International Scholars Journals

Advances in Food Science and Technology ISSN: 6732-4215 Vol. 7 (7), pp. 001-011, July, 2019. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Spray distribution uniformity of different types of nozzles and its spray deposition in potato plant

Bahadir Sayinci* and Saim Bastaban

Ataturk University, Faculty of Agriculture, Department of Agricultural Machinery, 25240, Erzurum, Turkey.

Accepted 15 April, 2019

Spray distribution uniformity on sampling posts and spray deposition in potato plants were investigated with six different types of spray nozzles (standard flat fan, hollow cone, air induction and twin jet hydraulic nozzles, spinning disc nozzle and air assisted rotary atomizer). Spray pressures were 4 bar for the hydraulic nozzles and 1.5 bar for the spinning disc nozzle and air assisted rotary atomizer. All trials were conducted at 6.0 km h^{-1} travel speed. For the spray distribution uniformity, three different sampling materials (petri dish, water sensitive paper and aluminum strip) on the sampling posts were used. Spray mixture containing water and brilliant blue was used as spray liquid. The concentration of spray samples were corrected with the calibration of the degradation of the dye exposed to direct sunlight and in a dark ambience. The air induction and twin jet nozzles had the lowest means in coefficient of variation (CV%) at all sampling materials. The highest deposit at the middle of the plants was provided with the air induction and twin jet nozzles. The hollow cone nozzle had the lowest mean in deposition at the bottom of the plants. The amount of dye with the air assisted rotary atomizer transferring the top, middle and bottom of the plants respectively, 35.2, 38.9 and 37.2% was found to be deposited on the underside of the leaves.

Key words: Hydraulic nozzle, spinning disc nozzle, rotary atomizer, spray deposition, spray uniformity, potato, pesticide application.

INTRODUCTION

Pesticides used against the factors which cause damage to the cultivated plant are more preferable to other agricultural control methods (Yildirim, 2008). This is because the effects of pesticides have a fast and easy application period. The total annual world pesticide production is approximately 3 million tons (Delen, 2008). In Turkey, the average annual production is 33 thousand ton; insecticide forms 47%, herbicide forms 24%, fungicide forms 16% of this production (Turabi, 2007). Pesticide consumption in Turkey (just as the active ingredient) in 2002 was 12.2 and 18.3 tons in 2006 with an increase of approximately 50 and 24.2% increase in 2007 was 22.7 tons (Durmuşoğlu et al., 2010).

In Turkey, an important source of carbohydrates, potato (*Solanum tuberosum* L.) is the second after wheat (Taçoğlu et al., 1998). Cultivated area of potato is 160 thousand hectares, production is 4.2 million tons and yield is 26 tons ha^{-1} (FAO, 2005). It was stated that approximately 85% of potato producers in Northeast of Turkey used the pesticide to control of diseases and pests, the major problems in the production were the mycoplasma, the solanacearum and the Colorado potato beetle was the most important harmful factor. It was determined that about 97% of potato producers in this region were struggling with Colorado potato beetle (Kara et al., 2006).

The standard flat fan with 110º fan angles and hollow cone nozzles are widely used in the conventional field sprayers in Turkey (Aksoy and Bayat, 1996; Dursun et al., 2005). But droplets produced by standard type of nozzles hold by the upper leaves of the plant first, it is hardly reached to the leaves of the plant close to the soil and to the lower surface of leaves (Zeren and Bayat, 1986). The standard flat fan nozzles are suitable for herbicide applications and they are also used for

*Corresponding author. E-mail: bsayinci@atauni.edu.tr. Tel: +90 442 2312692. Fax: +90 442 2360958.

insecticide and fungicide applications (Zhu et al., 2004). Hollow cone nozzles were designed to increase the spray coverage (Srivastava et al., 1993). Air induction nozzles create a spray with large droplet sizes and air inclusions that gives good control of spray drift (Womac et al., 2001). Twin jet nozzles produce two separate flat fan spray sheets, whereby the front spray sheet might slightly disturb the plant and open up space for droplets from the trailing spray sheet to better penetrate some plants (Zhu et al., 2004). Spinning disc nozzles spraying in low volume uses centrifugal energy to produce the droplets (Frost, 1981). Spinning disc nozzles produced droplets of 80 to 90 µm (at 5000 rpm and 0.144 L min^{-1} flow rate) and 130 to 140 µm (at 3500 rpm and 0.288 L min^{-1} flow rate) (Holland et al., 1997). Air assisted spray units have been developed with the aim of enhancing spray penetration, reducing the spray drift and providing a homogeneous coating on the target surface (Panneton et al., 2000). The deposition efficiency of droplets transferred on the underside of the leaf with the air flow was stated to be higher than hydraulic nozzles (Holownicki et al., 2000).

Uniformity of volumetric distribution is the most important indicator of the nozzle performance (Wang et al., 1995). In the measurements made by Prairie Agricultural Machinery Institute (PAMI, Canada) under laboratory conditions at stationary patternator, it was reported that the spray distribution was acceptable for 15% of the variation (Bode et al., 1983; Azimi et al., 1985). In most research, uniformity of volumetric distribution of spray nozzles have been identified in the laboratory using patternator (Krishnan et al., 1988; Ozkan et al., 1997; Womac et al., 2001; Sidahmed et al., 2004; Bayat and Yarpuz-Bozdogan, 2005). But, in field conditions, the number of the researches to determine the uniformity of spray distribution of spray nozzles is few. Also researches related to compared the spray application performances of air induction nozzles and air assisted rotary atomizer have not been found.

In this study, orifice sizes with the same four different types of hydraulic nozzles (standard flat fan (FF), hollow cone (HC), air induction (AI) and twin jet with air induction nozzles (TJ)), spinning disc nozzle (SD) and air assisted rotary atomizer (RA) were used. The objectives of this study were (1) to compare the distribution uniformity of the dye deposited on the artificial target surface and transferred to the artificial target by the spraying nozzles in open-air conditions and (2) to determine its efficiency on spray deposition of potato plants.

MATERIALS AND METHODS

Spray nozzles

Spray application performance was evaluated with four different types of hydraulic nozzles: Standard flat fan nozzle (FF) (Tecsi SRL, FF 11002, Treviglio (BG), IT), hollow cone pattern nozzle (HC) (Tim Ø1.0, Timsan Ltd., İst., TR), air induction nozzle (AI) (Agrotop, AI 11002 GmbH, Obertraubling, DEU) and twin jet with air induction (TJ) (Albuz AVI TWIN 11002, Ceramiques Techniques Desmarguest, Exreux, FRA) (Figures 1a to d). All nozzles were mounted 0.5 m above the top of targets and spaced 0.5 m apart. The operating pressure for all hydraulic nozzles tested was 4 bar. The flow rates of the nozzles were 0.83, 0.87, 0.90 and 0.90 L min^{-1} for the standard flat fan nozzle, hollow cone nozzle, air induction nozzle and twin jet nozzle, respectively. Sprays were discharged toward the target with an average rate of 175 L ha^{-1}.

Spinning disc nozzle (SD) (Micromax®, Controlled Droplet Application, CDA, Micron Sprayer Ltd., Bromyard, UK) was used for low volume applications (Figure 1e). The nozzles were mounted 0.3 m above the top of targets and spaced 1.1 m apart. The flow rate of this nozzle at 1.5 bar was 0.66 L min^{-1}. Sprays were discharged with a rate of 64 L ha^{-1}. Disc inclination angle was 30º according to vertical (Bode et al., 1983) and mounted in the opposite travel direction of the tractor. Discs were actuated by 12 V DC motor. Rotation speed of disc could be adjusted with the belt-pulley (Micron, 2008). The spinning disc nozzle was operated at a disc speed of 4500 rpm.

Sixth spray nozzle in the study were the air assisted rotary atomizer (RA) (Proptec™ Rotary Atomizer, RA, Ledebuhr Industries, Inc., MI, US) (Figure 1f). The nozzles were mounted 0.7 m above the top of targets and spaced 1.4 m apart. The flow rate of this nozzle at 1.5 bar was 1.32 L min^{-1}. Sprays were discharged with a rate of 94 L ha^{-1}. Rotary atomizer inclination was 45º and mounted in the travel direction of the tractor. Rotary atomizer, 12 mesh cages around the spinning disc, was 152 mm diameter. Air flow was provided with five blades fitting the shaft of the rotating cage and when air speed reached 30 km h^{-1}, air flow rate was 300 m^3 h^{-1}. Optimum operation revolution of the fan was the range of 1550 to 5000 rpm. The shaft fitting the fan and spinning cage was rotated by hydraulic motor. Maximum power requirement of the hydraulic motor driven from the tractor was 4.5 kW; pressure requirement was 166 bar. The optimum flow rate of hydraulic fluid was 15 L min^{-1} (Ledebuhr, 2008). Air speed was measured in the range of 20 to 25 km h^{-1} when the disc speed reached 3500 rpm.

Tractor and sprayer

In the study, a field tractor (Ford 5000 S), engine power of 49.4 kW, was used. The forward speed was controlled by speed radar (DJRVS II model, DICKEY-John Corp., Auburn, IL). All the trials were carried out in the travel speed of 6 km h^{-1}. During the trials, a field sprayer (Taral A.Ş., İstanbul, TR) having 600 L of tank capacity was used. Volumetric pressure control unit (Arag®, Rubiera, IT) was located at the sprayer.

Tracing material

Spray mixture contained water and blue dye in powder form namely “Brilliant Blue (FD&C Blue No. 1, AJANTA Food Colours Chemical Ind., IN)”. Quantitative measurements were made using a spectrophotometer (T60U, PG Instruments, Ltd., UK) set to wavelength of 629 nm. The FD&C dye was applied at 160 g L^{-1}. Dye solutions washed from the sampling surfaces were compared with a calibration from known washed deposits to determine dye deposition by each spray nozzle, on artificial surfaces and location within the plant canopy, leaf side. The amount of the dye deposits in per unit area was determined with the unit of µg cm^{-2}.

The degradation of brilliant blue exposed to direct sunlight and in dark ambience was determined. Three of volumes spray mixture (30, 60 and 90 µl) with a concentration of 1000 mg L^{-1} was deposited into two groups of 108 petri dishes. Twelve petri dishes were used for each of the volume and trials were replicated three

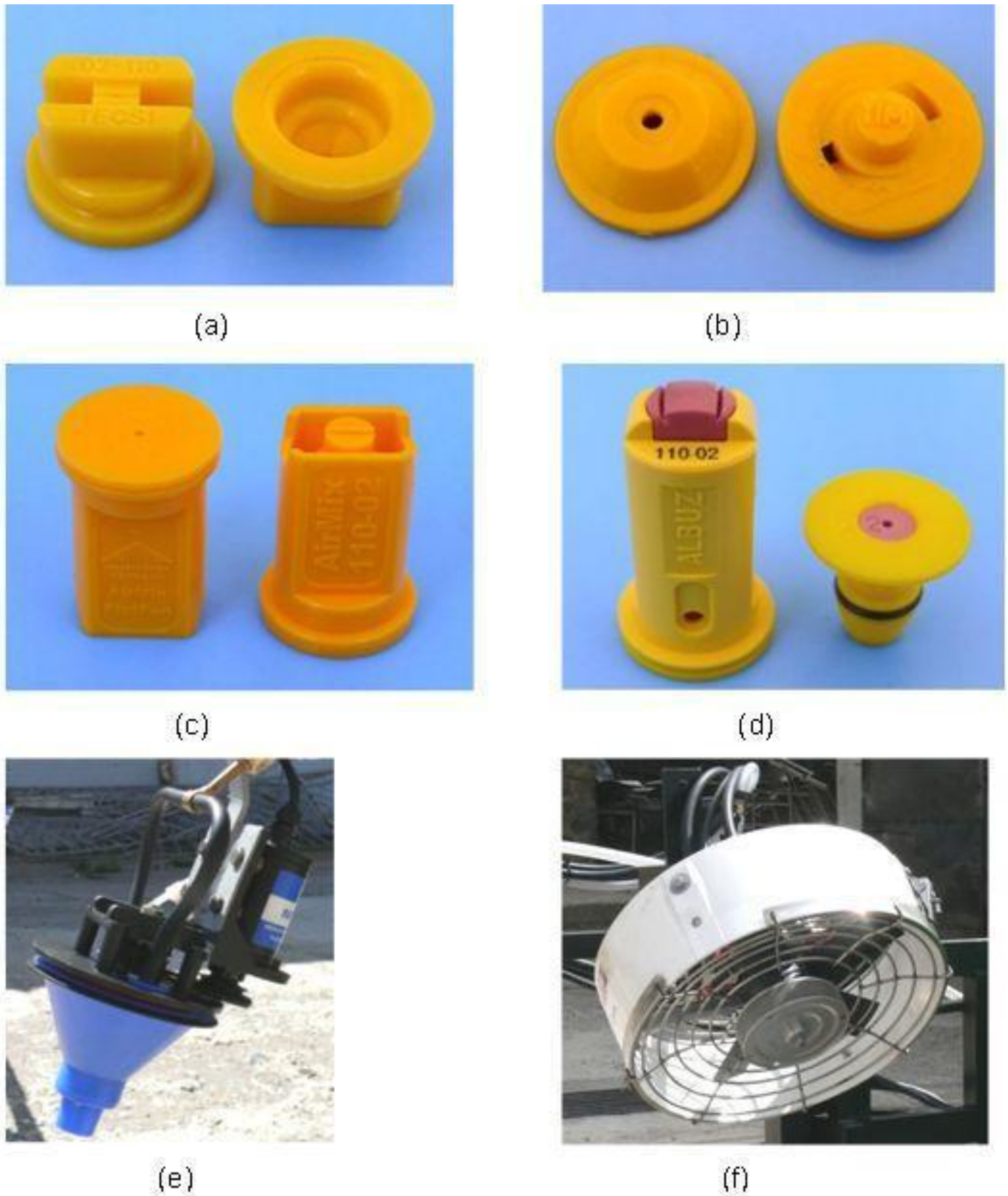

Figure 1. Spray nozzles (a) standard flat fan nozzle, FF, Tecsi SRL 11002 (b) hollow cone nozzle, HC, Tim Ø1.0 (c) air induction nozzle, AI, Agrotop 11002 (d) twin jet with air induction nozzle, TJ, Albuz AVI TWIN 11002 (e) spinning disc nozzle, SD, Micromax®, CDA (f) air assisted rotary atomizer, RA, Proptec^{TM} rotary atomizer.

times at the same time. Petri dishes in the first group were stored in a dark cabinet at an ambient temperature 25ºC. The second group was placed outside and exposed to direct sunlight at an ambient temperature interval of 22 to 24ºC. Nine samples were then taken from each group at 15 min intervals and dissolved in 25 ml water for concentration analysis. The degradation of dye under different conditions over time was used to adjust the sample reading on the spectrophotometer.

Data were analyzed by two-way ANOVA using SPSS package software (SPSSX, 2004). To ensure homogeneity of variance, the square root transformation was applied to all data. All significant differences were determined at the 0.05 level of significance.

Trials on sampling posts

The first trial was conducted on a concrete floor in 10×150 m area. Instead of plant, 20 sampling posts (Ø21 mm) which are 40 cm long were placed to the spraying area. Posts were placed 0.70×5.0 m nominal distance in 4×5 grid form. Three different sampling surfaces were held to the sticks which were mounted to the top, middle and bottom of the posts with a clip. Petri dishes (Ø85×14 mm) were used to determine the amount of dye transferred to the target; aluminum strips (2×3 cm) were used to determine the deposition efficiency of the drops on the target surface; water sensitive papers (WSP, 26 × 38 mm, Novartis, Syngenta Crop

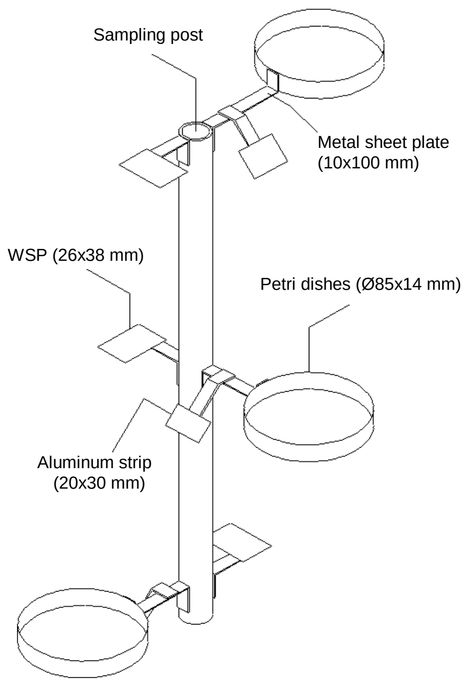

Figure 2. The artificial sampling materials on the sampling post.

Figure 3. Washing the leaf samples with the dual-side washer.

Protection, Basel, CH) were used to determine the spray coverage. Petri dishes and water sensitive papers were situated parallel with ground plane; as for aluminum strip samples, they are situated towards ground plane with 45º angle. Sampling surfaces which were placed top, middle and bottom of the posts have been kept in different directions with height. The schematic shape of the sampling post was shown in Figure 2.

All trials were repeated three times for each of the nozzle. After spraying, distilled water of 25 ml were placed in Petri dishes and mixed about 10 to 15 s. Aluminum strip samples were placed in sterile plastic cap and washed with distilled water of 25 ml. Solutions washed from the sampling surfaces (Petri dish and aluminum strip) were put in glass tubes and their absorbance were determined using the spectrophotometer.

Field experiment plan and sampling

Field experiments were conducted at Ataturk University Agricultural, Faculty Farm (Erzurum in Turkey). Experiment was established according to randomized block design. The research was conducted in three blocks, and each of them, six plots of 49 m^2 (4.2×12 m) were located. The distance between plots was 20 m. In this study, Marfona cultivar of potato seed was used. Potato planting was performed in furrow procedure. Tubers were planted in six rows, between row spacing was 0.70 m and over row spacing was 0.40 m. Fertilization, maintenance and irrigation procedures were performed according to the region.

Field experiments began after 75 days from planting and were completed in 10 days. During this period, plant height was about 46 cm, plant width was 60 cm. Before spraying, from the three rows in the middle of a test plot, four plants were chosen randomly. Upper and under surfaces of each of the four leaves from top, middle and bottom of the plant were washed separately using dual-side leaf washer shown in Figure 3. Washing process was made with an apparatus similar to washer which Scudeler and Raetano (2006) used in researches. Two screw-mouthed glasses tube (Ø16×100 mm) were inserted to the dual side leaf washer. Five milliliter of

Table 1. Meteorological data summary.

	Trials conducted with the artificial targets		Trials conducted in the field conditions	
	Mean	Min-max	Mean	Min-max
Temperature (ºC)	24	20-29	29	24-34
Relative humidity (%)	26	13-44	28	17-38
Wind speed (m s^{-1})	0.8	0.0-3.6	2.3	0.0-6.3

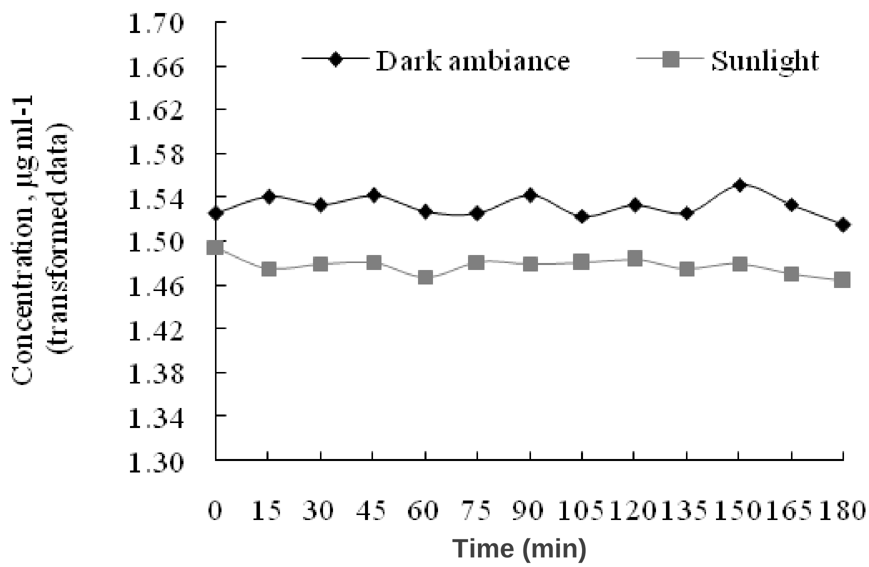

Figure 4. Degradation of dye exposed to direct sunlight and in the dark ambience.

distilled water was used to wash the leaf surface. Two different washers were used whose sampling areas were 2.7 and 3.8 cm^2 in the study. After the washing process, glass tubes were placed in tube stands and absorbance readings were made at spectrophotometer.

Sayinci and Bastaban (2009) stated that the dye concentration of 2.194 µg ml^{-1} increased to 2.335 µg ml^{-1} after the leaves immersed in dye solution. The dye materials washed from the leaves of the potato plants were multiplied by the concentration ratio of 2.194/2.335.

Meteorological data was measured by wireless weather station. All measurements were taken from a similar spraying height as the spray application test. Meteorological data summary were given in Table 1.

Water sensitive papers (WSP) were scanned at resolution of 600 dpi (Marçal and Cunha, 2008). WSP images were saved as gray, and with the extension *. jpg image file. Spray coverage was determined by UTHSCSA Image Tool 3.0 (The University of Texas Health Science, TX) image processing software (Zhu et al., 2008).

For each replication of the experiment, mean data ($\bar{x}$) at the top, middle and bottom of the target and their standard deviation (SD) was computed. Spray distribution uniformity (CV%) was determined by equity of [CV% = (SD / mean) × 100].

Statistical analysis

All data in the trials carried out on the sampling posts was subjected to ANOVA in repeated measures according to completely randomized design. In the trials in which artificial targets were used, repeated measurement factor was the sampling heights (top, middle and bottom). In the experiments conducted in field conditions, all the data was subjected to repeated measures of ANOVA according to the randomized block design. The leaf surfaces (upperside and underside of the leaf) were the repeated measurement factor. Differences between the means found significant were compared with Duncan's multiple range test in 0.05 significance level using SPSS package software (SPSSX, 2004).

RESULTS

Degradation of tracing material

Concentration changes of the dye solutions which were exposed to direct sunlight and in the dark ambience during 180 min were shown in Figure 4. The concentrations of the dye solutions in both ambiences were found to be different. Change of concentration of 180 min layover time was found to be negligible. Mean concentration and standard error of the solutions which were placed to the dark ambience was 1.532±0.038 µg ml^{-1} and confidence interval of the mean was 1.524 to 1.540 µg ml^{-1} in 95% significance level. Mean

Table 2. Comparing the spray distribution uniformity (CV%) according to the amount of the dye transferred to the target.

Spray nozzles	Top	Middle	Bottom	All
FF	23.1(15.5 - 30.6)	34.0(26.3 - 41.7)	38.1(29.9 - 46.4)	31.7 b[1](26.0 - 37.5)
HC	42.2(34.6 - 49.7)	44.4(36.6 - 52.1)	34.6(26.4 - 42.9)	40.4 c(34.6 - 46.1)
AI	12.4(4.9 - 20.0)	16.9(9.2 - 24.6)	19.9(11.6 - 28.1)	16.4 a(10.7 - 22.1)
TJ	17.4(9.9 - 25.0)	19.3(11.6 - 27.1)	21.1(12.8 - 29.3)	19.3 a(13.5 - 25.0)
SD	49.1(41.5 - 56.7)	49.0(41.3 - 56.7)	41.4(33.2 - 49.7)	46.5 c(40.8 - 52.3)
RA	35.0(27.4 - 42.5)	46.8(39.1 - 54.5)	50.0(41.7 - 58.2)	43.9 c(38.2 - 49.6)

[1]: Confidence intervals of mean at 95% significant level; means in a column followed by different letters are significantly different ($p<0.05$).

Table 3. Comparing the spray distribution uniformity (CV%) according to the spray coverage.

Spray nozzles	Top	Middle	Bottom	All
FF	24.3(10.5 - 38.0)	36.7(26.1 - 47.3)	37.0(27.3 - 46.8)	32.7 bc[1](26.0 - 39.3)
HC	29.1(15.4 - 42.8)	45.8(35.2 - 56.4)	31.0(21.3 - 40.8)	35.3 c(28.7 - 42.0)
AI	21.8(8.0 - 35.5)	20.6(10.1 - 31.2)	23.5(13.7 - 33.2)	22.0 a(15.3 - 28.6)
TJ	16.1(2.3 - 29.8)	23.7(13.2 - 34.3)	31.0(21.2 - 40.7)	23.6 ab(16.9 - 30.2)
SD	49.4(35.7 - 63.2)	43.3(32.8 - 53.9)	45.1(35.4 - 54.9)	46.0 d(39.3 - 52.6)
RA	51.5(37.7 - 65.2)	54.2(43.6 - 64.8)	46.0(36.2 - 55.7)	50.5 d(43.9 - 57.2)

[1]: Confidence intervals of mean at 95% significant level; means in a column followed by different letters are significantly different ($p<0.05$).

concentration of solutions exposed to sunlight were 1.478±0.031 µg ml^{-1} and confidence interval of the mean 1.472 to 1.484 µg ml^{-1} in 95% significance level. According to these results, when brilliant blue exposed to the sunlight, the concentration of the mixture decreased at a rate of 3.528%. In the trials conducted in open-air conditions, concentration of the dye washed from the artificial and leaf surfaces was multiplied by the rate of 1.532/1.478.

Spray distribution uniformity on the artificial sampling surfaces

The CV means of the dye amount transferred to the target are given in Table 2. Spray distribution uniformity (CV%) values according to the amount of the dye transferred to the target, for the AI and TJ nozzles were statistically different from other nozzles. The best value was for the AI nozzle (16.4%). As seen in Table 2, the AI and TJ nozzles were lower than the other nozzles. The HC nozzle, RA and SD nozzle had the highest CV at means of 40.4, 43.9 and 46.5%, respectively. As the CV values of the FF, HC, AI, TJ nozzles and RA increased from top to bottom of the sampling post, CV value of the SD decreased. The highest CV value of the HC nozzle was found at the middle of the post (44.4%).

The CV means of the spray coverage were given in Table 3. Value of the AI nozzle (22.0%) was statistically different from the other nozzles. The CV values for the AI and TJ nozzles were lower than the FF (32.7%) and HC (35.3%) nozzles. The RA and SD nozzle had the highest CV at means of 50.5 and 46.0%, respectively. As the CV values of the FF, HC, AI and TJ nozzles increased from top to bottom of the sampling post, CV values of the SD nozzle and RA decreased. The highest CV values of the HC nozzle and RA were found at the middle of the post.

The CV means of the dye amount deposited on the aluminum target surfaces were given in Table 4. Values of the AI (43.4%) and TJ (52.4%) nozzles were statistically different from other nozzles. The means in CV of the other nozzles ranged from 74.1 to 94.6%. The CV values of all hydraulic nozzles had tendency to increase towards to middle from the top. The lowest CV values of the SD nozzle and RA was found at the middle and bottom of the post, 83.4 and 83.1%, respectively.

The mean amount of dye transferred to the target and deposited on the artificial surface with spray nozzles was given in Table 5. As seen in Table 5, the AI (1.570 µg cm^{-2}) and TJ (1.468 µg cm^{-2}) values were statistically different from other nozzles. The HC nozzle had the second highest amount of dye (1.325 µg cm^{-2}). The SD nozzle had the lowest amount of dye transferred to the target (0.817 µg cm^{-2}). The lowest amount of dye deposited on the aluminum strips was obtained with the TJ nozzle (0.671 µg cm^{-2}). Value of the TJ nozzle was

Table 4. Comparing the spray distribution uniformity (CV%) according to the amount of dye deposited on the surfaces .

Spray nozzles	Top	Middle	Bottom	All
FF	68.0 (50.9- 85.2)	78.7(59.7 - 97.6)	83.0 (66.8 - 99.3)	76.6 b[1](62.0 - 91.2)
HC	60.5 (43.4- 77.7)	82.2 (63.3 - 101.2)	79.4 (63.2 - 95.6)	74.1 b(59.5 - 88.6)
AI	34.6 (17.4- 51.7)	39.3(20.4 - 58.3)	56.4 (40.1 - 72.6)	43.4 a(28.8 - 58.0)
TJ	43.5 (26.4- 60.7)	62.1(43.2 - 81.0)	51.6 (35.4 - 67.8)	52.4a(37.8 - 67.0)
SD	102.8 (85.7- 120.0)	83.4 (64.4 - 102.3)	97.5 (81.2 - 113.7)	94.6 b(80.0 - 109.1)
RA	94.4 (77.3 - 111.6)	87.6 (68.6 - 106.5)	83.1 (66.8 - 99.3)	88.3 b(73.8 - 102.9)

[1]: Confidence intervals of mean at 95% significant level; means in a column followed by different letters are significantly different ($p<0.05$).

Table 5. Comparing the amount of dye transferred to the target and deposited on the artificial surfaces (µg cm^{-2}).

Spray nozzles	The amount of dye transferred to the target (µg cm^{-2})	Spray deposits on the artificial target (µg cm^{-2})
FF	1.156 c[1](1.080 - 1.233)	0.844 a(0.761 - 0.927)
HC	1.325 b(1.249 - 1.402)	0.818 a(0.735 - 0.901)
AI	1.570 a(1.494 - 1.647)	0.723 ab(0.640 - 0.806)
TJ	1.468 a(1.392 - 1.545)	0.671 b(0.588 - 0.754)
SD	0.817 d(0.740 - 0.893)	0.835 a(0.752 - 0.918)
RA	1.053 c(0.976 - 1.129)	0.846 a(0.763 - 0.929)

[1]: Confidence intervals of mean at 95% significant level; means in a column followed by different letters are significantly different ($p<0.05$).

Table 6. Comparing the amount of the dye (µg cm^{-2}) deposited on the top, middle and bottom of the potato plant.

Spray nozzles	Top	Middle	Bottom
FF	0.557a[1] (0.468 - 0.646)	0.481 bc(0.391 - 0.570)	0.412 a(0.343 - 0.482)
HC	0.658a (0.569 - 0.747)	0.508 bc(0.419 - 0.597)	0.29 b(0.221 - 0.360)
AI	0.596a (0.507 - 0.684)	0.570 ab(0.481 - 0.660)	0.345 ab(0.275 - 0.414)
TJ	0.703a (0.614 - 0.792)	0.654 a(0.564 - 0.743)	0.432 a(0.362 - 0.501)
SD	0.700a (0.612 - 0.789)	0.402 c(0.313 - 0.491)	0.406 a(0.336 - 0.475)
RA	0.657a (0.569 - 0.746)	0.495 bc(0.405 - 0.584)	0.424 a(0.354 - 0.494)

[1]: Confidence intervals of mean at 95% significant level; means in a column followed by different letters are significantly different ($p<0.05$).

statistically different from other nozzles.

Spray deposition in potato plant

The mean spray deposits at the top, middle and bottom of the potato plant was given in Table 6. At the top of plants, the spray deposits from the all nozzles ranged from 0.557 to 0.703 µg cm^{-2}. There was no statistically difference in spray deposits at the top of plants between nozzles. The AI and TJ nozzles delivered the highest spray deposits at the middle of the plants. The SD nozzle discharged the lowest spray deposit at the middle of the plants. The spray deposits at the bottom of plants from the nozzles except the hollow cone nozzle ranged from 0.345 to 0.432 µg cm^{-2} and the differences between the means was found to be statistically negligible. At the bottom of the plants, the hollow cone nozzle discharged significantly the lowest spray deposits.

The means in CV of spray deposits on the upperside and underside of the leaves were given in Table 7. The CV values of the all spray nozzles, apart from the SD and RA nozzles, on the upperside of the leaves increased towards to bottom from the top of plants. On the

Table 7. Distribution uniformity (CV%) of the amount of the dye deposited on the upperside and underside of the potato leaves.

Leaf side	Spray nozzles	Top	Middle	Bottom
Upperside	FF	57.8(31.3 - 84.3)[1]	62.6(25.9 - 99.3)	73.9(49.7 - 98.2)
	HC	62.5(36.0 - 89.0)	64.0(27.3 - 100.7)	78.5(54.3 - 102.8)
	AI	41.2(14.8 - 67.7)	41.0(4.3 - 77.7)	61.9(37.6 - 86.1)
	TJ	37.1(10.7 - 63.6)	49.7(13.0 - 86.4)	50.0(25.8 - 74.3)
	SD	66.0(39.5 - 92.5)	87.7(51.0 - 124.4)	72.0(47.7 - 96.2)
	RA	76.6(50.1 - 103.0)	102.2(65.5 - 138.9)	79.5(55.2 - 103.7)
Underside	FF	74.8(54.0 - 95.6)	74.7(52.8 - 96.7)	81.2(64.0 - 98.3)
	HC	62.4(41.6 - 83.2)	62.8(40.8 - 84.7)	58.0(40.9 - 75.2)
	AI	79.8(59.0 - 100.6)	96.8(74.9 - 118.8)	71.6(54.4 - 88.7)
	TJ	49.6(28.8 - 70.4)	58.1(36.1 - 80.0)	72.5(55.4 - 89.6)
	SD	67.5(46.7 - 88.2)	58.8(36.9 - 80.8)	67.7(50.6 - 84.8)
	RA	61.6(40.8-82.4)	85.4(63.4 - 107.3)	79.3(62.1 - 96.4)

[1]: Confidence intervals of mean at 95% significant level.

Table 8. Deposition rate (%) on the underside of the leaf of the amount of dye transferred to the top, middle and bottom of the potato plants.

Spray nozzles	Top	Middle	Bottom
FF	18.3(12.9 - 23.7)[1]	11.5(5.7 - 17.3)	12.7(6.2 - 19.2)
HC	18.0(12.6 - 23.4)	17.4(11.6 - 23.2)	21.9(15.4 - 28.4)
AI	11.7(6.3 - 17.1)	10.2(4.4 - 16.0)	13.6(7.1 - 20.1)
TJ	8.9(3.5 - 14.3)	7.1(1.3 - 12.9)	14.1(7.6 - 20.6)
SD	17.9(12.5 - 23.3)	21.8(16.0 - 27.6)	17.6(11.1 - 24.0)
RA	35.2(29.8 - 40.6)	38.9(33.1 - 44.7)	37.6(31.1 - 44.0)

[1]: Confidence intervals of mean at 95% significant level.

upperside of the leaves, the SD nozzle and RA had the highest CV at the middle of the plants. The lowest values in CV on the upperside of the leaves at all parts of the plants were provided with the AI and TJ nozzles. The values in CV on the upperside of the leaves ranged from 41.0 to 61.9% for the AI nozzle, ranged from 37.1 to 50.0% for the TJ nozzle. On the underside of the leaves, as the values in CV for the HC and AI nozzles decreased from top to bottom, for the FF nozzle, TJ nozzle and RA increased. On the underside of the leaves, the lowest CV value in deposition was obtained with the TJ nozzle at the top and middle of the plants and the HC nozzle at the bottom of the plants. The lowest CV value (58.8%) of the SD nozzle was found at middle of the plant.

Deposition efficiency (DE) on the underside of the leaves of the dye transferred to the top, middle and bottom of plants was given in Table 8. In all the parts of the plants, the highest values in DE ranging from 35.2 to 38.9% were obtained with the RA. At the top of the plants, the means of DE (17.9 to 18.3%) for the FF, HC and SD nozzles were found to be statistically similar. At the top and middle of the plants, the TJ nozzle had the lowest the values in DE ranging from 7.1 to 8.9%. At the bottom of the plants, the HC nozzle had the second highest value in DE (21.9%). At this part of the plant, the FF, AI and TJ nozzles provided the lowest values in DE ranging from 12.7 to 14.1% and differences of the means were found to be statistically negligible.

DISCUSSION

Coarse droplets from the AI nozzle (Nuyttens et al., 2007); fine droplets from the FF, HC and SD nozzles (Nuyttens et al., 2007; Qui et al., 2008; Yarpuz--Bozdogan and Bozdogan, 2009a, b); very fine droplets from the RA (Halley et al., 2008) were produced. It was concluded that the spray distribution uniformity of the nozzles that produced coarse droplets was more homogeneous than the nozzles that produced fine droplets. When compared according to the type of the nozzles, the values in CV of the SD and RA were found higher than the hydraulic nozzles.

Zhu et al. (2002) used the Petri dishes to determine the spray penetration of hydraulic nozzles into peanut plants. Womac et al. (2001) used the water sensitive papers to determine the transversal distribution uniformity in spraying of air induction hydraulic nozzles. In this study, the means in CV which were determined with two different sampling materials (Petri dishes and water sensitive paper) were found to be statistically negligible. The most of the means in CV relating to the all spray nozzles was higher than the reference value of 15% reported in previous studies (Bode et al., 1983; Azimi et al., 1985). But, Womac et al. (2001) has also indicated that the means in CV determined from hydraulic nozzles at open air-conditions was higher than that of the static spray pattern uniformity tests.

In the trials carried out on the sampling posts, the findings related to the hydraulic nozzles were found to be consistent with Zhu et al.'s (2004) results. They have stated that the values in CV increased from top to bottom of the peanut plants. Because one of the most important factors affecting the penetration of drops in spray applications is physical properties of the plant, the increasing of the CV value at the middle and bottom of the plants is an expected condition. As a matter of fact, in this study, the means in CV related to the amount of dye deposited on the upperside of the potato leaves for all spray nozzles increased from top to the bottom of the plants.

Smith et al. (2000) indicated that the deposition efficiency of the drop on the target surface changed depending on the size of drop and features of the target surface. In this study, samples of aluminum strips, whose surface is smooth, were used to compare the deposition of the drops produced with the different types of spray nozzles. To ensure the flow of drops from the surface, samples were placed slopped. The values in CV determined from the surface of the aluminum strips were higher than the water sensitive papers and Petri dishes samples. That the deposition resistance of the droplets on the surface of the aluminum strip is low increased the exchange interval of the CV. Therefore, the CV values determined from the aluminum strips with the spray nozzles produced fine and very fine droplets (FF, HC and SD nozzles and RA) were found to be similar.

In this study in which three different sampling surfaces were used, some common results were found for the spray nozzles. Accordingly, the CV values of the AI and TJ nozzles in all sampling surface were found lower than the other spray nozzles. Similarly, the CV values determined at the middle of the post with hollow cone nozzle in three sampling surfaces were higher than the top and bottom of the post. The means in CV of the FF, AI and TJ nozzles increased from top to bottom of the post, whereas the CV means of the SD and RA nozzles decreased. In the trials in which aluminum strip and water sensitive paper were used, the CV values determined with the RA decreased from top to bottom of the post, while they increased in Petri dishes. Accordingly, as the transferring distance of the drops produced with the RA increased, it was concluded that spray distribution uniformity was deteriorated.

Petri dishes used as the sampling surface in the spray deposition give only the idea about the amount of the dye transferred to the target. If the plane, in which droplets sprayed to the target are transferred, thought three dimensional, the deposit of the dye on the sloped surfaces may be different. Indeed, the amount of the dye which was transferred to the Petri dishes with the spinning disc nozzle and air assisted rotary atomizer were found to be lower compared with hydraulic nozzles. However, when the amount of the dye which deposits on the surface of the aluminum strips is investigated, the means in deposition related to the other spray nozzles except the twin jet nozzle were found to be similar. On the other hand, the amount of the dye deposited on the aluminum strip surfaces of the spinning disc nozzle was higher than that of the Petri dishes. These cases seem to prove that the position of the target is important for drop's reaching to the surface.

In this study, the aim of using the surface of aluminum strip is to compare with a big difference the deposition efficiency of the drops produced by the spray nozzles, on surface. Of course, the surface characteristics of the aluminum strip and the potato leaf are not the same. Because the surface of the potato leaf is pubescent, the amount of dye deposited on the leaf surface is expected to be higher than the smooth surface such as aluminum strip. However, because the wind speed measured in field trials was higher than the trials conducted on the sample posts, spray loses increased with the effect of drift. Therefore, the means in deposition on the potato leaves were found to be lower than the aluminum strip samples.

Because the coarse droplets were not able to deposit on the surface and fine droplets transferred outside of the target due to drift, the amount of dye deposited at the top of the potato plants was found to be similar at the all spray nozzles. Zhu et al. (2004) stated that the spray deposits at the bottom of plants tended to decrease linearly, as leaf area index increased. After all, it was stated that the auxiliary air flow applications increased the spray penetration (Womac et al., 1992; Piché et al., 2000a, b). But, spray penetration of the AI and TJ nozzles at the middle of potato plants was found to be higher than the RA. Zhu et al. (2004) stated that spray penetration of full cone hydraulic nozzle was higher than standard flat fan nozzle. The spray penetration of the hollow cone nozzle used in this study was found to be the lowest at the bottom of plants.

On all the sampling surfaces, also including potato leaf, the AI and TJ nozzles had the lowest means in CV; the RA had the highest means in CV. According to the results of the trial conducted on the sampling posts, the transferring efficiency towards to the target of the drops produced from the SD nozzle and RA were lower than the hydraulic nozzles, whereas, a significant portion of the drops transferred in potato plants with the SD nozzle and RA was deposited on the underside of the leaf. That the position angle on boom arm of the SD nozzle was 30º and the spray height was 30 cm was thought to be effective in transportation of the drops towards to the underside of the leaf. Air turbulence from the RA has significant effect for transportation of the drops on the underside of the leaves. In many research, it was stated that air assisted sprayers were more effective than conventional sprayers in the chemical control of pests feeding on the underside of leaves within the bottom zone of the plant (Taylor and Andersen, 1989; Coates and Palumbo, 1997; Holownicki et al., 2000; Bayat and Bozdogan, 2005; Bozdogan and Yarpuz-Bozdogan, 2008).

ACKNOWLEDGMENTS

This study was prepared from Ph. D thesis. This research was funded by Scientific Research Fund of Ataturk University (BAP 2006/20 and BAP 2007/15) and Scientific and Technological Research Council of Turkey (TUBITAK 107 O 262).

REFERENCES

Aksoy H, Bayat A (1996). Micromax tip döner diskli memeye ait işletme karakteristikleri ve ilaç uygulama etkinliğinin saptanmasi. 6. Uluslararasi Tarimsal Mekanizasyon ve Enerji Kongresi. Ankara, 2-6 Eylül., pp. 400-407. [In Turkish].

Azimi AH, Carpenter TG, Reichard DL (1985). Nozzle spray distribution for pesticide application. T. ASAE, 28(5): 1410-1414.

Bayat A, Yarpuz-Bozdogan NY (2005). An air-assisted spinning disc nozzle and its performance on spray deposition and reduction of drift potential. Crop Prot., 24: 651-960.

Bozdogan AM, Yarpuz-Bozdogan N (2008). Determination of dermal bystander exposure of malathion for different application techniques. Fresenius Environ. Bull., 17(12a): 2103-2108.

Bode LE, Butler BJ, Pearson SL, Bouse LF (1983). Characteristics of the micromax rotary atomizer. T. ASAE, 24(4): 999-1004.

Coates W, Palumbo J (1997). Deposition, off-target movement, and efficacy of Capture TM and Thiodan TM applied to cantaloupes using five sprayers. Appl. Eng. Agric., 13(2): 181-188.

Delen N (2008). Fungusitler. Nobel Yayinevi. İzmir, pp. 318. [In Turkish].

Durmuşoğlu E, Tiryaki O, Canhilal R (2010). Türkiye'de Pestisit Kullanimi, Kalinti ve Dayaniklilik Sorunlari. Türkiye Ziraat Mühendisliği 7. Teknik Kongresi. Ankara, 11-15 Ocak, Bildiriler Kitabi, 2: 589-607. [In Turkish].

Dursun E, Çilingir İ, Erman A (2005). Tarimsal savaşim ve mekanizasyonunda yeni yaklaşimlar. TMMOB Ziraat Mühendisleri Odasi 6. Teknik Kongresi. Ankara, pp. 669-686. [In Turkish].

FAO (2005). Statistical database. Available on line in http://www.fao.org [27 October 2006].

Frost AR (1981). Rotary atomization in the ligament formation mode. J. Agr. Eng. Res., 26: 63-78.

Halley S, Van E, Hofman V, Panigrahi S, Gu H (2008). Fungucide deposition measurement by spray volume, drop size, and sprayer system in cereal grains. Appl. Eng. Agric., 24(1): 15-21.

Holland JM, Jepson PC, Jones EC, Turner CA (1997). Comparison of spinning disc atomisers and flat fan pressure nozzles in terms of pesticide deposition and biological efficacy within cereal crops. Crop Prot. 16(2): 179-185.

Holownicki R, Doruchowski G, Godyn A, Swiechowski W (2000). Variation of spray deposit and loss with air-jet directions applied in orchards. J. Agr. Eng. Res., 77(2): 129-136.

Kara A, Kaya C, Kisa TDZ, Pehluvan M, Kadioğlu S, Taçoğlu M (2006). Kuzeydoğu Anadolu'da Patates Üretimi ve Sorunlari. IV. Ulusal Patates Kongresi. Niğde, 6-8 Eylül. pp. 285-291. [In Turkish].

Krishnan P, Williams TH, Kemble LJ (1988). Technical Note: Spray pattern displacement measurement technique for agricultural nozzles using spray table. T. ASAE, 31(2): 386-389.

Ledebuhr (2008). Proptec TM Rotary Atomizers. Available online in http://www.ledebuhr.net/sprayers/kits/atomizers.php. [14 July 2008].

Marçal ARS, Cunha M (2008). Image processing of artificial targets for automatic evaluation of spray quality. T. ASABE, 51(3): 811-821.

Micron (2008). Micromax 3-speed. Available online in http://www.micron.co.uk/product/micromax_3-speed#tech_specs. [01 August 2008].

Nuyttens D.. Baetens K.. Schampheleire MD, Sonck B (2007). Effect of nozzle type. size. and pressure on spray droplet characteristics. Biosyst. Eng., 97(3): 333-345.

Ozkan HE, Miralles A, Sinfort C, Zhu H, Fox RD (1997). Shields to reduce spray drift. J. Agr. Eng. Res., 67: 311-322.

Panneton B, Philion H, Thériault R, Khelifi M (2000). Spray chamber evaluation of air-assisted spraying on potato plants. T. ASAE, 43(3): 529-534.

Piché M, Panneton B, Thériault R (2000a). Field evaluation of air-assisted boom spraying on broccoli and potato. T. ASAE, 43(4): 793-799.

Piché M, Panneton B, Thériault R (2000b). Reduced drift from air-assisted spraying. Can. Agr. Eng., 43(3): 117-122.

Qui L, Miller PCH, FU Z (2008). The classification of the drift risk of sprays produced by spinning discs based on wind tunnel measurements. Biosyst. Eng., 100, 38-43.

Sayinci B, Bastaban S (2009). İlaç tutunmasinda kullanilan farkli örnekleme materyallerinde boyar maddenin geri kazanimi. 25. Tarimsal Mekanizasyon Ulusal Kongresi. Isparta, 01-03 Ekim., pp. 237-242. [In Turkish].

Scudeler F, Raetano CG (2006). Spray deposition and losses in potato as a function of air-assistance and sprayer boom angle. Sci. Agric. (Piracibaba. Braz.) 63(6), November/December, pp. 515-521.

Sidahmed MM, Awadalla HH, Haidar MA (2004). Symmetrical multi-foil shields for reducing spray drift. Biosyst. Eng., 88(3): 305-312.

Smith DB, Askew SD, Morris WH, Shaw DR, Boyette M (2000). Droplet size and leaf morphology effects on pesticide spray deposition. T. ASAE, 43(2): 255-259.

SPSSX (2004). SPSSX for Windows Release. 13.0 (Sep 01. 1993). Copyright SPSS Inc.. 1989-2004. New York, USA.

Srivastava AK, Goering CE, Rohrbach RG (1993). Engineering Principles of Agricultural Machines. ASAE Textbook, 6: 601.

Taçoğlu M, Olgun M, Kumlay AM, Kaya C, Pehluvan M, Partigöç F (1998). Doğu Anadolu Bölgesinde patates yetiştiriciliği problemleri ve çözüm yollari. Doğu Anadolu Tarim Kongresi. Erzurum, 14-18 Eylül., pp. 253-264. [In Turkish].

Taylor WA, Andersen PG (1989). The use of air assistance in field crop sprayer to reduce drift and modify drop trajectories. Proc. Brighton Crop Prot.Conf.-Weeds, 2: 631-639.

Turabi MS (2007). Bitki Koruma Ürünlerinin Ruhsatlandirilmasi. Tarim İlaçlari Kongre ve Sergisi Bildirileri. Ankara, 25-26 Ekim, pp. 50-61. [In Turkish].

Yildirim E (2008). Tarimsal Zararlilarla Mücadele Yöntemleri ve İlaçlar. 2. Baski. Atatürk Üniversitesi Ziraat Fakültesi Yayinlari Yayin No: 219, Erzurum, p. 350 [In Turkish].

Wang L, Zhang N, Slocombe JW, Thierstein GE, Kuhlman DK (1995). Experimental analysis of spray distribution pattern uniformity for agricultural nozzles. Appl. Eng. Agric., 11(1): 51-55.

Womac AR, Mulrooney JE, Scott WP (1992). Characteristics of air-assisted and drop-nozzle sprays in cotton. T. ASAE, 35(5): 1369-1376.

Womac A, Etheridge R, Seibert A, Hogan D, Ray S (2001). Sprayer speed and venture-nozzle effects on broadcast application uniformity. T. ASAE, 44(6): 1437-1444.

Yarpuz-Bozdogan N, Bozdogan AM (2009a). Comparison of field and model percentage drift using different types of hydraulic nozzles in pesticide applications. Int. J. Environ. Sci. Tech., 6(2): 191-196. Yarpuz-Bozdogan N, Bozdogan AM (2009b). Assessment of dermal bystander exposure in pesticide applications using different types of nozzles. J. Food, Agric. Environ., 7(2): 678-682.

Zeren Y, Bayat A (1986). Elektrostatik yüklemede bitki üzerinde ilaç tutunma etkinliğinin belirlenmesi. Tarimsal Mekanizasyon 10. Ulusal Kongresi. Adana, 5-7 Mayis, pp. 280-294. [In Turkish].

Zhu H, Dorner JW, Rowland, DL, Derksen RC, Ozkan HE (2004). Spray penetration into peanut canopies with hydraulic nozzle tips. Biosyst. Eng., 87(3): 275-273.

Zhu H, Rowland DL, Dorner JW, Derksen RC, Sorensen RB (2002). Influence of plant structure, orifice size, and nozzle inclination on spray penetration into peanut canopy. T. ASAE, 45(5): 1295-1301.

Zhu H, Zondag RH, Derksen RC, Reding M, Krause CR (2008). Influence of spray volume on spray deposition and coverage within nursery trees. J. Environ. Hortic., 26(1): 51-57.