on the settings are given in Table No. 10.

Table No. 10: Drift of the drops produced by a TwinFluid 042/TK-SS10 nozzle operated by different settings, in a wind tunnel depending on the wind velocity

Setting	Liquid pressure (bar)	Air pressure (bar)	Total relative coverage (%)		
			Wind velocity (m s^{-1})		
			2.0	4.0	6.0
1.	2.00	1.25	184.0 ± 1.9	230.0 ± 2.2	241.0 ± 6.3
2.	2.50	1.25	147.0 ± 0.7	223.0 ± 4.5	256.0 ± 9.0
3.	1.50	0.75	141.0 ± 1.1	182.0 ± 2.7	198.0 ± 4.4
4.	1.50	0.50	134.0 ± 1.5	153.0 ± 3.1	189.0 ± 0.9

The total relative coverage value by a wind velocity of 2.0 m s^{-1} was between 134.0 ± 1.5 % - 184.0 ± 1.9 %, by 4.0 m s^{-1} it was within the range 153.0 ± 3.1 % - 230.0 ± 2.2 %, and by a wind velocity of 6.0 m s^{-1} it changed between 189.0 ± 0.9 % - 256.0 ± 9.0 % depending on the settings (Table No. 10).

The comparison as groups of the four kinds of settings showed that concerning all three wind velocities there was a significant difference between each setting concerning total relative coverage (2.0 m s^{-1}: $F_{3.8}$=800.409, P<0.001; 4.0 m s^{-1}: $F_{3.8}$=1113.007, P<0.001; 6.0 m s^{-1}: $F_{3.8}$=1170.545, P<0.001).

Based on the pairwise comparison, by a wind velocity of 2.0 m s^{-1} all four settings were characterized by significantly different total relative coverage (P<0.05). However, by a wind velocity of 4.0 m s^{-1} and 6.0 m s^{-1} there was no significant difference between settings No. 1 and No. 2. in the degree of drift of the particles generated - characterized by the tested parameter - (P>0.05).

Between the rest of the setting pairs even by higher wind velocities there were significant differences in total relative coverage (P<0.05).

3.3 New scientific results (theses)

- (thesis 1): Based on the results of the inspections of drop production of the nozzles TeeJet AIXR11004VP and TeeJet AI11004VS I state, that between the Air Induction flat fan nozzles there is no significant difference by 3.0 and 4.0 operating pressure in the 10 % volume drop diameter of the drops created, and in the rate of occurrence of the droplets smaller than 100 μm.

- (thesis 2): Based on the results of the drift measurements performed in a wind tunnel on the nozzles TeeJet TP11004VP, TeeJet DG11004VS, TeeJet AIXR11004VP and TeeJet AI11004VS I state, that during the use of conventional, Drift Guard, and Air Induction flat fan nozzles the amount of drifted spray liquid damaging the environment elements can be moderated by decreasing the operating pressure from 4.0 bar to 3.0 bar, and the distance of drift related to the contamination source can be reduced.

- (thesis 3): Between the TeeJet TP11004VP standard, and TeeJet DG11004VS Drift Guard flat fan nozzles, there is no significant difference in the degree of drift of created drops in a wind tunnel by the operating pressure of 4.0 bar and wind velocities of 2.0 m s^{-1}, 4.0 m s^{-1}, and 6.0 m s^{-1}.

- (thesis 4): Based on the results of the drift measurements performed in a wind tunnel on the nozzles AIXR11004VP and TeeJet AI11004VS I state, that in case of Air Induction flat fan nozzles by an operating pressure of 3.0 and 4.0 bar, and a wind velocity of 4.0 and 6.0 m s^{-1} there is no significant difference in the degree of drift of the drops produced, and there is no detectable difference concerning the environment loading effects coming from their use.

- (thesis 5): Based on the results of the inspections of drop production of the TwinFluid 042/TK-SS10 nozzle I state, that in case of TwinFluid nozzles equipped with deflector nozzle by an air-pressure of 1.25 bar no significant change occurs in the 10 % volume drop diameter of the drops generated and in the rate of occurrence of droplets smaller than 100 μm by changing the liquid pressure between 2.00 - 2.50 bar, and in case of a liquid pressure of 1.50 bar due to changing the air pressure within the range 0.50 - 0.75 bar.

- (thesis 6): Based on the results of the drift measurements performed in a wind tunnel on the nozzle TwinFluid 042/TK-SS10 I state, that during the use of nozzles with TwinFluid system equipped with deflector nozzle, in case of an air-pressure of 1.25 bar the changing of the liquid pressure within the range of 2.00 - 2.50 bar by a wind velocity of 4.0 m s^{-1}, and 6.0 m s^{-1} does not result in a significant change concerning the degree of drift of the drops created, thereby the environment damaging effects cannot be influenced.

4. CONCLUSIONS, RECOMMENDATIONS

Drawn from the results recorded and jointly assessed concerning the total drop production characteristics (d_{v10}, d_{v50}, d_{v90} and the ratio of drops smaller than 100 µm) of the TeeJet TP11004VP (conventional), DG11004VS (Drift Guard), AIXR11004VP (Air Induction Extended Range) and AI11004VS (Air Induction) flat fan nozzles identified by measurement the conclusion shows that by decreasing the operating pressure the size of the droplets created increases, the inclination of the particles to drift moderates. The conclusion was drawn on the basis of the fact that the three d_v values tested by an operating pressure of 4.0 bars was lower for all four flat fan nozzles, and the rate of occurrence of drops smaller than 100 µm increased in case of all nozzles related to the data registered by an operating pressure of 3.0 bar.

From the data of the drift measurements in a wind tunnel (including one of my new scientific results) I was led to the conclusion that drops produced on a lower pressure drift away in a smaller amount and to a smaller distance. This conclusion was based on the fact that the fixed total relative coverage in case of a wind velocity of 4.0 m s^{-1} for the DG nozzle was identical, while in case of the other three nozzles it was higher by 4.0 bar than by 3.0 bar, and by a wind velocity of 6.0 m s^{-1} a higher total relative coverage was identified for all nozzles as a consequence of increasing pressure. Besides, the value of the coverage identified by the marked measurement points (except for the one under the nozzle) and/or the distance from the nozzle of the coverage in a degree of ≥1 % also increased due to the increase in pressure.

Based on the above results and conclusions I accepted my hypothesis No. 1 as true.

From a practical aspect it can be useful to recommend that before starting spraying and even during the treatments (especially lacking no wind conditions) special care should be taken of selecting the right operating pressure and keeping it on a constant value as the pressure significantly influences the drop production of the nozzles mounted on the sprayer, therefore, it plays an outstanding role in the work quality and efficiency, and in relation to the environmental effects of spraying.

The test results concerning the four drop production characteristics together show that by both preset pressure the nozzle type TP generated the droplets smallest in size, and the order of the rest of the types (irrespective of pressure) was the following concerning particle size: DG → AIXR → AI. These data led me to the conclusion that the smallest particles are produced during the use of conventional flat fan nozzles, the types Drift Guard create larger droplets, and using Air Induction flat fan nozzles the drop size may even be further increased.

Therefore, my hypothesis No. 2 also seemed to prove true, that is I expected to be able to draw conclusions totally in accordance with the above in connection with the small size drops generated by the nozzles and the degree of drift that is the data concerning parameters mostly influencing possible environmental effects.

The results concerning the d_{v10} and the rate of occurrence of particles smaller than 100 μm and the total relative coverage registered were performed separate from the characteristics identified by the other measurements, however, after its detailed assessment and statistical analysis I could only drew lessons partly supporting the above mentioned.

Based on the data and conclusions below I considered by hypotheses No. 2 partly true, at the same time hypothesis No. 3 was discarded as it proved to be false.

By both test pressure d_{v10} was the lowest in case of the nozzle type TP, and the ratio of drops smaller than 100 μm was the highest. The total relative coverage value identified in a wind tunnel, except for one, was high in case of both operating pressure and all three wind velocities.

Based on the test results concerning the nozzle TP11004VP the application of conventional flat fan nozzles for field-spraying - in no wind conditions - may be advantageous as no considerable drift is expectable, and due to the large amount of small droplets the amount of chemicals and water can be reduced, achieving favourable work quality. However, it may be a disadvantage that delivering the drops generated to the target surface may come up against difficulties as the large amount of small particles with low kinetic energy (rather inclined to drift) may easily evaporate, furthermore, even by a gentle breeze (wind velocity < 2.0 m s^{-1}) drift may occur, therefore increasing the risk of environment pollution.

In case of the nozzle type DG d_{v10} singificantly increased by both preset pressure, and the rate of occurrence of particles smaller than 100 μm significantly decreased related to the TP nozzle. It comes from these results that due to the spacial insert located in the nozzle the Drift Guard flat fan nozzles are suitable for producing small droplets with a high inclination for drift in a smaller amount than the standard flat fan nozzles.

Based on this it was supposed that the type DG significantly decreases the degree of drift related to the TP type irrespective of the pressure and the wind velocity. However, during the inspections of drop production it was also found in connection with the DG nozzle that d_{v10} was relatively low for both pressure values, and the droplets smaller than 100 μm were present in a considerable amount.

The results of drift measurements in a wind tunnel did not prove my hypothesis to be true. The nozzle type DG was able to significantly decrease the total relative coverage by a pressure of 3.0 bar only by a wind velocity of 6.0 m s^{-1}, related to the nozzle TP, and by a pressure of 4.0 bar - as a new scientific result - there was no significant difference by any wind velocity values between the two nozzles concerning the parameter mentioned above.

Based on the assessment and analysis of the results of inspections of drop production and drift measurements performed, on the whole the conclusion can be drawn that, although the DG11004VS flat fan nozzles create less small particles extremely inclined to drift related to the nozzles type TP, even so the right for their name Drift Guard and their suitability for fulfilling their function can be questioned as they cannot undoubtedly decrease the degree of drift of the spray drops produced.

The conclusion coming from the above results is that during the field-spraying performed using DG11004VS Drift Guard flat fan nozzles the amount of substance used related to the conventional flat fan nozzles cannot be decreased, no work quality improvement is expectable since less smaller drops are generated, and the degree of drift cannot certainly be reduced, therefore, their use in practice is not recommended.

The AIXR and AI type nozzles provided significant increase concerning d_{v10} even by an operating pressure of 3.0 and 4.0 bar related to the TP and DG types, and the rate of occurrence of drops smaller than 100 μm was also significantly decreased related to the other two nozzles.

The value of the total relative coverage identified within the framework of drift measurements were - except for one - significantly smaller by both operating pressure and all three wind velocities in case of AIXR and AI than by the other two nozzle types.

Based on these results the advantages of using Air Induction flat fan nozzles can be approached from two sides. The inclination to drift of the drops produced by them is much lower than that of the particles generated by the standard and the Drift Guard flat fan nozzles as there are air bubbles in them.

This characteristic has a good chance to provide for the safe reaching of the surface to be treated, that is their use even in stronger wind (even 6.0 m s^{-1}) can significantly decrease drift endangering the environment, and the droplets containing air explode when hitting the target surface creating smaller particles, providing for the sufficiently even and sufficient coverage and proper work quality.

Based on my new scientific results according to which there was no significant difference concerning the total relative coverage characterizing the degree of drift of the particles generated, and the d_{v10} characteristic of the drops created, and the percent ratio of the droplets smaller than 100 μm between the AIXR11004VP Air Induction Extended Range and the AI11004VS Air Induction flat fan nozzles neither by an operating pressure of 3.0 bar, nor by 4.0 bar, I found the following conclusion. Despite of their significantly different construction from a technical aspect (dimensions; design and location of the boreholes for air induction; the design of the nozzle insertion and chamber determining the flowing conditions, etc.) it can be expected that the amount of the small drops produced by the two given nozzles, the drift inclination of the particles, and the drift reducing capacity of the nozzles are the same.

Both Air Induction nozzles can, therefore, be recommended for satisfactory quality, environmentally sound field-spraying. In case you have to choose from the types AIXR or AI, it is enough to find the balance between the sensibility coming from the dimensions of the nozzles, and the purchase price. These characteristics are more favourable in case of the AIXR nozzles.

According to the conclusion based on the joint evaluation of the data gained concerning the total drop production characteristic measured with the TwinFluid 042/TK-SS10 nozzle used on John Deere sprayers, the total size of the drops increases in order with the following settings: Setting No. 1 (liquid pressure: 2.00 bar, air pressure: 1.25 bar) → Setting No. 2 (2.50 bar, 1.25 bar) → Setting No. 3 (1.50 bar, 0.75 bar) → Setting No. 4. (1.50 bar, 0.50 bar), since the values of the three tested d_v (except for one) increased in this order, while the rate of occurrence of the small drops decreased according to that.

From these data my hypotheses No. 4 seemed to be right, although, I expected that based on the detailed evaluation and statistical analysis of the results gained concerning the key parameters from an environmental aspect, conclusions in accordance with those above can be drawn.

However, with the results and teachings below my hypothesis No.4 could only be accepted as ture in connection with four pairs of settings.

Changes from setting 1 to settings 3 and 4, and the changes from setting 2 to settings 3 and 4 (1. ↔ 3. and 1. ↔ 4., and 2. ↔ 3. and 2. ↔ 4.) resulted in significant differences for the four marked pairs of settings (arrows show the changes in directions) concerning d_{v10} and the rate of occurrence of drops smaller than 100 μm.

The related results of the drift measurements in a wind tunnel were in total accordance with the data given above as in connection with the marked pairs, by all three wind velocities the total relative coverage significantly decreased due to the appropriate direction changes (1. → 3. and 1. → 4., and 2. → 3. and 2. → 4.).

This led me to the conclusion that by the considerable and proper direction changes of the liquid and air pressure together can significantly increase or decrease the amount of small drops - specially inclined to drift - produced by the TwinFluid 042/TK-SS10 nozzles, and at the same time, the degree of drift of the particles created can significantly be reduced together with the distance of drift.

Based on my results and conclusions during field-spraying the amount of spray liquid used can be reduced depending on the existing environmental conditions by the specialistic operation of the TwinFluid nozzles, and the quality of treatments can be improved, and drift can be further reduced.

At the same time, the data on inspections of drop productin gained as new scientific results showed that as an effect of the changes from setting 1 to 2, and from 3 to 4 (1. ↔ 2. and 3. ↔ 4.) no significant changes were found by any pair of settings neither in d_{v10}, nor in the rate of occurrence of drops smaller than 100 µm, that is the inclination to drift of the particles has not significantly changed.

However, according to the results of the drift measurements in a wind tunnel due to changing from setting 3 to 4 (3. → 4.) the total relative coverage identified significantly decreased by all three wind velocities. Therefore, this result did not support my new scientific result, however, concerning settings 1 and 2 - also as a new scientific result - I gained data in accordance with that as in case of wind velocities 4.0 m s^{-1} and 6.0 m s^{-1} the change between the two settings (1. → 2.) did not result in a significant decrease concerning the parameter mentioned above.

From the results of the inspections of drop production it can be concluded that if only the liquid pressure or only the air pressure is changed a little during the operation of the TwinFluid 042/TK-SS10 type nozzle according to the recommendations of the manufacturer, it cannot be certainly expected that the characteristics concerning small droplets change, that is the effect to be made on the quantity of the substance spread out and the work quality, and the inclination for drift of the particles is questionable.

Based on the data of the drift measurements - supporting and complementing the conclusion drawn from drop production test results - I draw the conclusion that with the changing between settings 1 and 2 (1. → 2.) by a wind velocity of 4.0 m s^{-1} or stronger in case of field-spraying the drift of the droplets created by the TwinFluid 042/TK-SS10 nozzle probably cannot be reduced, that is the live and inorganic environmental elements contaminated by drifted spray, and furthermore, the distance of drift related to the contamination source.

To sum it up it can be stated that the practical use of the nozzle type TwinFluid 042/TK-SS10 requires high level skills and intensive care. Information conveyed by the company manufacturing the nozzle, and the traders wishing to sell these technical solution in large quantities should be treated with reservations, it is worth taking the help of a skilled expert before starting spraying, and, furthermore, even during protective activities.

5. PUBLICATIONS RELATED TO THE TOPIC OF THE DOCTORAL THESIS

5.1 Edited, full text scientific communication published in scientific journals

Foreign language, article published abroad in an impact factor journal

1. GULYÁS Z., SZOBOSZLAY S. és FENYVESI L. (2012): Liquid atomization and spray drift measurement in a wind-tunnel for twin fluid system with a deflector nozzle. *Turkish Journal of Agriculture and Forestry*, 36 (4) 469-475. p. (doi:10.3906/tar-1107-7, IF 2011: 0,703)

Foreign language, Hungarian published article published in a non-impact factor journal

1. GULYÁS Z. (2006): Test results of chemical saving sprayers. *Hungarian Agricultural Engineering*. (HU ISSN 0864-7410) N° 19/2006 77-79. p.
2. DIMITRIEVITS GY. GULYÁS Z., KOVÁCS L. és MAGÓ L. (2004): Plant-perceiving spraying machine in orchards. *Hungarian Agricultural Engineering* (HU ISSN 0864-7410) N° 17/2004 21-23. p.

5.2 Full text professional, propagation communication, study published in professional journals

Communication published in a professional journal

1. DIMITRIEVITS GY. és GULYÁS Z. (2012): Permetezőfúvókák kiválasztása és szakszerű alkalmazása. *BASF Növényvédelmi Tippek*, 2012/Szántóföldi különszám 19-21. p.
2. DIMITRIEVITS GY. és GULYÁS Z. (2012): Nem elég a hatékony növényvédő szer: jól is kell kiszórni! *BASF Növényvédelmi Tippek*, 2012/3 14-17. p.
3. GULYÁS Z. (2012): Környezetkímélő szántóföldi permetezési eljárások. *Értékálló Aranykorona,* XII. (2) 24-25. p.
4. DIMITRIEVITS GY. és GULYÁS Z. (2012): Közvetlen vegyszerbeadagolású permetezőgép fejlesztése. *Mezőgazdasági Technika*, LIII (1) 6-7. p.
5. GULYÁS Z., SZOBOSZLAY S. és FENYVESI L. (2010): Aktív injektoros, ütközőlapos fúvóka cseppképzés-vizsgálatának, illetve szélcsatornában végzett elsodródásvizsgálatának eredményei. *Mezőgazdasági Technika*, LI (12) 2-5. p.
6. BABLENA A. és GULYÁS Z. (2010): A szántóföldi növényvédelem. *agrárium AGRÁR- ÉS PIACGAZDASÁG*, 20 (2010/9 – Gépesítési melléklet) 10-11 p.

7. GULYÁS Z. és KOVÁCS L. (2010): Korszerű eszközök a növényvédelmi kijuttatás-technikában. *Értékálló Aranykorona*, X (3) 34-36. p.
8. GULYÁS Z. és KOVÁCS L. (2009): Ültetvénypermetezés gazdaságosabban. *agrárium AGRÁR- ÉS PIACGAZDASÁG*, 18 (2009/4) 9-10. p.
9. GULYÁS Z. (2009): Szántóföldi permetezés gazdaságosabban. *agrárium AGRÁR- ÉS PIACGAZDASÁG*, 18 (2009/3) 22-23. p.
10. GULYÁS Z. (2009): A környezetkímélő állománykezelés korszerű műszaki lehetőségei. *Értékálló Aranykorona*, IX (2) 29-31. p.
11. GULYÁS Z. (2009): A permetezés fejlesztési lehetőségei. *Magyar Mezőgazdaság*, 64(4) 20-23. p.
12. DIMITRIEVITS GY., GULYÁS Z. és KOVÁCS L. (2007): Szántóföldi permetezés - hatékonyan. *Magyar Mezőgazdaság*, 62 (12) 22-23. p.
13. GULYÁS Z. (2004): Hogyan csökkentsük a permetlé elsodródását? *Agrárágazat*, V (1) 32-37. p.
14. GULYÁS Z. és KOVÁCS L. (2004): Elsodródás ellen: korszerű fúvókák. *Mezőgazdasági Technika*, XLV (2) 2-3. p.

5.3 Edited book/note (part), propagation book

Book writing, Hungarian

1. DIMITRIEVITS GY. és GULYÁS Z. (2011): A növényvédelem gépesítése. Budapest: Szaktudás Kiadó Ház, 255 p.

5.4 Communication published in Congress publications (concerning ISBN, ISSN or other, authenticated publications)

Full text communication, published in an occasional (not periodical) congress publication, in foreign language, in edited format

1. KOCSIS L. és GULYÁS Z. (2008): Investigation of reduction of the environment damaging effects during spraying. In: TOME 2 (ISBN 978 - 2 - 87286 - 061 - 6) III International Scientific Symposium - Farm machinery and process management in sustainable agriculture, Walloon Agricultural Research Centre (CRA-W), Agricultural Engineering Department, Gembloux, Belgium, 225-229. p.
2. GULYÁS Z. és DIMITRIEVITS GY. (2004): Versuche mit angewandten verlustmindernden technischen Lösungen beim Spritzen. In: VDI-Berichte Nr. 1855, 2004 (ISSN 0083-5560; ISBN 3-18-091855-1) 62. VDI-MEG Internationale Tagung Landtechnik, Dresden, Germany, 455-462. p.

Full text communication, published in an occasional (not periodical) congress publication, in Hungarian, in edited format

1. DIMITRIEVITS GY., GULYÁS Z. és KOVÁCS L. (2007): Környezetkímélő, vegyszertakarékos permetezési eljárások. In: Konferencia-Kiadvány 2. kötet (ISBN: 978-963-611-443-5ö; ISBN: 978-963-611-445-9) XXXI. MTA-AMB Kutatási és Fejlesztési Tanácskozás az agrárgazdaság gépesítéséről, Szent István Egyetem Gépészmérnöki Kar, Gödöllő, 23-26. p.
2. DIMITRIEVITS GY., KOVÁCS L., GULYÁS Z. és SALLAI P. (2005): A gyümölcsfa permetezés korszerű műszaki lehetőségei. In: Konferencia-Kiadvány 1. kötet (ISBN: 963 611 429 3 ö; ISBN: 963 611 430 7) XXIX. MTA-AMB Kutatási és Fejlesztési Tanácskozás az agrárgazdaság gépesítéséről, Szent István Egyetem Gépészmérnöki Kar, Gödöllő, 50-52. p.

Single sided foreign or Hungarian summary based on a lecture held or a poster presented

1. KALMÁR I., KALMÁRNÉ VASS E., NAGY V. és GULYÁS Z. (2010): Szántóföldi mérések a permetezőgépek keretlengései csökkentésének megalapozásához. In: Az előadások és konzultációs témák tartalmi összefoglalói magyarul és angolul (ISBN: 978-963-269-165-7) MTA-AMB Kutatási és Fejlesztési Tanácskozás Nr. 34. A mezőgazdasági energia előállítás, az energia növények termesztése, betakarítása, előkészítése és felhasználása, Szent István Egyetem Gépészmérnöki Kar, Gödöllő, 46. p.
2. KALMÁR I., KALMÁRNÉ VASS E., NAGY V. és GULYÁS Z. (2010): Próbapadi mérések a haladási sebesség permetfedettségi jellemzőkre gyakorolt hatásának demonstrálásához. In: Az előadások és konzultációs témák tartalmi összefoglalói magyarul és angolul (ISBN: 978-963-269-165-7) MTA-AMB Kutatási és Fejlesztési Tanácskozás Nr. 34. A mezőgazdasági energia előállítás, az energia növények termesztése, betakarítása, előkészítése és felhasználása, Szent István Egyetem Gépészmérnöki Kar, Gödöllő, 32. p.
3. GULYÁS Z. (2006): Vegyszertakarékos permetezőgépek vizsgálata. In: Konferencia-Kiadvány (ISSN: 0237-9902) XXXI. Óvári Tudományos Nap - Élelmiszer Alapanyag-előállítás - Quo Vadis?, Nyugat-Magyarországi Egyetem Mezőgazdaság- és Élelmiszertudományi Kar, Mosonmagyaróvár, 112. p.

5.5 Communication published in Congress publications (concerning unauthenticated publications)

Single sided foreign or Hungarian summary

1. GULYÁS Z. (2009): Test of technical solutions for reduction of the environment damaging effects of spraying. In: Skróty referatów (Book of Abstracts) Wirtualny Instytut Rolnictwa Zrównowazonego (WIRZ) Konferencja Naukowo-Techniczna - "Nowe techniki i technologie w rolnictwie zrównowazonym", Kielce, Poland, 34. p.
2. DIMITRIEVITS GY., GULYÁS Z. és KOVÁCS L. (2004): Results of environmentally friendly spray application techniques in Hungary. In: Book of Abstracts International Conference „Environmentally Friendly Spray Application Techniques", Warsaw, Poland, 149. p.