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METHODOLOGICAL ARTICLE

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Aerial treatments in forest protection – research methodology

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Abstract

Treatment effectiveness in forest protection against harmful insects depends not only on pesticide efficacy of the product applied, but also on a number of other factors including assurance that a given insecticide reaches the pest living in the canopy. In the treatments with the use of aerial equipment (silva-aerial) it is advisable to consider species and age diversity of protected tree stands. The paper presents research methodology on the assessment of spray structure and density, penetration of spray droplets into the canopy as well as a degree of coverage and incorporation in tree crowns. The methodology proposed takes into account characteristics of the forest area studied and its surroundings, as well as the parameters and equipment of the measurement line. There were determined: operation requirements for the aircraft and its test and registration equipment as well as demands on pilot qualifications, flight performance on the measurement line and weather conditions allowing for conducting test trials. In the paper, there are presented a set of values and mathematical formulas needed for the analyses. Taking into account ecological threats, there were included the methods on evaluation of spray drift of the liquid distributed over the forest.

Key words

aerial treatment, spray deposit, test methodology, drift

Introduction

Aerial treatments carried out in forests basically comprise two aspects, i.e. pest control and fire protection. These have already had a century-long tradition. In Poland, the first silva- aerial treatment was carried out on 10 June 1925, for control of the nun moth *Lymantria monacha* L. within the Pomerania region. The pesticide then applied was calcium arsenate. After the second world war, aerial treatments were restarted in 1948, in the Zagłębie Dąbrowskie region (southern Poland), to control the black tipped-sawfly (*Acantholyda nemoralis* T.) Since then, "due to weak biological condition of Poland's forests" (prof. Głowacka, personal communication), planes and later on – helicopters were continuously used until the year 2000 for pest control, especially in pine forests. A variety of products was applied in aerial treatments, which are broadly described by Głowacka (1992, 2009, 2012). In its second field of activity in forestry, aviation plays a great role in control of forest fires. For example, in the 1980s, aircraft interventions against fires in France resulted in a decrease of the average fire area from 22.4 ha to 3.9 ha (5-fold reduction).

On the other hand, aerial treatments are associated with technological and technical difficulties which affect treatment efficacy, and also they can threat ecological balance – especially for the reason that applied plant protection products may be drifted beyond the

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treated area. The issue of pesticide drift when the product is applied with the use of ground and – particularly – aerial equipment has been one of the most important aspects being analyzed on scientific, theoretical and legal bases. The aim is to prevent adjacent cultivation areas, water reservoirs as well as urbanized and recreation areas against negative effects of pesticide drift (ISO-international standard 2005; Thistle at al. 2010; Teske et al. 2003; Van de Zande 2013; Butler 2013; Holloway and Gerber 2014). The technological process of aerial treatment takes place in the open area. Thus, it is affected by natural factors, such as: terrain elevation, woodland types, water watercourses and reservoirs as well as meteorological conditions (temperature, relative air humidity, wind direction and speed, turbulence, convection). Technical problems concern among others determination of optimal flight height and speed of an agricultural aircraft, the working width of the treatment over forest areas, which all allow for achieving a desirable pesticide dose and spray consistency. The final outcome obtained is a result of assumed technical conditions acting in chorus with the abovementioned factors and shows as biological efficacy of the treatment.

The studies on aerial treatments carried out in Canada (Courshee 1978; Armstrong 1981), Great Britain (Spillman and Joyce 1976) and Poland (Drużyński 1978; Fafiński 1983) were mainly focused on evaluation of treatment biological efficacy. In the literature, there has lacked information on penetration of spray droplets into the canopy of coniferous and deciduous trees conditional on droplet average volume diameters, spray density and coverage in different crown layers as well as that on associations of these factors with treatment biological efficacy. Moreover, there exists a need for evaluation of treatment quality depending on different aircrafts used for spraying. This is directly connected with economic factors involved in treatment efficiency and the total cost of the activity undertaken.

The aforesaid issues were addressed by long-term studies conducted in forest areas with the use of both planes and helicopters, by the Institute of Aerial Application of Chemicals in Agriculture (University of Warmia and Mazury, Poland) in co-operation of the Forest Research Institute (e.g. Rowiński 1996). The study methodology elaborated for research project purposes was described by Wodecka (1986), Perlowitz and Wolf (1988), Woziński et al. (1989) and Wodecka and Ruciński (1993).

The methodology described below constitutes considerable broadening of the aforesaid studies and includes examination of technological and technical parameters of aerial treatments as well as meteorological conditions during pertinent trials carried out. There also was decided to include the ecological factor associated with a possibility of spray drift over the areas surrounding treated areas and to present the methodology on drift evaluation. The methodology proposed can become an important element in standardization of aerial treatment assessments. What is more, it can smooth the progress of calculations in a very important aspect of research, that are quantitative comparisons of the experimental results.

Methodology

Aircraft

An agricultural aircraft may be despatched with the equipment for aerial application of pesticides, installed in accordance with the research program and certified based on the results of technical tests, including field testing of mass distribution needed for the determination of the treatment working width (Rowiński et al. 2011). The aircraft pilot should have good experience in agro-flights or else there should be a test pilot appointed.

Forest area characteristics

The area of a forest section under the trial is ≥5 ha, however adjoining forest areas (if exist) should allow for descending to the height of working flight as well as for 10 sec flight with the working speed over the measurement trees and then for safe ascending up to the procedural height of return after turning off sprayers. It means that the length of the surrounding area should be at least 200 m for the helicopter and 500 m for the plane.

Tree stand description

Scots pine (or other forest tree species) stand. The height of trees app. 6 m, which allows for taking off probes and installing the new ones before next flight. The parameters reported include:
– age class,
– plantation density,
– height,

– forest site type,
– quality (understood as crown symmetry, prerequisite in appropriate assessment of pesticide droplet number deposited on probes).

Measurement line

In the middle part of the forest section studied, there is designated the measurement line consisting of 5 trees growing about 5 meters apart. The line must be straight and situated perpendicularly to the direction of wind. There also are designated three direction lines – plane flight lines. The pattern for the measurement line is presented in figure 1.

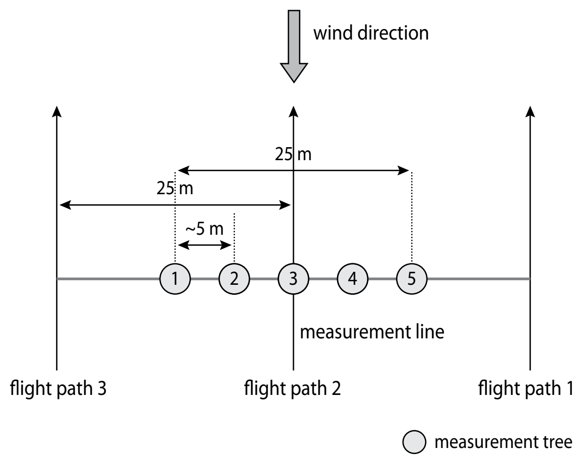

Figure 1. Measurement line pattern: tree height [m], crown height [m], crown width [m] tree DBH [m]

On the trees selected, there are fixed bands for securing probes mounted on the bars of the length equivalent to the crown radius at a given tree height measured with reference to the tree top at ¼, $^2/_4$, ¾ of its height and under the tree. The probes are arranged horizontally, taking into account:
– zone of tree crown height,
– crown section determined with reference to the direction of the wind and aircraft flight,
– crown layer.

The number and order of the probes attached to the trees is the same for each tree, according to the following system:

T-tree top	4 tree sections	exterior layer	4 probes
¼ height	as above	three layers	12 probes
$^2/_4$ height	as above	as above	12 probes
¾ height	as above	as above	12 probes
Ground	as above	middle layer	4 probes
In total:	5 zones	3 layers	44 probes

Measurement probes

Different types of probes can be used, and these are:
1. „Kromekote" cards– System „Swath Kit" (Mierzejewski 2007).
2. Ciba-Geigy water sensitive paper – System „Swath Kit".
3. Sections of photo-film coated with plastic (different for water and oil based liquids) – method developed at the University Warmia and Mazury in Poland.
4. Other probes for determination of quantity of the parameters described below.

In the method by University Warmia and Mazury, after spraying, dried out probes with round spots of droplets falling onto the film are collected for further analyses (Rowiński et al. 1985).

Model liquids

In order to exclude risks for employees and field experimental areas, the trials are carried out on safe model liquids instead of real plant protection products:
– water with adjuvant and fluorescent marker,
– 2% water nigrosin solution,
– 2% oil nigrosin solution,
– other markers.

Measurement flight

The measurement flight is performed at the height of 8 m or 10 m over tree tops, with working speed; it is a steady, rectilinear flight along the direction line assigned above the forest area (flight line); an aircraft is not tilted or banked and does not use instruments for increasing lift. Turning on or off sprayers is denoted with the marker equivalent to 5 sec of the working flight before reaching the measurement line and 5 sec flight behind the measurement line, respectively. The flights are performed against the wind with maximum $\pm 15^0$ deviation of wind direction. For the parameters described, measurements should be repeated from 3 to 5 times.

Measurement equipment

Measurement equipment allows for measurements and records of:

- technical parameters: flight speed and height,
- liquid pressure in the installation behind the pump, in boom sprayers and in other parts,
- intensity of liquid flow,
- atomizer spin,
- other parameters such as: duration of equipment work, product dose applied, etc.,
- emergencies,
- aircraft should be equipped in GPS system for directing towards the measurement line (Majewski 2012),

as well as measurements of weather conditions:

- average wind speed and gusted wind speed as well as wind direction at tree height,
- temperature at 2 m and 10 m height for evaluation of thermal stability,
- relative air humidity.

The measurements should be carried out in vicinity of the measurement line.

Whether conditions required for test running

- Wind speed at a range 1.5–3.5m/s. Winds with lesser speeds tend to often change their direction and this results in necessity of adjusting the situation of the measurement line.
- It is desired to determine thermal stability through the measurement of air temperature at 2 m and 10 m height. Thermal stability (K_{st}) is described by the following equation:

$$K_{st} = 10\,(T_{10} - T_2)/V_s^2 \tag{1}$$

where:
T_2, T_{10} – temperatures at respective heights (2 m and 10 m)
V_s – average wind speed

Appropriate weather conditions for test running are those with neutral state of the atmosphere, with the value of thermal stability index $K_{st} > -0.1$.

- Relative air humidity $\psi > 60\%$.
- The tests should be conducted at relatively low sun exposure, better early in the morning E (5–8 a.m.) and in the afternoon (4–8 p.m.).

Analysis of trial results

Sets of droplets

In general, droplet analyses are carried out with the use of computer software. There are several methods of the analysis of droplet spectrum (Riley 2014). For example, in the studies carried in Poland (Rowiński 1996), there were used specially designed probes. Spray droplets were collected as colourful spots on probe surfaces. A few minutes after the spray, the droplets dried out and there was obtained a consolidated picture of spray. The images were analyzed using a computer software for picture analyses. The results show a collection of droplet spots grouped by classes according to spot size. Droplet size can be calculated based on experimentally derived mathematical formulas, in line with characteristics of the working liquid. Table 1 presents examples of adjusting equations.

Table 1. Adjusting equations

Model liquid	Equation	Droplet spot diameter (*ds*)
Water nigrosin	$d = -0.087 + 0.54155d_S + - 0.13643d_S^2 + 0.01459d^3$	$0 < d_S < 1.7$ mm
Oil nigrosin	$d = -0.0029 + 0.42861d_S + + 0.04285d^2 - 0.01872d^3$	$0 < d_S < 3.0$ mm

where:
d_s – diameter of droplet spot (μm),
d – diameter of droplet (μm).

The structure of liquid droplets comprises:

- relative quantitative share of droplets in different size classes

$$\overline{n_i} = \frac{n_i}{N} \cdot 100\ [\%] \tag{2}$$

Droplet sets obtained allow for the analysis of fraction and accumulation distributions and also for determination of droplet diameters. In the analyses, most important are:

- mean volumetric diameter

$$d_v = \left[\frac{\sum_{i=1}^{k} n_i d_i^3}{N} \right]^{\frac{1}{3}} \tag{3}$$

where:
d_v – mean volumetric diameter [μm],
n_i – droplet number in size class,
N – total number of droplets in sample,
d_i – mean diameter in size class [μm];
– volume median commonly used in European studies:

$$d_{VM} = 0{,}5L\frac{0{,}5\sum_{i=1}^{k} n_i d_i^3 - \left(\sum_{i=1}^{m-1} n_i d_i^3 + 0{,}5 n_m \cdot d^3{}_m\right)}{n_m d_m{}^3} \cdot l_m \quad (4)$$

where:
d_{VM} – volume median [μm],
L – interval of droplet size in a set,
l_n – class interval with median,
n_m – number of droplets with median,
d_m – mean diameter in median class [μm].

Doses

The input value which is used in the analyses of spray processes is the technical dose which is determined by the following equation:

$$D_T = \frac{W_s}{B \cdot V_r} \cdot 10^4 \quad [\mathrm{dm}^3 / \mathrm{ha}] \quad (5)$$

where:
D_T – technical dose [dm³/ha],
W_s – flow intensity [dm³/s],
B – working width [m],
V_r – aircraft working speed [m/s].

The value of the technical dose is precisely determined by fixed measurable values. The technical dose is sprayed as liquid droplet cloud, which is affected by a number of disturbances associated with aircraft flight and weather conditions (wind, turbulence, convection currents), in the treated area which enforce droplet motion, drift and evaporation.

As a result of these factors, the dose measured on the treated area (on soil), the so called field dose – D_p is lower than the technical dose. The field dose is determined under field conditions with the use of the methods such as photometry, fluorescence, radiation or other, assuming that the marker of the model liquid is not subject to evaporation.

Droplet evaporation is calculated based on the value of the rate measured in the treatment area (on soil) and the value of the actual dose – D_R. The latter is determined based on the number of droplets and the value of the mean droplet diameter in a sample by means of the following equation:

$$D_R = \frac{\Pi}{6} \cdot \frac{d_v{}^3 \cdot N}{f_p \cdot n} \cdot 10^{-6} \quad [\mathrm{dm}^3 / \mathrm{ha}] \quad (6)$$

where:
D_R – actual dose [dm³/ha]
d_v – mean volumetric diameter [μm]
N – total number of droplets in sample
f_p – probe surface area [cm²]
n – probe number

The ratio of the actual dose and the technical dose is defined by the so called recovery factor:

$$\psi = \frac{D_R}{D_T} \cdot 100 \; [\%] \quad (7)$$

Treatment evaluation

The aerial treatment is evaluated through determination of:
– spray structure
– spray density
– spray coverage
– spray penetration rate
– canopy capacity

Spray structure

The structure of spray refers to the distribution of droplets according to their size classes:
– dispersion 25–125 μm
– ultra-low volume spraying 50–150 μm
– medium-volume spraying 100–300 μm
– high-volume spraying 200–500 μm

The index assumed is associated with the classification of spraying or following the technical requirements for sprayers in a given country.

Spray density

Average spray density is expressed by the number of droplets deposited on 1 cm² of the treated area of (e.g. on probe surface).

$$g = \frac{N}{n \cdot f_p} \quad (8)$$

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Spray coverage

This factor (average spray coverage) is mostly used in evaluations of fungicide sprays (e.g. in orchards) and it is expressed as the ratio of the total area covered by spray droplets on the probe area and the total probe area:

$$P = \frac{\sum_{i=1}^{k} n_i \cdot f_i}{n \cdot f_p} \cdot 100\ [\%] \tag{9}$$

where:
P – coverage [%]
f_i – area of coverage by droplets in a given size class

In some studies, there are estimated coverage values for independent determination of the coverage on upper and lower leaf surfaces and the ratio of the values obtained.

Spray penetration

Spray penetration is expressed as the ratio of the percentage share of the mass of spray droplets deposited on the probes installed on different layers of tree crown and droplet mass deposited in the whole tree crown:

$$\Pi_i = \frac{V_{k(w)}}{\sum V_k} \cdot 100;\quad \frac{V_{k(3/4)}}{\sum V_k} \cdot 100;\quad \frac{V_{k(2/4)}}{\sum V_k} \cdot 100;\quad \frac{V_{k(1/4)}}{\sum V_k} \cdot 100\quad [\%] \tag{10}$$

while:

$$\sum_{i=1}^{4} \Pi_i = 100\% \tag{11}$$

So as to assess deposit under the tree, the fifth element is included in the equation:

$$\Pi_p = \frac{V_{k(p)}}{\sum V_k} \cdot 100\ [\%] \tag{12}$$

Canopy capacity

Canopy capacity is the sum of tree crown surfaces (treatment area) including their size, density and foliage. This is the measure of spray volume, necessary for achieving required efficacy of the treatment on a given crown layer. This parameter is expressed as the ratio of the liquid volume deposited on the tree top at ¼ of the middle layer of tree crown:

$$C = \frac{V_{k(w)}}{V_{k(3/4)}} \cdot 100\ [\%] \tag{13}$$

Based on the above, there is possible to determine an appropriate dose for the treatment. Using canopy capacity value and recovery factor value, there can be calculated the dose:

$$D = \frac{\Pi}{6} \cdot g \cdot d_v^3 \cdot \frac{C}{\psi} \tag{14}$$

The value obtained should be equivalent to the value of the technical dose.

Methodology for drift tests

The differences between the above spray application spray methodology and that for trials on drift are:
– distribution of trees every 10 m (parallel to the wind direction),

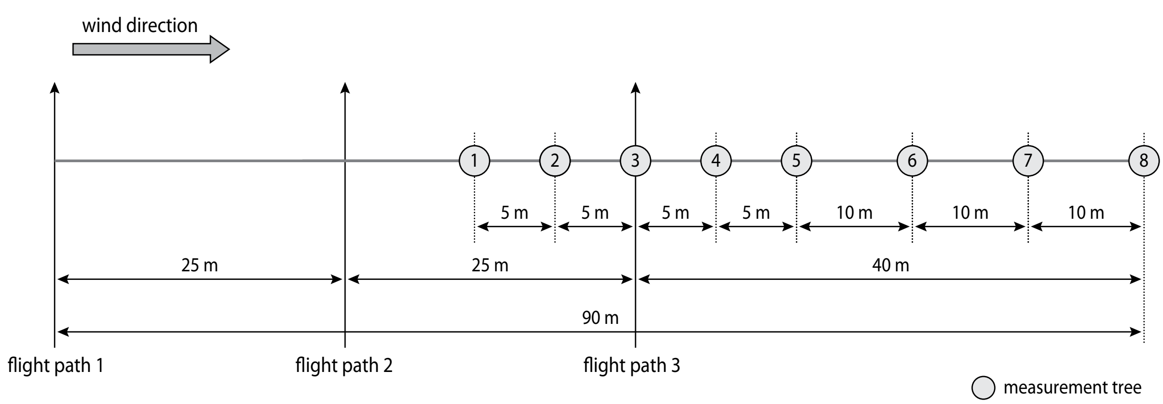

Figure 2. Measurement line pattern in trials on spray drift

– 3 aircraft flights perpendicular to the measurement line and wind. After 3 flights, probes are collected and next trial is arranged.

Additionally to the tests described above, there is also analyzed the change of parameter values along the measurement line. Figure 2 presents the pattern of the measurement line arranged for drift testing. The tests on liquid drift should be carried out at wind speed: 3.0–4.5 m/s (5 m/s).

Reporting

Trial reports are prepared in accordance with the requirements of the contracting party.

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