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Dutch summary:
De geschatte driftreductie op 4.5 tot 5.5 m van de Mitterer VV en VR boomgaardspuiten is 98,2 respectievelijk 99,1 % ten opzichte van een referentie boomgaardspuit. De metingen zijn uitgevoerd in 2021 en 2022 bij bespuitingen van een appelboomgaard in het volblad stadium (BBCH 75-91).

De drift van de Mitterer VV boomgaardspuit is gemeten in combinatie met Lechler ID 90 01 C spuitdoppen bij 5 bar, 300 RPM PTO, versnellingsbak van de ventilator in langzame (schildpad) stand, de buitenste bomenrij eenzijdig bespoten (alleen naar binnenkant perceel) en met de buitenste 4 spuitgangen de luchtondersteuning volgens een vast randrijprotocol. De geschatte driftreductie van de Mitterer VV boomgaardspuit in vergelijking met een referentiespuit is gelijk aan 98,2% op de evaluatiestrook op 4,5-5,5 m van de buitenste bomenrij. Het 95%-betrouwbaarheidsinterval ligt daarbij tussen 97,8% en 98,6%.

De drift van de Mitterer VR boomgaardspuit is gemeten in combinatie met Lechler ID 90 01 C spuitdoppen bij 5 bar, de buitenste bomenrij eenzijdig bespoten (perceel alleen naar binnen) en met de buitenste 4 spuitgangen de luchtondersteuning volgens een vast randrijprotocol. De geschatte driftreductie van de Mitterer VR boomgaardspuit in vergelijking met een referentiemachine is gelijk aan 99,1% op de evaluatiestrook op 4,5-5,5 m van de buitenste bomenrij. Het 95%-betrouwbaarheidsinterval loopt daarbij van 98,2% tot 99,5%.

Key words: orchard sprayer, spray drift, nozzle type, air assistance, spray drift reduction

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Pictures on front page: Gerrit van Steenbergen (20211014_150312.jpg), Arjan de Bruine (DSC_6160.JPG)

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1. Introduction

Reducing the emission of crop protection products in fruit production plays an important role in the implementation of Sustainable Crop Protection (EZ, 2013), the Activities Decree on Environmental Management (Min I&W, 2022) and the authorization of crop protection products (Ctgb, 2021). For all individual orchard plots, the application of crop protection agents must be carried out with at least 75% drift-reducing techniques (DRT75). Here, the above-mentioned Activities Decree states that for fruit production systems, the crop-free zone for a DRT75 (TCT, 2022a) should be at least 4.5 m. If a 3 m crop-free zone is used, crop protection agents must be implemented with a minimum 90% drift-reducing technique (DRT90).

The emission of plant protection products in fruit cultivation is relatively large compared to other agricultural sectors. This is partly caused by the upward and horizontal spray direction and the often powerful air support in fruit cultivation sprayers. Consequently, a lot of spray liquid is sprayed through the foliage of the tree rows. To reduce emission, various technical and cultivation measures are possible. Technical measures can include the use of suitable nozzle types, shielding and air support. A cultivation measure is, for example, the creation of a windbreak (wind hedge), or the creation of a larger cultivation-free buffer zone which increases the distance between the sprayed crop and the surface water. Experiments have shown that spraying with fine spray nozzles can result in significant drift to the air (Michielsen et al., 2007, Zande et al., 2014). This emission may be relevant for environmental impact at larger distances from plots, or have consequences for nearby residents and buildings (Gezondheidsraad, 2014). In this report, only drift deposition at short distances is evaluated for deposition on surface water for classification in a drift reduction class.

The Mitterer cross flow orchard sprayers allow the user to vary air support for both sides of the sprayer independently. In the experiments, an edge row protocol was used, where air support is limited to the outside of the plot. Furthermore, a low fan speed was employed by adjusting the PTO RPM and fan gearbox or by controlling the tractor hydraulics, one-sided spraying was applied to the outer tree row and 90% drift-reducing nozzles were used (Lechler ID 90 01 at 5 bar; TCT, 2022b).

This study compares two Mitterer orchard sprayers with a conventional cross flow fan sprayer with respect to downwind drift deposition on the ground while spraying an apple orchard at the full-leaf stage (after May 1st). The drift measurements comply with the established requirements from the authorization of plant protection products (Ctgb, 2021), the Activities Decree on Environmental Management (Min I&W, 2022) and international agreements regarding the recognition of drift measurements (ISO22866, 2005; ISO22369, 2006). This report describes the drift measurements and their analysis Chapter 2 discusses the experimental setup, followed by the results and discussion and conclusion in Chapters 3 and 4, respectively.

2. Materials and methods

2.1 Settings and specifications of candidate sprayers

In field trials, executed in 2021-2022, drift has been measured for two Mitterer orchard sprayers. The sprayers that have been measured are crossflow fan sprayers with adjustable air settings (figures 2.1 and 2.2). The Mitterer VV model has a single fan and an air crossflow box with valves controlling the air going out of the box on both sides independently. The Mitterer VR model has three crossflow blowers on each side, each fan giving air support for 3 nozzles (figure 2.8). For the Mitterer VR sprayer, the tractor's hydraulics are used to set the fan speed for the sprayer. Each side of the sprayer is connected to one hydraulic channel which gives the operator the opportunity to separately change both sides of the sprayer in terms of air supply. The sprayer terminal in the tractor (figure 2.6) indicates the fan speed, which is given in table 2.1.

During each measurement a spraying application was executed in the outer 9 paths of the orchard (see Section 2.4). In paths 5-9 a standard air setting was used. The outer four paths employed a predefined protocol for the air settings, limiting the amount of air being blown towards the outside of the orchard. The outer tree row is being sprayed only from the outside inwards, so in path 1 and 2 the candidate sprayers only spray on one side, no air is applied on the side that is not spraying (table 2.1). For spraying, a 90 % drift reducing nozzle was used (figure 2.4, Lechler ID 90 01 C at 5 bar; TCT, 2022b).

Table2.1 *Air and liquid settings used while measuring the Mitterer crossflow fan sprayers. The lower air setting is always applied to the outside of the orchard, in the case of one-sided spraying, the spraying is also done towards the inside of the field. Air valve setting 0 indicates the valve being closed, 100 means completely open. The field was sprayed inside out, starting with path 9 successively to path 1.*

Path (workflow)	Tree row	VV Air valve setting Left - right	VV terminal-indication	VR Fan speed (rpm) Left / right	spraying
1 (9)	1	0 - 100	100 – 0	0 / 1100	One-sided
2 (8)	1 – 2	100 – 0	0 – 100	1100 / 0	One sided
3 (7)	2 – 3	20 – 100	80 – 0	300/ 1100	
4 (6)	3 – 4	100 – 20	0 – 80	1100 / 300	
5 (5)	4 – 5	100 – 100	0 – 0	1100 / 1100	
6 (4)	5 – 6	100 – 100	0 – 0	1100 / 1100	
7 (3)	6 – 7	100 – 100	0 – 0	1100 / 1100	
8 (2)	7 – 8	100 – 100	0 – 0	1100 / 1100	
9 (1)	8 – 9	100 – 100	0 – 0	1100 / 1100	

The spray drift deposits for the Mitterer orchard sprayers are compared to those for the reference crossflow fan orchard sprayer with Albuz ATR Lilac nozzles (reference technology; TCT, 2017, figure 2.9).

Figure 2.1 *The Mitterer VV orchard sprayer during drift measurements.*

Figure 2.2 *The Mitterer VR orchard sprayer during drift measurements*.

Table2.2 *Nozzle height [cm] relative to the ground on the Mitterer orchard sprayers, left and right are identical.*

Nozzle no.	1	2	3	4	5	6	7	8	9
VV	62	88	114	142	175	208	241	274	
VR	65	84	103	154	173	192	240	259	278

For both Mitterer machines, spraying was executed with 7 nozzles (Table 2.2, nozzle 1-7), such that the spray height was consistent with the tops of the fruit trees. The settings are elaborated in table 2.4.

Figure 2.3 *The gearbox setting for the Mitterer VV sprayer is set to the slow (turtle) setting.*

Figure 2.4 *The Lechler ID 90 01 C nozzle*

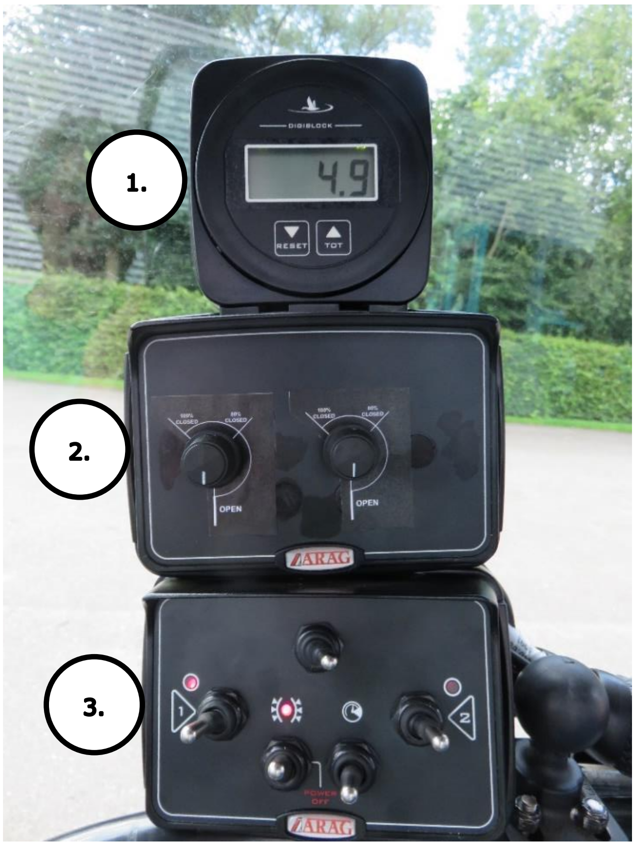

Figure 2.5 *The terminal for the Mitterer VV sprayer in the cab of the tractor. From top to bottom, the three units are: 1. The Manometer indicating the liquid pressure of the spraying system, 2. The control for the air valves. And 3. The control of the spraying.*

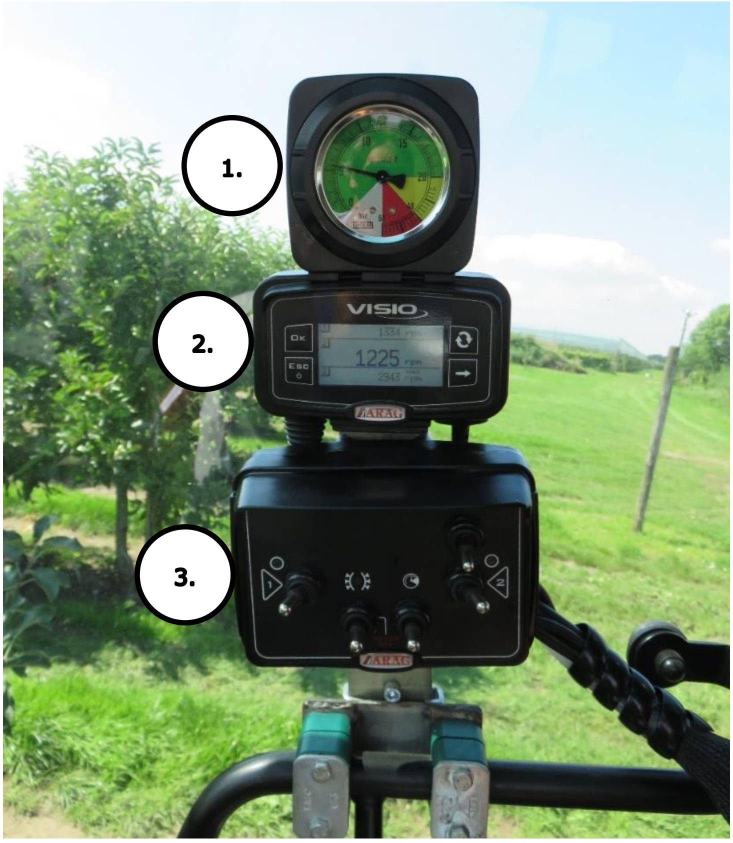

Figure 2.6 *The terminal for the Mitterer VR sprayer in the cab of the tractor. From top to bottom, the three units are: 1. The Manometer indicating the liquid pressure of the spraying system, 2. The fan speed indication. And 3. The control of the spraying.*

Figure 2.7 *The air valve of the Mitterer VV sprayer, the size of the opening can be adjusted left and right independently using the terminal in the tractor cab.*

Figure 2.8 *the Mitterer VR orchard sprayer has 3 crossflow fans on each side, each fan is combined with 3 nozzles. The fans are powered by the tractor's hydraulics, per side on a separate channel. The fan speed can be adjusted by controlling the tractors hydraulics.*

2.2 Characteristics reference sprayer

The reference cross flow sprayer (Munckhof, Horst) is an axial fan sprayer equipped with a cross flow airbox on the fan (Figure 2.9). Table 2.3 shows the positions of the nozzle holders of the cross-flow sprayer above ground surface.

Table 2.3 *The positions of the nozzle holders [cm] of the reference sprayer above ground surface.*

Nozze no.	1	2	3	4	5	6	7	8	9	10
left	50	68	84	99	120	153	180	215	250	285
right	48	66	81	99	121	153	181	216	251	286

Spraying with the reference machine was done with 2 x 8 open nozzles, with the lower (approx. 50 cm) and upper nozzle (at approx. 285 cm) closed. The upper spraying nozzle was at a height of 2.50 m in accordance with the tops of the fruit trees. The settings are given in table 2.4.

Figure 2.9 *Reference sprayer.*

2.3 Summary spray techniques used

Table 2.4 summarises the spraying techniques used during the drift measurements.

Table 2.4 *Settings for the reference and the Mitterer sprayers during the field trials.*

Spuit	reference	Mitterer VV	Mitterer VR
PTO rpm	540	300	300
Fan gearbox setting	High	Low (turtle)	Not applicable
Nozzle	Albuz	Lechler	Lechler
	ATR Lilac	ID 90 01 C	ID 90 01 C
nozzle principle	hollow cone	air-injector flat fan spray nozzle	air-injector flat fan spray nozzle
pressure [bar]	7	5	5
no. Of nozzles	2x8	2x7	2x7
application rate [l/min]	0.42	0.51	0.51
driving speed [km/h]	6.9	7.5	7.5
spraying volume [l/ha]	215	200	190

2.4 Description of measurements

2.4.1 Measurements

The experiments were conducted in 2021-2022 (table 2.5). They were carried out at the experimental orchard of WPR at Randwijk, on plot East. This plot is planted with the apple variety Elstar. The fruit trees were planted with 3.0 m spacing between rows and 1.1 m spacing within each row. The trees were about 2.50 m high and at the full-leaf stage (BBCH 75-91). All measurements were done in accordance with the drift measurement protocols from the TCT (TCT, 2017) and ISO22866.

Table 2.5 *Dates for the field measurements of the Mitterer orchard sprayers.*

Date	Mitterer VV model (# repetitions)	Mitterer VR model (# repetitions)
14-10-2021	2	2
15-11-2021	1	1
18-11-2021	1	1
19-11-2021	1	
10-6-2022	2	
22-6-2022		1
1-7-2022	1	
25-7-2022	1	3
total	**9**	**8**

The orchard had a length of 55 m, drift deposition measurements were done on the grass plot adjacent to the orchard. The measurement setup consisted of two measuring strips perpendicular to the last row of the orchard (duplicate measurements) such that the distance between the two strips was approximately 2 m, see figure 2.10. Figure 2.11 shows the experimental field with the measurement setup on either side (top) and the last eight tree rows when drift deposition was measured. After each application, the drift collectors were collected, packed and stored individually so the deposition per strip could be determined.

Collectors (Technofil TF 290; 10x100 cm, 10x50 cm) were placed at the following positions to measure drift deposition to the ground (Figure 2.9):

At 1.5 meters, parallel to the outer tree row, a collector of 1 meter length.
At 3 - 15 meters, continuous collectors of 0.5 meters (perpendicular to the tree row).
At 20 and 25 meters a collector of 1 meter (perpendicular to the tree row).

The distance was measured from the centre of the outer tree row.

Before and during spraying, the sprayer setting and the prevailing wind were checked and recorded. According to the measurement protocol (TCT, 2017), the wind speed should be between 1 and 5 m/s and the wind direction should not deviate more than 30° from perpendicular. Only when these conditions were met spraying was started. At the end, meteorological data was averaged (Section 2.6). If the average wind direction and or wind speed during the passage interval did not met the criteria of the protocol, the measurements were rejected.

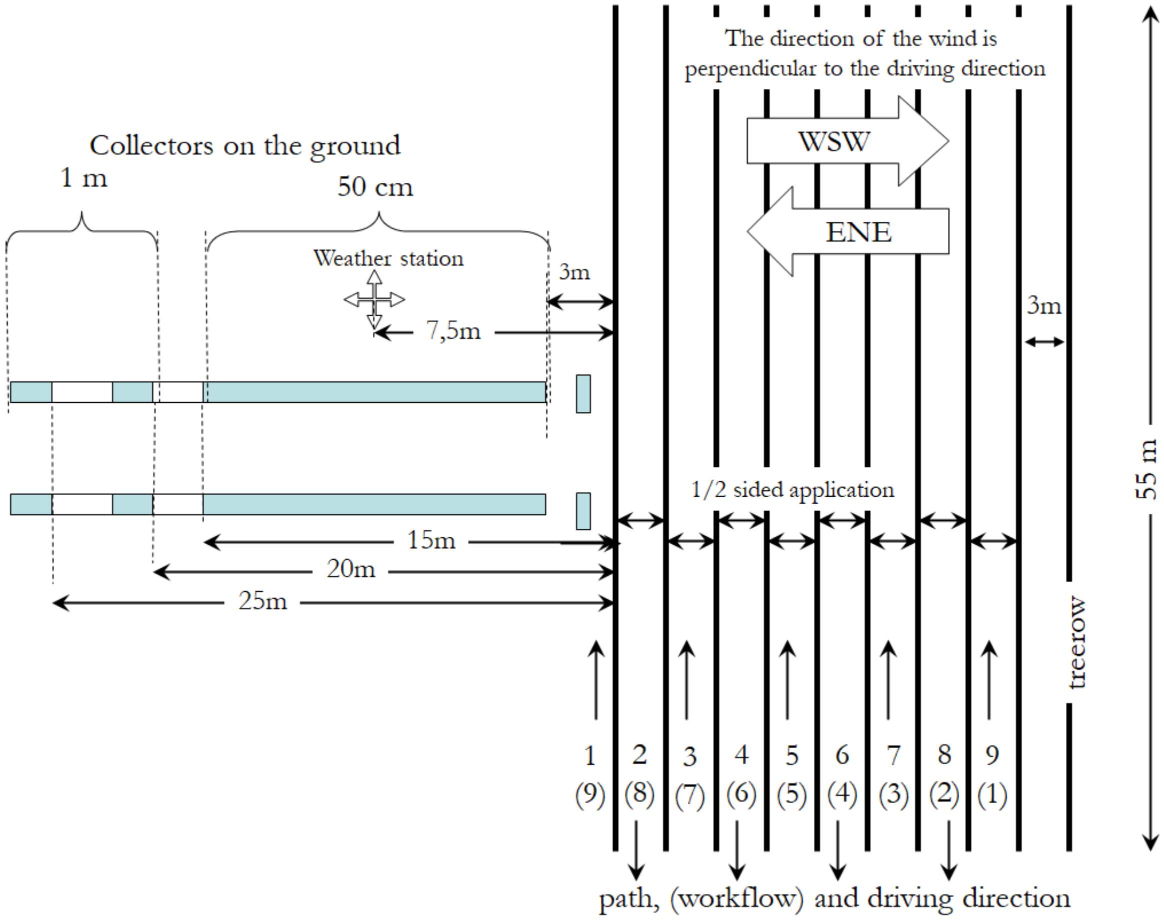

Figure 2.10 *Schematic representation of experimental field and measurement setup.*

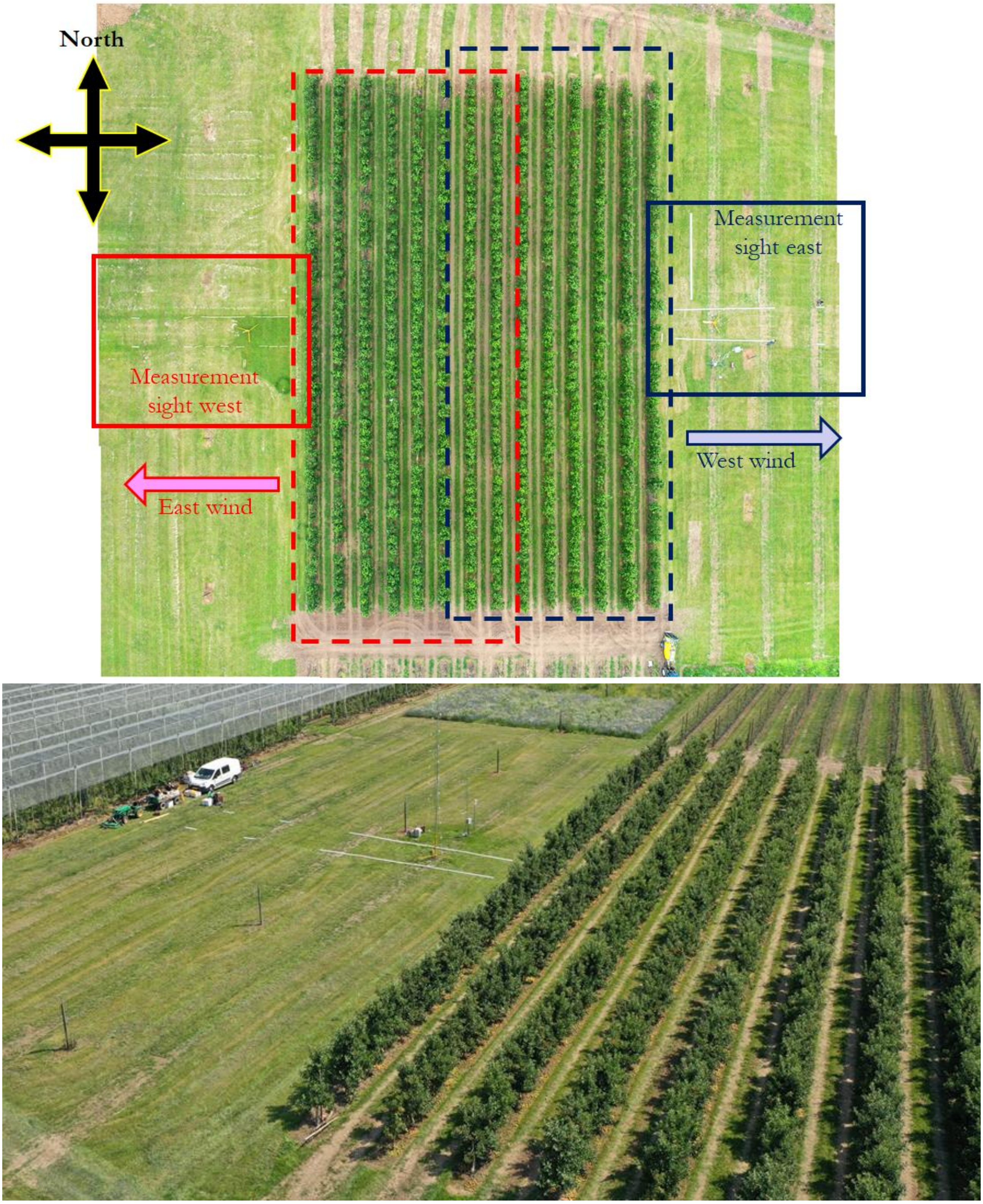

Figure 2.11 *Top view of experimental field (above) and of the tree rows and measurement setup.*

2.4.2 Analyses

Spraying was done with water to which Acid Yellow 250 (AY250, DC Finechemicals, CAS number 93859-32-6, 2-5 g/l) and a non-ionic effluent (Agral Gold, 0.075 ml/l) had been added. After spraying, the drift collectors were collected and coded for further analysis of the amount of AY250. Samples of the tank liquid were taken from a spraying nozzle each measuring day to measure the AY250 concentration of the sprayed liquid. In the laboratory, the collectors were rinsed with demineralized water such that the AY250 was in solution. From this solution, the concentration of AY250 was measured using a fluorometer (Perkin Elmer FL 8500; λ_{ex}=450 nm; λ_{em}=500 nm). Blank collectors and demineralized water were analysed to determine the background fluorescence. The concentration of AY250 in the tank samples was also determined fluorometrically.

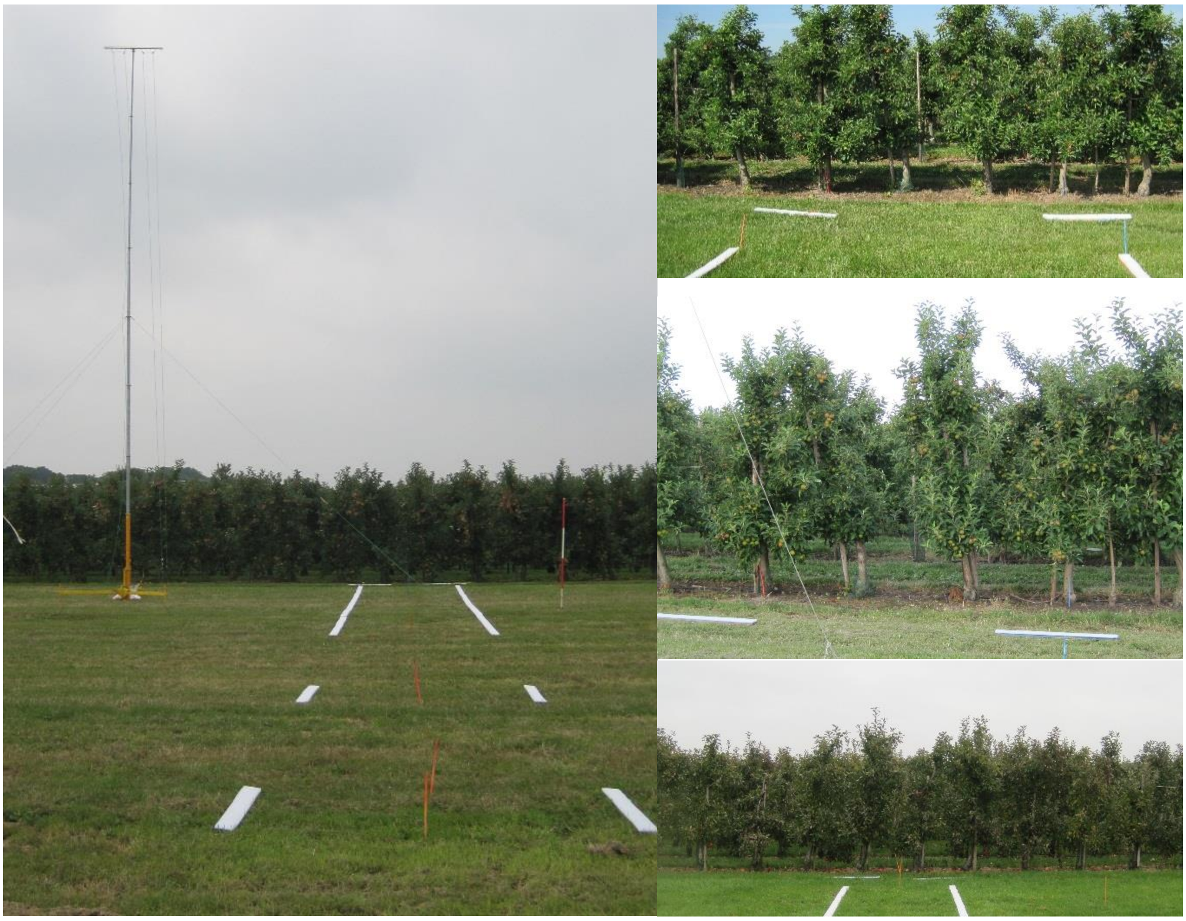

Figure 2.12 *The drift measurement setup (left); collectors on the ground up to 25 m from outer tree row; impression of leaf mass of apple trees and collectors close to outer tree row at two measurement sites (right).*

2.5 Method for estimating the drift reduction rate

For the comparison of the drift deposition of the Mitterer sprayers (VV and VR) with the reference machine, the drift values (% of spray volume) were estimated for the evaluation strip corresponding to the position of the ditch and the water surface within it. The cultivation-free zone is defined in the Environmental Management Activities Decree (Min I&W, 2022) as the distance between the ditch insertion and the outermost crop row (for fruit cultivation 3 m in Figure 2.13). The evaluation strip is then the area between 4.5 and 5.5 meters from the centre of the outermost row of trees.

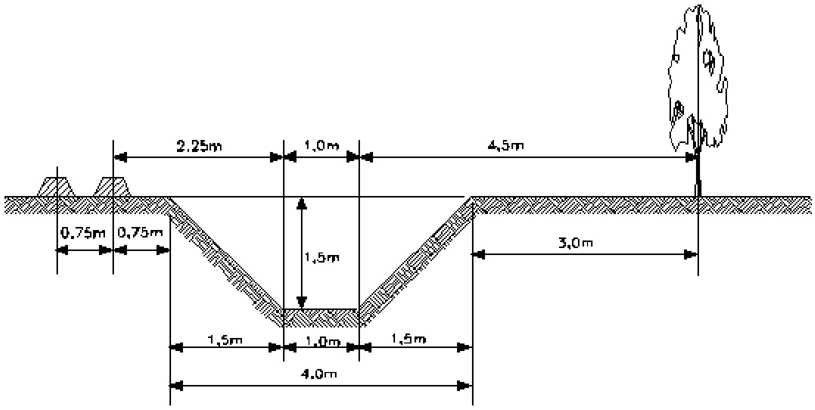

Figure 2.13 *Schematic representation of the location of the ditch, slope and water surface in relation to the last crop row in potatoes (left) and the outer tree row in fruit crops (right) (Huijsmans et al., 1997).*

2.5.1 General description of the estimation method

The aim is to compare the percentage drift deposition of a Test machine (T) in a certain distance interval relative to the sprayed orchard with the percentage drift deposition of a Reference machine (R). It is assumed that the percentage deposition decreases monotonously with the distance (x) from the orchard. Moreover, drift deposition at an infinite distance is zero. Deposition data for Test machines are generally well described by a single exponential curve, while a double exponential curve is required to obtain a satisfactory fit for Reference machines. Therefore, define the single $P_T(x)$ and double $P_R(x)$ exponential curves for drift deposition as

$$P_T(x) = \beta \exp(-\delta\, x)$$

$$P_R(x) = \beta_1 \exp(-\delta_1\, x) + \beta_2 \exp(-\delta_2\, x)$$

These functions are monotonously decreasing and zero at infinity when both β and δ are positive. The percentage deposition of a machine M in the distance interval (x_a, x_b) is then given by the integral

$$I_M = \int_a^b P_M(x)\, dx$$

The integrals for $P_T(x)$ and $P_R(x)$ are given by

$$I_T = \beta\, [\exp(-\delta\, x_a) - \exp(-\delta\, x_b)]/\delta$$

$$I_R = \beta_1\, [\exp(-\delta_1\, x_a) - \exp(-\delta_1\, x_b)]/\delta_1 + \beta_2\, [\exp(-\delta_2\, x_a) - \exp(-\delta_2\, x_b)]/\delta_2$$

The reduction percentage X of machine T relative to machine R in the interval (x_a, x_b) is then given by

$$X = 100 - 100\, I_T / I_R$$

The percentage deposition of a crop protection product cannot be measured directly. Instead, artificial collectors are placed at different distances from the last row of an orchard. The last row is then sprayed with water to which a fluorescent liquid has been added. The collectors are flushed with demineralized water and subsequently the fluorescence of the filtrate is measured. The measured fluorescences are then employed to estimate the parameters of the distance functions $P(x)$ for the Test and Reference machine. The estimated parameters can then be used to estimate the reduction percentage X including an associated 95% confidence interval.

An experiment in which a Test machine is compared with a Reference machine is conducted as follows. First two rows of cloth are laid out at different perpendicular distances from the orchard. De orchard is then sprayed by one of the machines and the cloths are collected. Secondly, two rows of new cloths are placed in the same position and the orchard is sprayed by the other machine. The position of the cloths are thus identical for the two machines but weather conditions, e.g. wind speed and direction, can be somewhat different. The parameters of the exponential curve, $P_T(x)$ for the Test machine and $P_R(x)$ for the Reference machine, are estimated separately for each row. A reduction percentage is then estimated for each row. In this way several experiments with duplicated rows are performed, usually on different days but sometimes on the same day. The separate estimates of the reduction percentage are combined into one single estimate, including a 95% confidence interval, by conducting a so-called meta-analysis.

2.5.2 Detailed description of the estimation method

Define the following symbols

F_{demi}	Fluorescence of demineralized water
F_{cloth}	Fluorescence of a clean cloth, assumed to be constant
x_i	Distance of the i-th cloth with respect to the last row of the orchard (m)
A_i	Size of the i-th cloth (m2)
Y_i	Fluorescence of the i-th cloth
D_i	Dilution factor which is used to obtain measurement Y_i
F_i	Fluorescence of the sprayed liquid on the i-th cloth
P_i	Percentage deposition of the sprayed liquid on the i-th cloth (%)

Note that the fluorescence is expressed in an arbitrary unit as measured by the fluorimeter.

The fluorescence (Y_i) of the i-th cloth is the sum of the fluorescence of the sprayed liquid (F_i), of the cloth itself (F_{cloth}), and of the demineralized water which is used to flush the cloth (F_{demi}), i.e. $Y_i = (F_i + F_{cloth} + F_{demi})$. In some cases, especially for cloths at a short distance with large depositions, the fluorescence is too large to be measured by the fluorimeter. The demineralized water is then diluted with a factor D_i. This will dilute both F_i and F_{cloth} but not F_{demi}. So in general

$$Y_i = \ (F_i/D_i + F_{cloth}/D_i + F_{demi})$$

The primary interest is in the fluorescence F_i of the sprayed liquid which is given by

$$F_i = D_i\ (Y_i - F_{demi}) - F_{cloth}$$

Note that, due to measurement errors, F_i can become negative when calculated directly from the observed fluorescence values Y_i, F_{demi} and F_{cloth}. This is clearly undesirable and therefore a modelling approach is used. To obtain the percentage drift deposition P_i, the fluorescence F_i is corrected for a calibration constant K, a water flush volume V, the concentration of the fluorescent liquid in the spraying tank C and the area A_i of the cloth. The deposition of the liquid on the cloth per unit area of the cloth then equals $(F_i\,K\,V)/(C\,A_i)$. Finally, a correction is required for the field release Q of the liquid. The percentage deposition P_i is then given by

$$P_i = \ F_i\ \frac{(K\,V)/(C\ \mathrm{A_i})}{(Q/100)}\ \times 100\%$$

Combining these equations it follows that the relationship between the measured fluorescence Y_i and the percentage deposition P_i is given by

$$Y_i = (Z_i/D_i)\,P_i + \ F_{cloth}/D_i\ +\ F_{demi} \qquad \text{with} \qquad Z_i = \ (Q\ C\ A_i)/(10000\ K\ V)$$

Assuming a single exponential curve $P_T(x)$ for the percentage P_i, it follows that

$$Y_i = (Z_i/D_i)\,\beta\,\exp(-\delta\, x_i) + F_{cloth}/D_i + F_{demi}$$

or, equivalently, with cloth corrected fluorescence measurements Y_i^*

$$Y_i^* = Y_i - F_{cloth}/D_i = (Z_i/D_i)\,\beta\,\exp(-\delta\, x_i) + F_{demi}$$

Similar equations can be derived for the double exponential curve $P_R(x)$ for P_i.

The cloth corrected fluorescence measurements Y_i^*, together with repeated fluorescence measurements of demineralized water in the same measurement series, are employed to estimate the parameters β, δ and F_{demi} of the curve. Because the variance of the measurements Y_i^* increases with the mean, gamma distributed errors rather than normal errors are assumed. The estimated β and δ parameters, and their standard errors, for both the Test and Reference machine are then used to calculate the reduction percentage for each row along with a 95% confidence interval. This interval is obtained by application of the so-called delta method on the logit scale; the interval on the logit scale is then back-transformed to the percentage scale.

2.5.3 Meta-analyse

The estimated reduction factors X for each duplicated row in multiple experiments, and their associated standard errors, are subjected to a meta-analysis in order to obtain a single estimate of the reduction factor of a Test machine. In the meta-analysis individual estimates are weighted by their standard errors such that more precise individual estimates have a larger weight than less precise estimates. The meta-analysis is performed on the logit scale because normality is better guaranteed on the logit scale than on the percentage scale, especially when reduction percentages are close to 100%. In the meta-analysis two variance components are distinguished: variance between experiments and variance between duplicated rows within the same experiments. The estimated constant of the meta-model and the accompanying 95% confidence interval are back-transformed to the percentage scale to give the final result of the statistical analysis.

2.5.4 Remarks

1. The statistical method employs the untransformed cloth corrected fluorescence measurements. The background fluorescence F_{demi} is a parameter in the statistical model.
2. In the calculation of the cloth corrected fluorescence Y_i^*, it is assumed that the fluorescence F_{cloth} of a cloth is known. However, F_{cloth} is also measured and is thus subjected to measurement error. Since F_{cloth} is small, smaller than 500, relative to measured fluorescence Y_i, which is generally larger than 8000, measurement error in F_{cloth} can be ignored.
3. For experiments conducted in 2021 and 2022 F_{cloth} is set to 340 and 125 respectively. The precise value of F_{cloth} only has a minor effect on the final result.
4. Cloths of the two rows of a Test machine in the same experiment are measured in the same fluorescence series. Cloths of the two rows of the Reference machine also form a single measurement series, however, this series can be measured on another day. In each series the calibration factor K is determined; this value can vary somewhat from day to day. The calibration factor is assumed to be constant for a series. In the same series usually four measurements of demineralized water are conducted.
5. For some fluorescence measurements an additional dilution factor D_i is employed. Such measurements are not comparable to un-diluted measurements. Therefore, in a graphical display with the fitted exponential curves diluted measurements are depicted by $D_i\,(F_i - M) + M$ in which M is the mean of the demineralized water measurements in the same series.
6. The exponential curves are fitted by noting that for fixed values of the δ's, the model is linear in the β's and in the F_{demi} parameter. This implies that, given fixed δ values, the linear parameters can be estimated by a generalized linear model with the gamma distribution and the identical link function. Employing this predicate, a grid search only for the δ parameters is required. For the single exponential model the grid search is performed by the one-dimensional optimization function *optimize*() in *R*. For the double exponential model the "*L-BFGS-B*" method in the *R* function *optim*() is employed. In both cases initial intervals are obtained by a simple equidistant grid search between δ=0.001 and δ=5.

7. The exponential curves are only monotonously decreasing when the β and δ parameters are positive. For δ this is ensured by estimating δ^*, defined by $\delta = \exp(\delta^*)$, rather than δ. In some cases the best estimate for δ^* is minus infinity, implying a zero estimate of δ, resulting in problems for the estimation algorithm. Therefore a lower limit for δ^* is imposed such that the estimate of δ is larger than or equal to 0.001. This lower limit results in a curve which slowly reaches the asymptote for large distances.
8. Negative estimates of β are set to zero. This results in a constant curve for the single exponential model and a single exponential model for the double exponential model.
9. In some cases a reduction factor of 100% is obtained, for example when a constant model is fitted for a Test machine. A logit transformed estimate of the reduction percentage, required for the meta-analysis, is then not available. Therefore, reduction percentages larger than 99.9% are bounded to 99.9% and the associated variance is calculated by assuming that the lower 95% confidence limit equals 99.5%.
10. The meta-analysis is calculated by the *rma.mv*() function in the *R* package *metafor* employing "*random = ~ 1 | experiment/row)*"
11. The meta-analysis reveals that it is generally appropriate to distinguish between the variance between and within experiments. The estimated correlation between the logit transformed reduction in the same experiment equals 0.00 for the Mitterer VV and 0.73 for the Mitterer VR machine.

Appendix 1 shows graphs for all experiments showing the measured values and fit curves of the statistical model.

In Appendix 3, the fit curves for each repetition are converted to drift deposition, plotted against the distance from the orchard. This is therefore the estimated drift deposition of the reference and test machine separately from each other.

2.6 Weather conditions

During spraying, weather conditions were recorded by measuring temperature (Pt100 at 0.5 m and 4 m height), humidity (% RH with a Rhotronic at 1.5 m height), wind direction (0° = perpendicular to the rows of trees) at 10 m height and wind speed (cup anemometers at 0.5, 2, 3, 4 and 10 m height) at 5-second time intervals. The weather station was located 7.5 m from the outer tree line (Figure 2.10). At each passage of the sprayer the data logger time was recorded. Measured weather data were averaged afterwards for the passage interval defined as the time interval 10 seconds before to 10 seconds after the logged passage time. Appendix II shows the results of the measurements of the weather conditions.

The experiments were conducted in 2021 and 2022, the dates can be found in table 2.5. The average overall data is shown in table 2.6.

Table 2.6 *Average weather conditions (at passage intervals) for the different objects during the drift measurements.*

technique	n-repetitions	temperature [°C] at		% RH	wind direction	windspeed [m/s] at				
		0.5 m	4 m		0° = perpendicular	0.5 m	2 m	3 m	4 m	10 m
Reference	9	16.6	15.7	70	-12	0.9	1.6	2.3	2.7	4.5
Mitterer VV	9	16.3	15.6	70	-12	0.9	1.7	2.4	2.9	4.6
	average	**16.4**	**15.7**	**70**	**-12**	**0.9**	**1.6**	**2.4**	**2.8**	**4.5**
Reference	8	18.6	17.5	64	-7	0.9	1.8	2.6	3.0	4.9
Mitterer VR	8	18.2	17.1	64	-10	1.0	1.7	2.5	3.0	4.9
	average	**18.4**	**17.3**	**64**	**-9**	**1.0**	**1.8**	**2.5**	**3.0**	**4.9**

3 Results

The measured drift reduction on the evaluation strip (4.5-5.5 m) during spraying in the full-leaf situation (BBCH 75-91) is shown in Figure 3.1, the numbers are in Appendix 1.

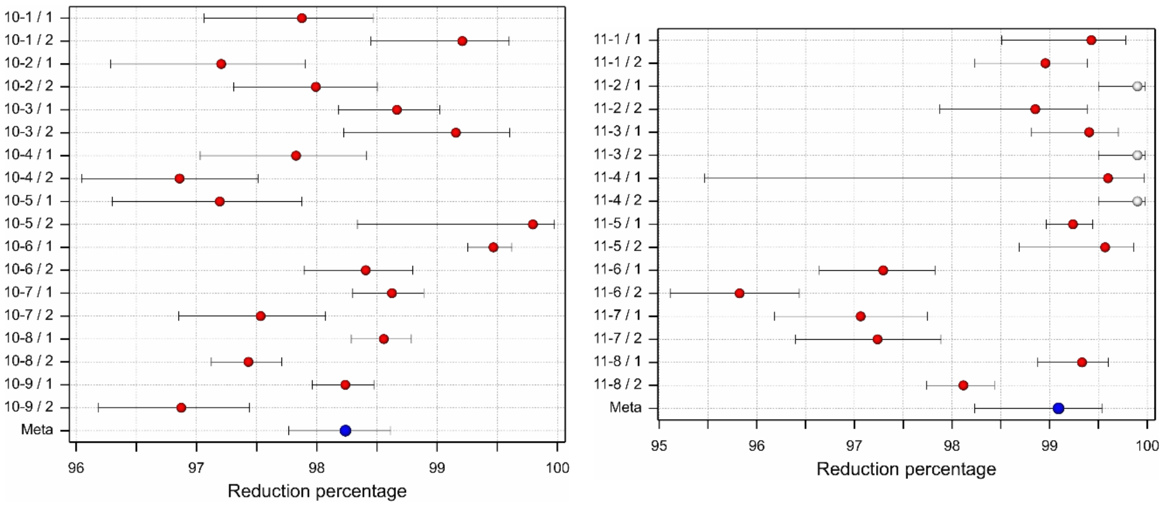

Figure 3.1 *The drift reduction on the evaluation strip of the different repetitions of the experiments, for the Mitterer VV Model (left) and for the Mitterer VR model (right). Each strip of an experiment is shown separately, 2 values per experiment. The experiment rows are coded as: object no - repetition / measurement strip. For each experiment, the estimated reduction including a 95% confidence interval is given. The strips that are represented by a white dot represent measurements that obtained 100% reduction, for calculation reasons 99.9% reduction was assumed (see remark 9 in paragraph 2.5.4). The meta-analysis gives an estimated (mean) drift reduction of 98.2% for the VV Model and 99.1 % for the VR model.*

The Mitterer VV orchard sprayer, Lechler ID 90 01 C nozzles at 5 bar, 300 rpm PTO, fan gearbox in slow (turtle) setting, the outer tree row sprayed unilaterally (plot inward only) and with the outer 4 passes of application the air support valves following a fixed edge row protocol, has been compared to a reference sprayer. On average, the drift reduction is 98.2% (confidence interval 97.8 - 98.6). The Test and Reference machine are significantly different at a significance level of 5%.

The Mitterer VR orchard sprayer, Lechler ID 90 01 C nozzles at 5 bar, the outer tree row sprayed unilaterally (plot inward only) and with the outer 4 passes of application the air support following a fixed edge row protocol, has been compared to a reference sprayer. On average, the drift reduction is 99.1% (confidence interval 98.2 - 99.5). The Test and Reference machine are significantly different at a significance level of 5%.

4 Discussion and conclusion

The estimated drift reduction at a distance between 4.5 and 5.5 m of the Mitterer VV and VR orchard sprayers are respectively, 98.2 and 99.1 % compared to a reference sprayer. Measurements have been executed in 2021 and 2022 spraying of an apple orchard at the full-leaf stage (BBCH 75-91).

The Mitterer VV orchard sprayer was measured in combination with Lechler ID 90 01 C nozzles at 5 bar, 300 rpm PTO rpm, air support gearbox in slow (turtle) setting, the outer tree row sprayed unilaterally (plot inward only) and with the outer 4 passes of application the air support following a fixed edge row protocol. The estimated drift reduction of the Mitterer VV orchard sprayer compared to a reference machine is equal to 98.2% on the evaluation strip 4.5-5.5 m from the outer tree row. The 95% confidence interval thereby ranges from 97.8% to 98.6%.

The Mitterer VR orchard sprayer was measured in combination with Lechler ID 90 01 C nozzles at 5 bar, the outer tree row sprayed unilaterally (plot inward only) and with the outer 4 passes of application the air support following a fixed edge row protocol. The estimated drift reduction of the Mitterer VR orchard sprayer compared to a reference machine is equal to 99.1% on the evaluation strip 4.5-5.5 m from the outer tree row. The 95% confidence interval thereby ranges from 98.2% to, 99.5%.

In the results, a spreading of the estimated reductions can be observed, both between the measurements as well as between the measurement strips in one measurement. The cause of the observed differences cannot be directly declared, however, there is always variation between measurements, which could be due to weather circumstances, tree development, variation by sprayer performance etc; common variations to cope with in agricultural (or biological) research. These variations underpin the necessity to have enough repetitions of measurements (test protocol points at 8-10 repetitions of the measurements) to give robust results.

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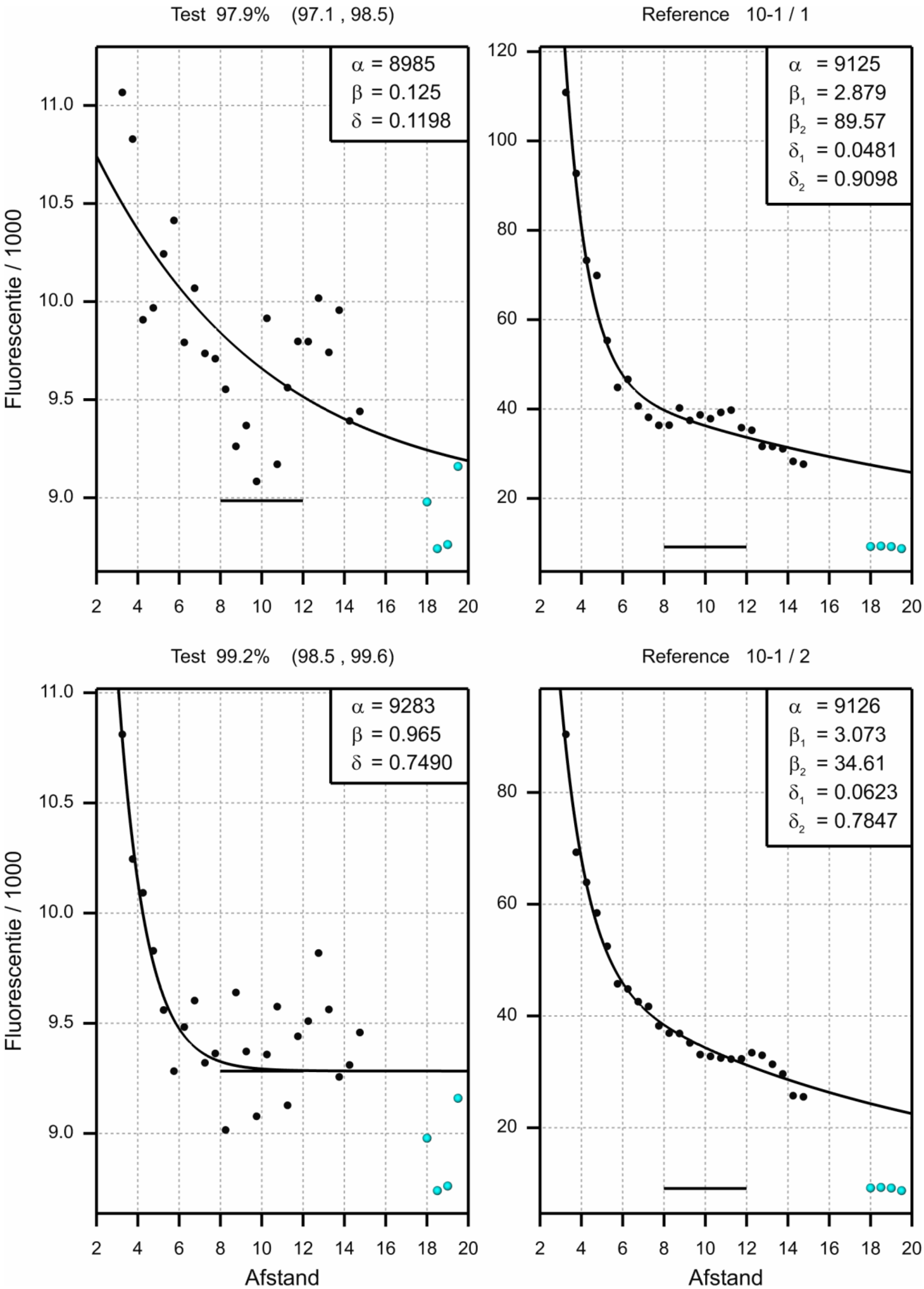
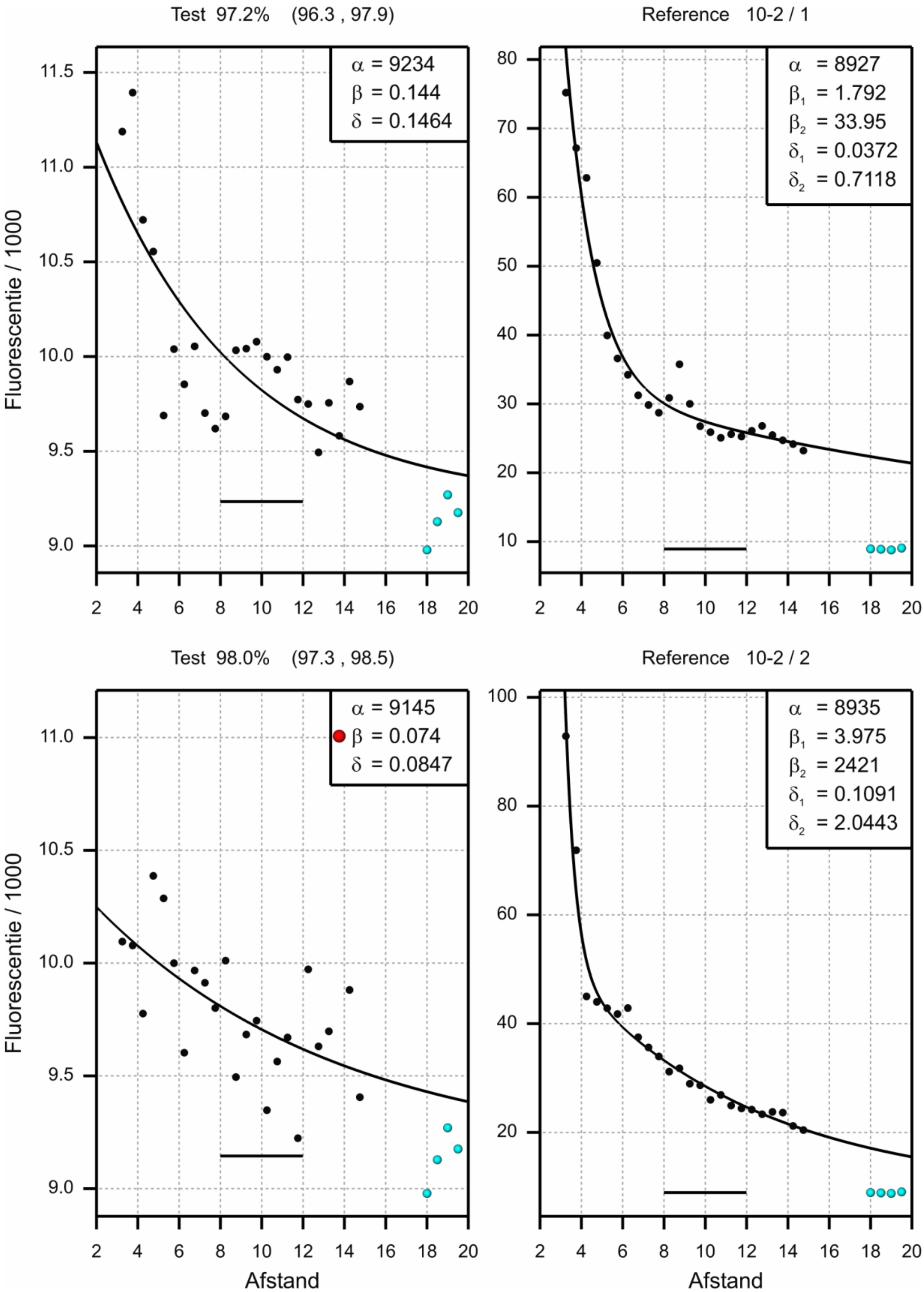
Appendix 1 Estimated exponential curves

Each page shows the two strips for a single experiment. On the left are the figures for the test machine and on the right for the corresponding reference machine. Above the test figures the estimated drift reduction for the specific row is given with the corresponding confidence interval. Above the reference figure is the date of the experiment and the number of the experiment (in brackets, object number - repetition / experiment strip). The first 9 pages are the repetitions of the Mitterer VV sprayer (object 10), the next 8 pages are the repetitions for the Mitterer VR sprayer (object 11).

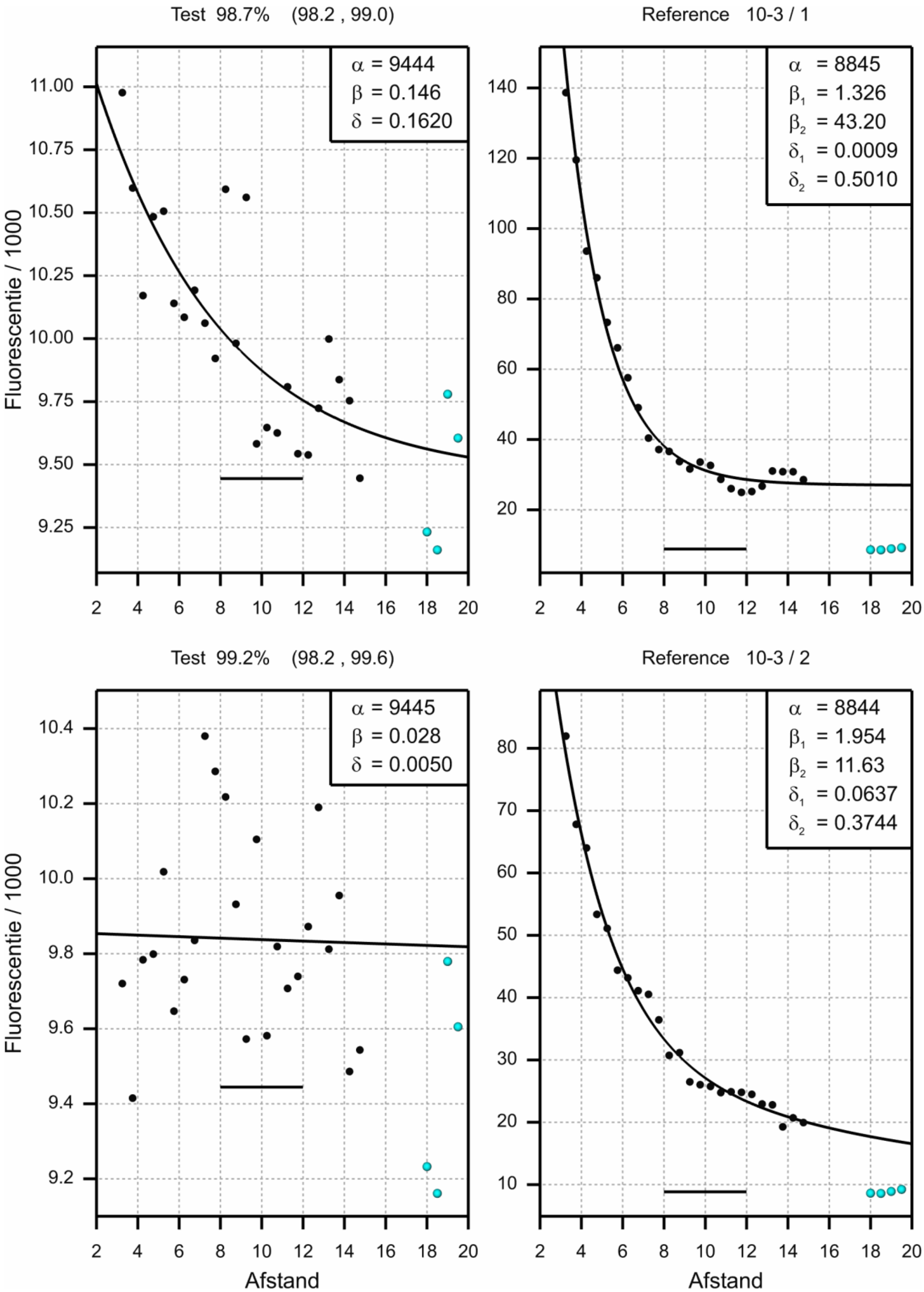
In each figure, the estimated parameters of the exponential curve are given in the upper right corner. The black dots represent the measured cloth corrected fluorescence of the collectors, red dots were not used when fitting the exponential curve. The blue dots are the collector corrected fluorescence of demineralized water belonging to the measurement series, the distance at which they are shown is fictional, the corresponding distance according to the exponential model is actually infinity. The black horizontal line between 8 and 12 m. is the estimated asymptote to which the exponential curve runs, this corresponds to the *alpha* parameter.

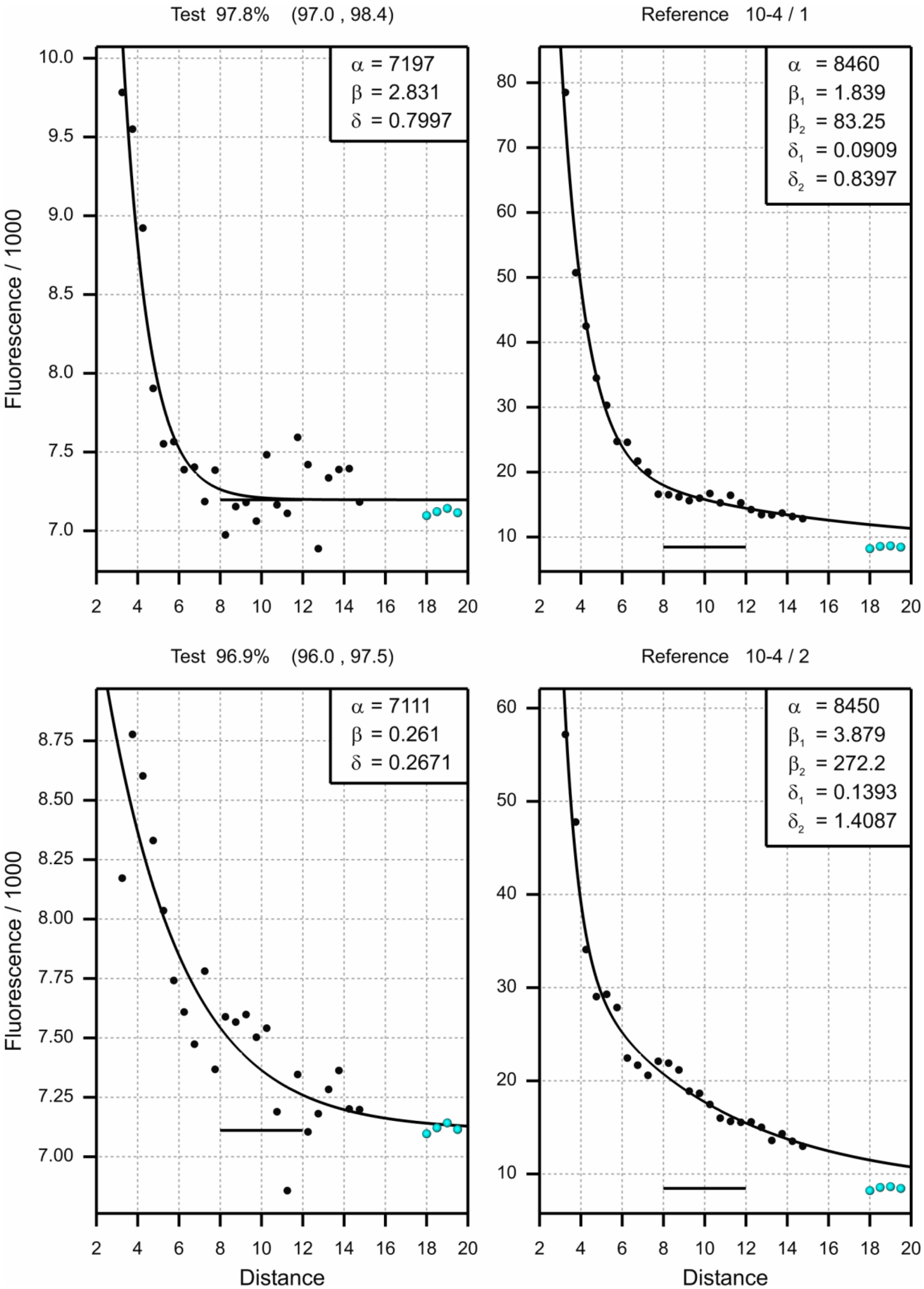


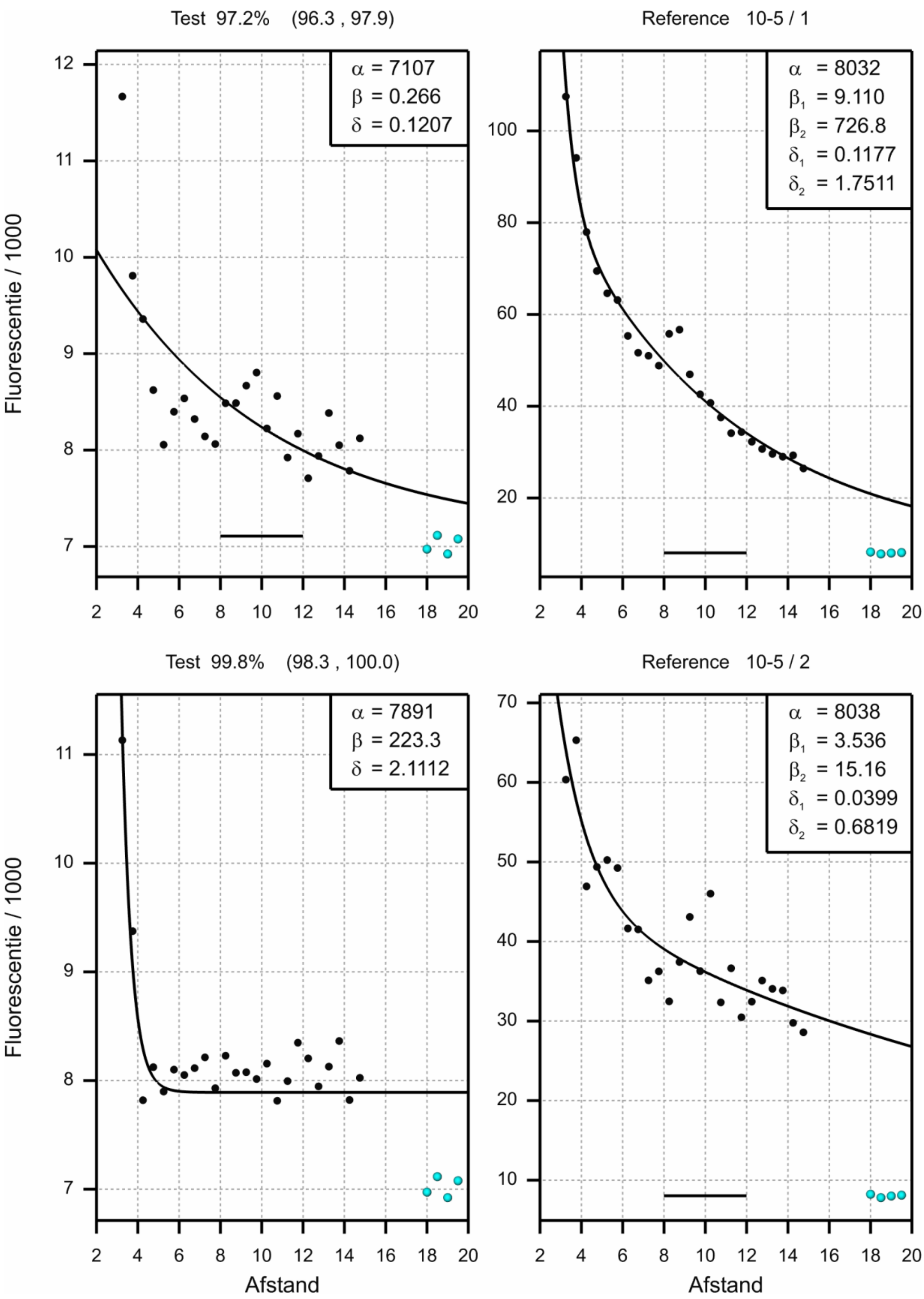
Test 97.9% (97.1 , 98.5)
α = 8985
β = 0.125
δ = 0.1198
Fluorescentie / 1000
11.0
10.5
10.0
9.5
9.0
2 4 6 8 10 12 14 16 18 20
Reference 10-1 / 1
α = 9125
β1 = 2.879
β2 = 89.57
δ1 = 0.0481
δ2 = 0.9098
120
100
80
60
40
20
2 4 6 8 10 12 14 16 18 20
Test 99.2% (98.5 , 99.6)
α = 9283
β = 0.965
δ = 0.7490
Fluorescentie / 1000
11.0
10.5
10.0
9.5
9.0
2 4 6 8 10 12 14 16 18 20
Afstand
Reference 10-1 / 2
α = 9126
β1 = 3.073
β2 = 34.61
δ1 = 0.0623
δ2 = 0.7847
80
60
40
20
2 4 6 8 10 12 14 16 18 20
Afstand



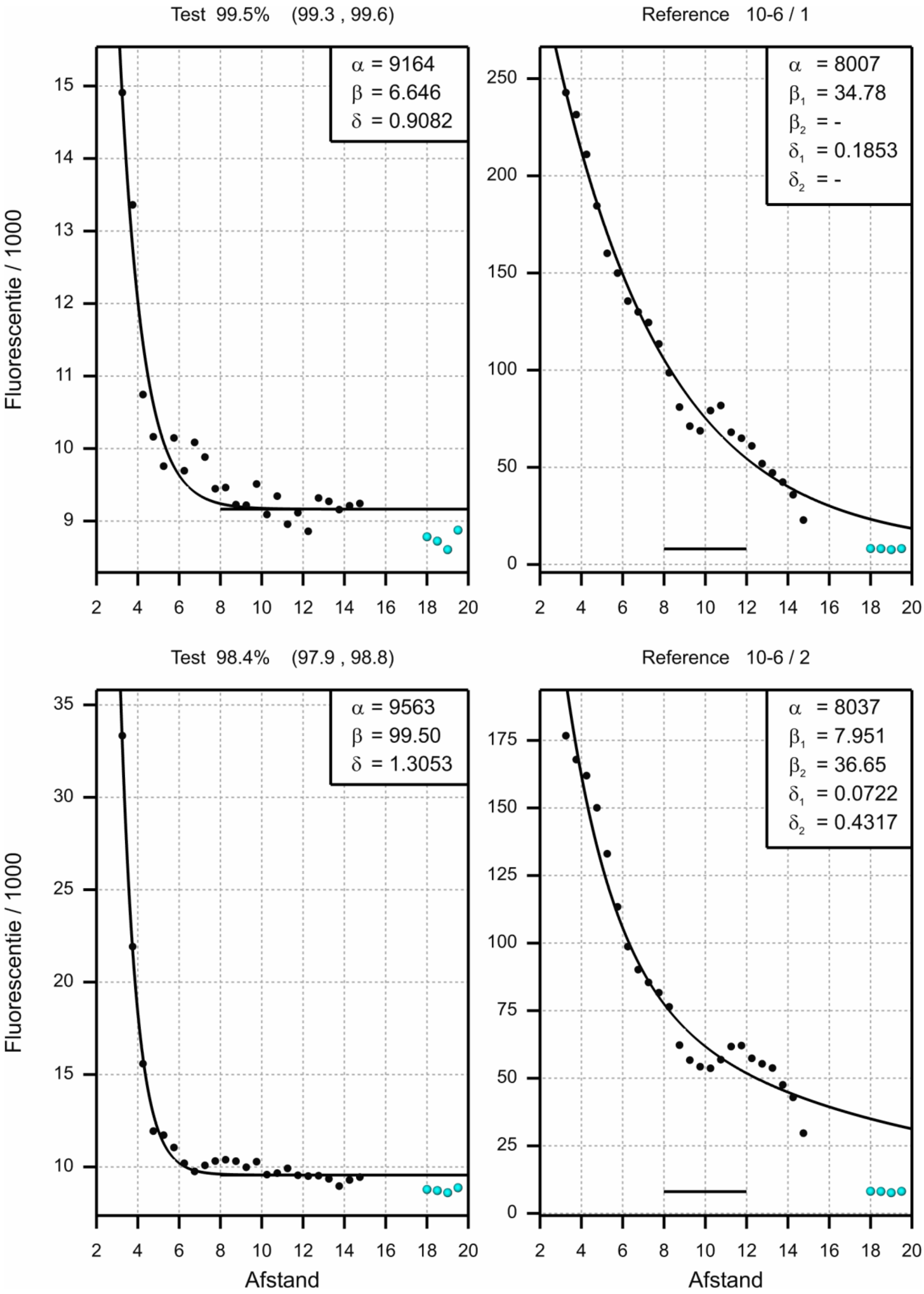
Test 97.2% (96.3 , 97.9)
α = 9234
β = 0.144
δ = 0.1464
Reference 10-2 / 1
α = 8927
β1 = 1.792
β2 = 33.95
δ1 = 0.0372
δ2 = 0.7118
Test 98.0% (97.3 , 98.5)
α = 9145
β = 0.074
δ = 0.0847
Reference 10-2 / 2
α = 8935
β1 = 3.975
β2 = 2421
δ1 = 0.1091
δ2 = 2.0443
Fluorescentie / 1000
Afstand

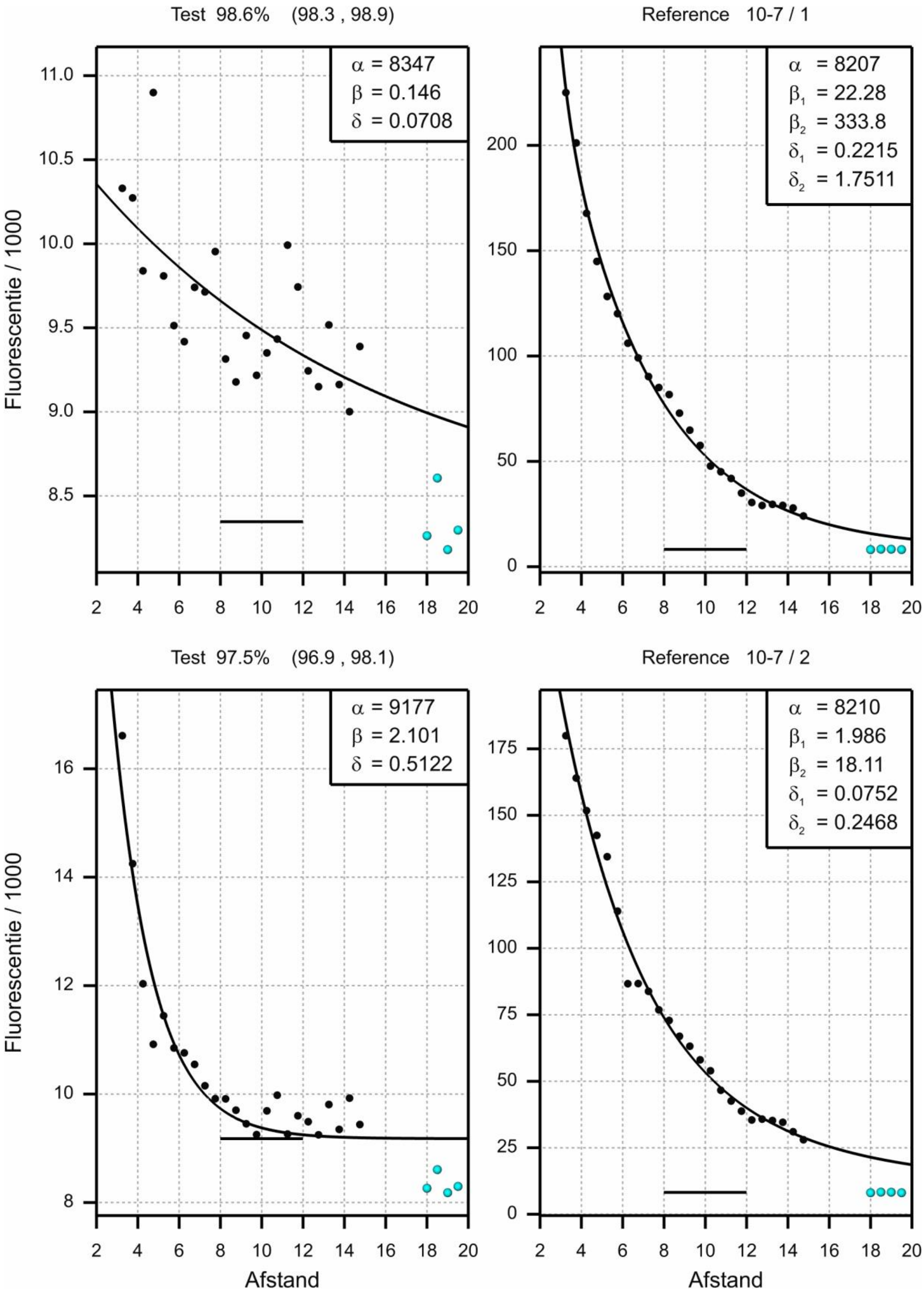

Test 98.7% (98.2 , 99.0)
α = 9444
β = 0.146
δ = 0.1620
Reference 10-3 / 1
α = 8845
β1 = 1.326
β2 = 43.20
δ1 = 0.0009
δ2 = 0.5010
Test 99.2% (98.2 , 99.6)
α = 9445
β = 0.028
δ = 0.0050
Reference 10-3 / 2
α = 8844
β1 = 1.954
β2 = 11.63
δ1 = 0.0637
δ2 = 0.3744
Fluorescentie / 1000
Afstand


Test 97.8% (97.0 , 98.4)
α = 7197
β = 2.831
δ = 0.7997
Reference 10-4 / 1
α = 8460
β1 = 1.839
β2 = 83.25
δ1 = 0.0909
δ2 = 0.8397
Test 96.9% (96.0 , 97.5)
α = 7111
β = 0.261
δ = 0.2671
Reference 10-4 / 2
α = 8450
β1 = 3.879
β2 = 272.2
δ1 = 0.1393
δ2 = 1.4087
Fluorescence / 1000
Distance

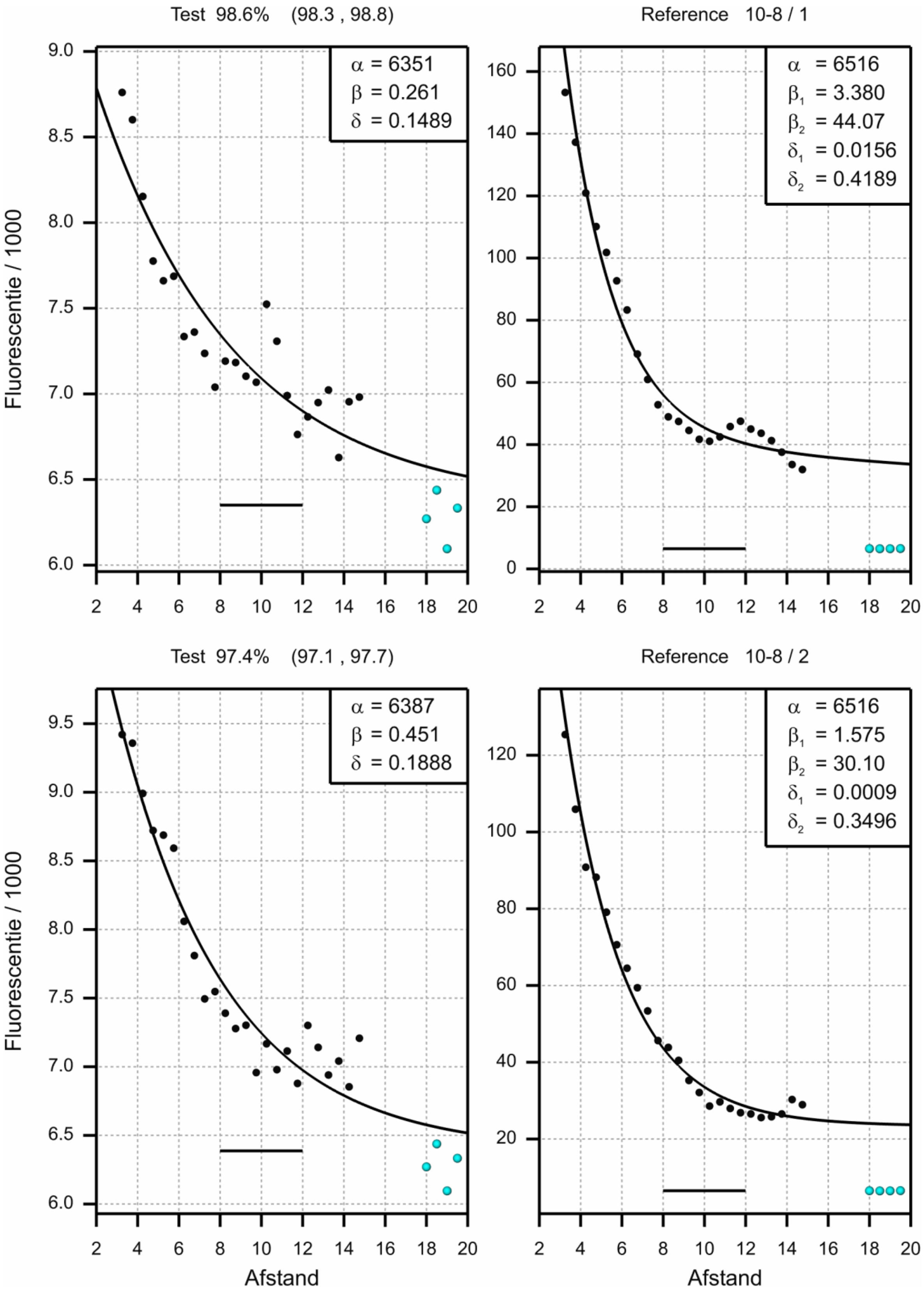


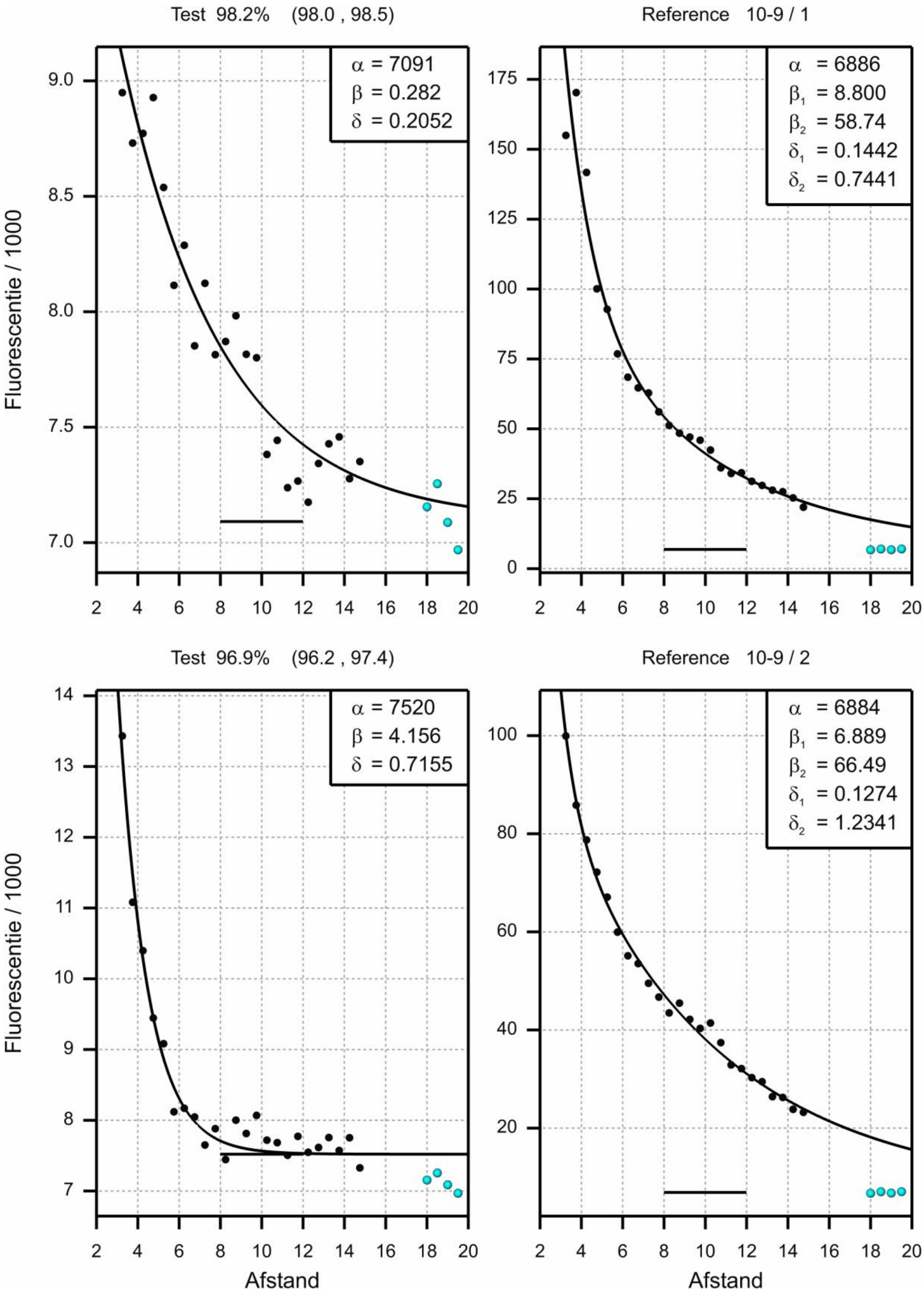
Test 97.2% (96.3 , 97.9)
α = 7107
β = 0.266
δ = 0.1207
Reference 10-5 / 1
α = 8032
β1 = 9.110
β2 = 726.8
δ1 = 0.1177
δ2 = 1.7511
Test 99.8% (98.3 , 100.0)
α = 7891
β = 223.3
δ = 2.1112
Reference 10-5 / 2
α = 8038
β1 = 3.536
β2 = 15.16
δ1 = 0.0399
δ2 = 0.6819
Fluorescentie / 1000
Afstand

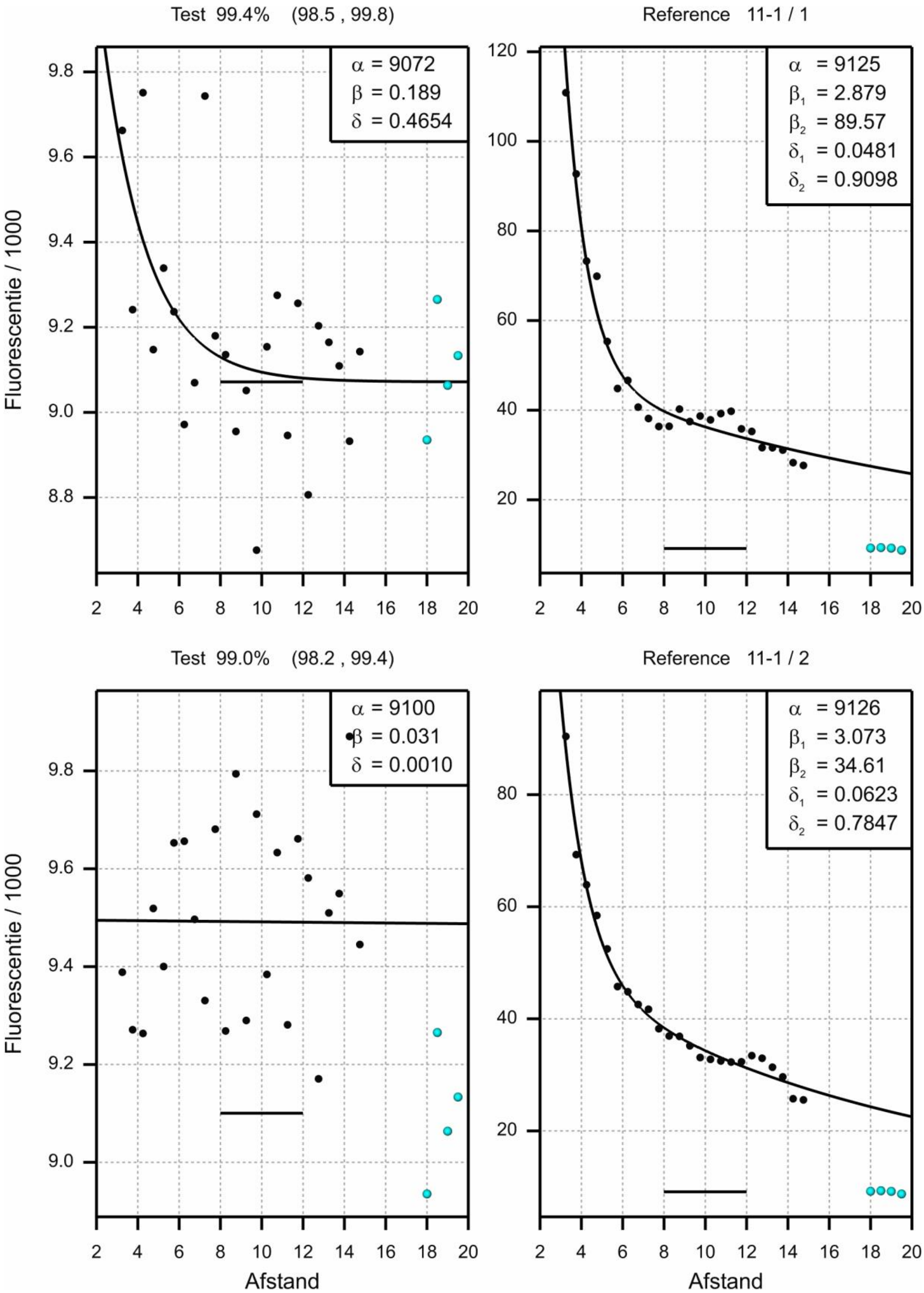

Test 99.5% (99.3 , 99.6)
α = 9164
β = 6.646
δ = 0.9082
Reference 10-6 / 1
α = 8007
β1 = 34.78
β2 = -
δ1 = 0.1853
δ2 = -
Test 98.4% (97.9 , 98.8)
α = 9563
β = 99.50
δ = 1.3053
Reference 10-6 / 2
α = 8037
β1 = 7.951
β2 = 36.65
δ1 = 0.0722
δ2 = 0.4317
Fluorescentie / 1000
Afstand

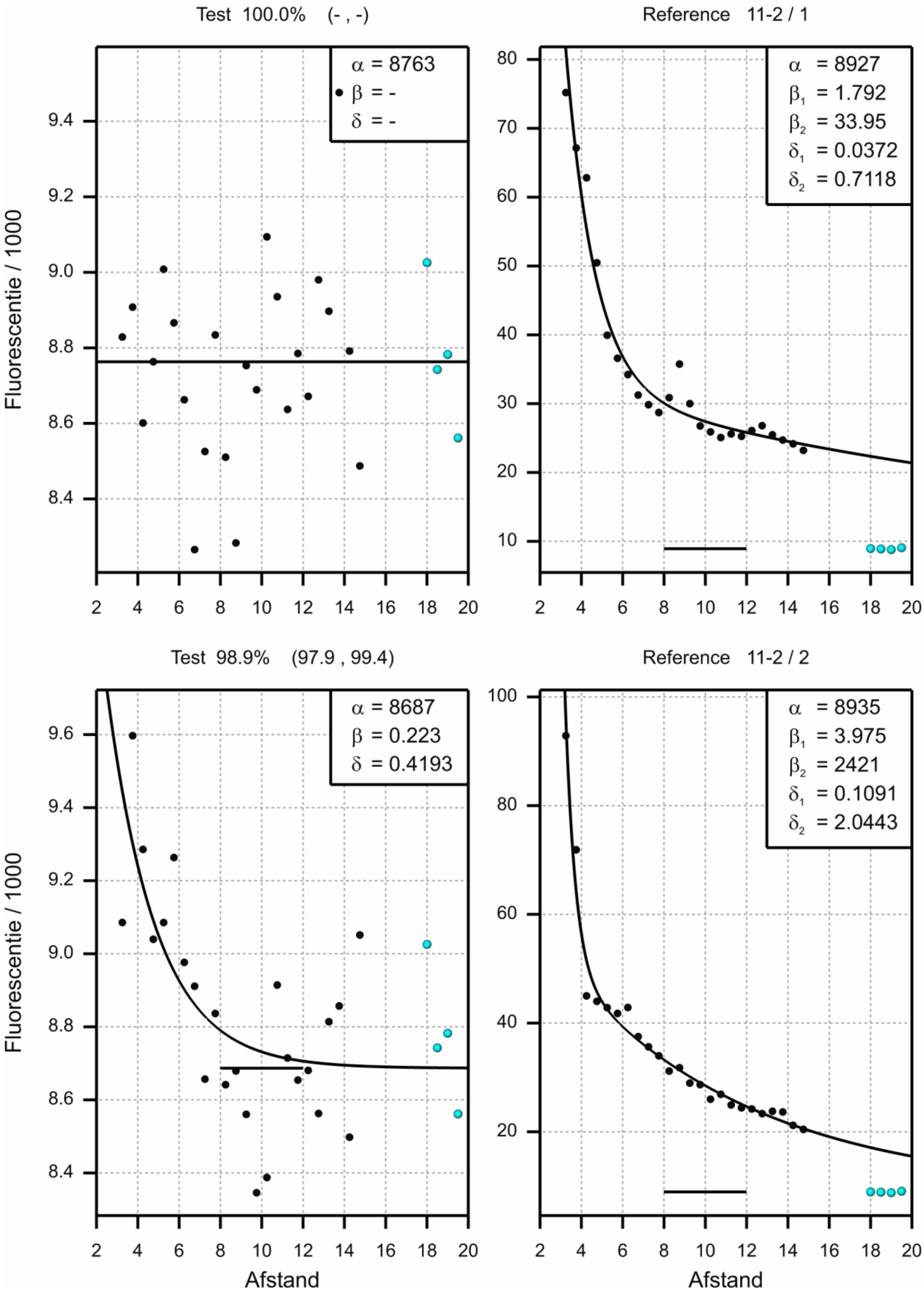


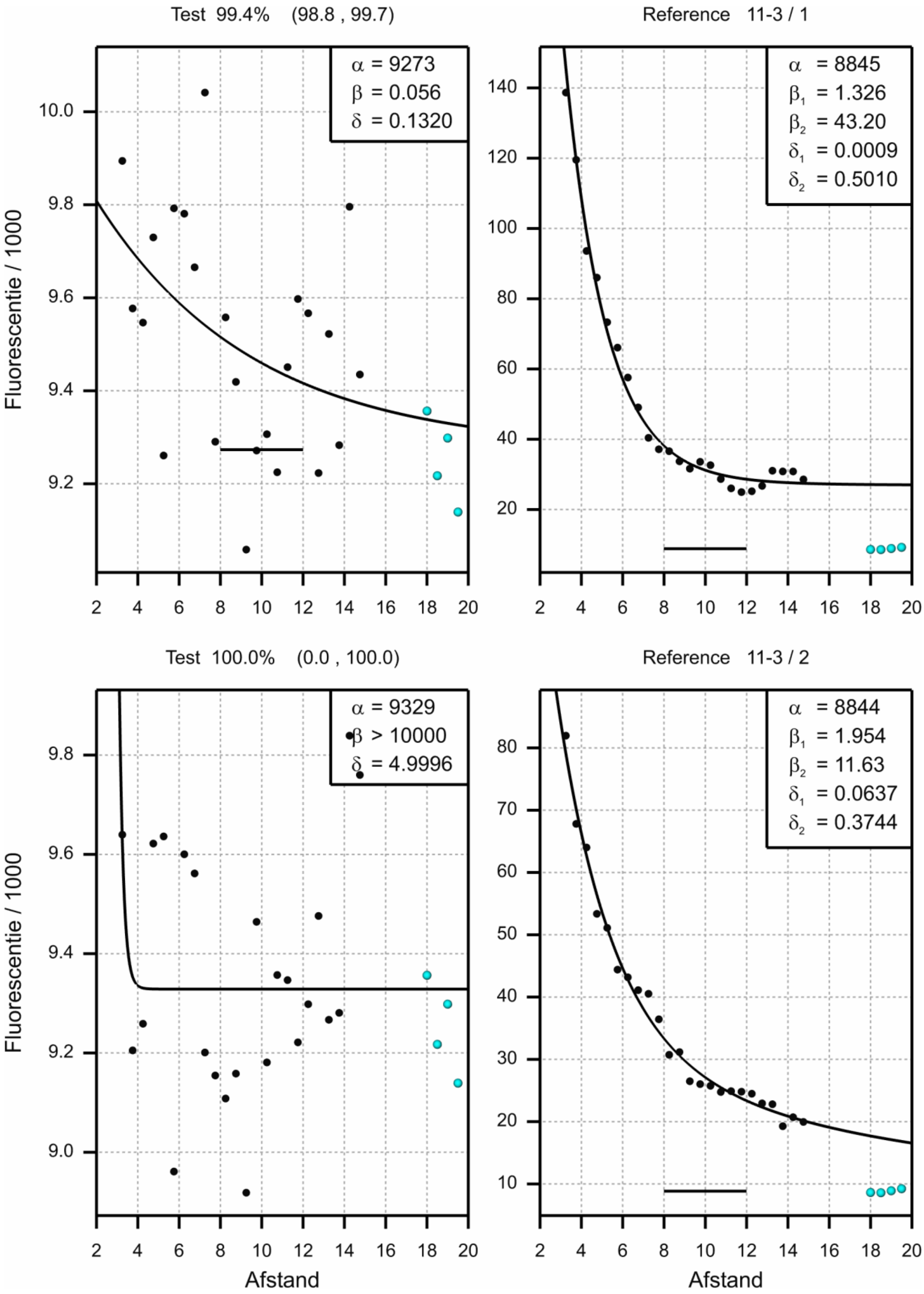
Test 98.6% (98.3 , 98.9)
α = 8347
β = 0.146
δ = 0.0708
Reference 10-7 / 1
α = 8207
β1 = 22.28
β2 = 333.8
δ1 = 0.2215
δ2 = 1.7511
Test 97.5% (96.9 , 98.1)
α = 9177
β = 2.101
δ = 0.5122
Reference 10-7 / 2
α = 8210
β1 = 1.986
β2 = 18.11
δ1 = 0.0752
δ2 = 0.2468
Fluorescentie / 1000
Afstand

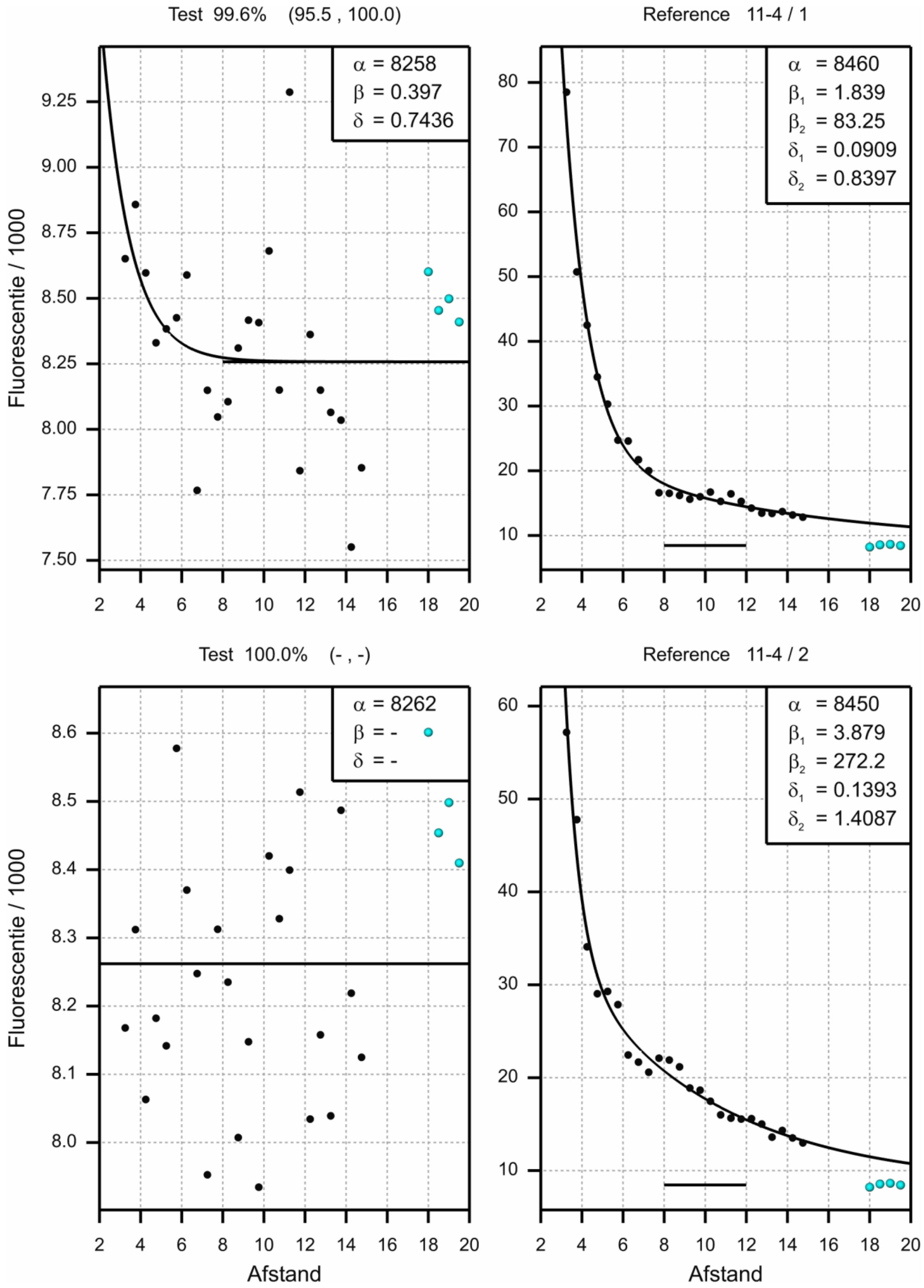

Test 98.6% (98.3 , 98.8)
α = 6351
β = 0.261
δ = 0.1489
Reference 10-8 / 1
α = 6516
β1 = 3.380
β2 = 44.07
δ1 = 0.0156
δ2 = 0.4189
Test 97.4% (97.1 , 97.7)
α = 6387
β = 0.451
δ = 0.1888
Reference 10-8 / 2
α = 6516
β1 = 1.575
β2 = 30.10
δ1 = 0.0009
δ2 = 0.3496
Fluorescentie / 1000
Afstand

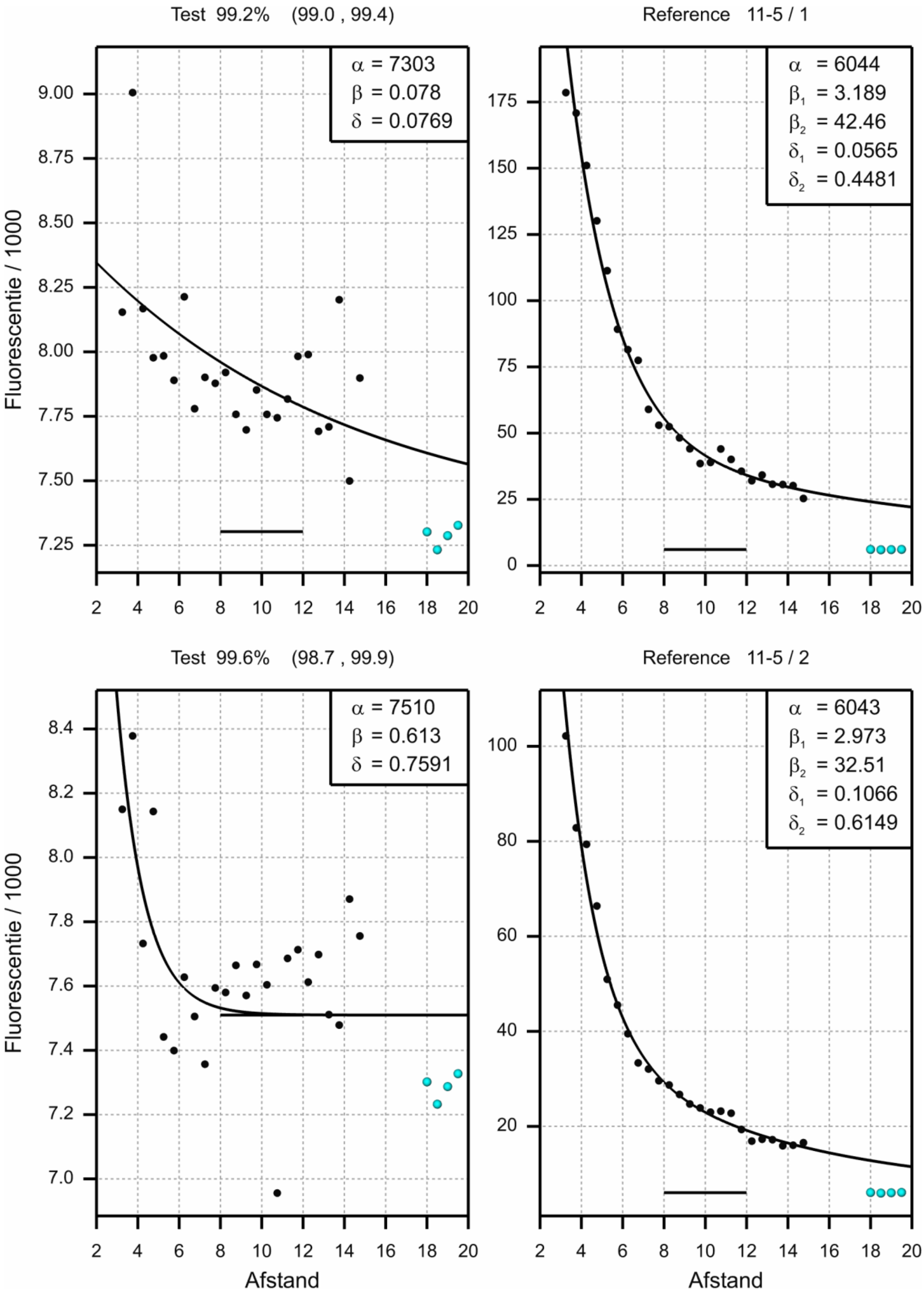

Test 98.2% (98.0 , 98.5)
α = 7091
β = 0.282
δ = 0.2052
Reference 10-9 / 1
α = 6886
β1 = 8.800
β2 = 58.74
δ1 = 0.1442
δ2 = 0.7441
Test 96.9% (96.2 , 97.4)
α = 7520
β = 4.156
δ = 0.7155
Reference 10-9 / 2
α = 6884
β1 = 6.889
β2 = 66.49
δ1 = 0.1274
δ2 = 1.2341
Fluorescentie / 1000
Afstand


Test 99.4% (98.5 , 99.8)
α = 9072
β = 0.189
δ = 0.4654
Reference 11-1 / 1
α = 9125
β1 = 2.879
β2 = 89.57
δ1 = 0.0481
δ2 = 0.9098
Test 99.0% (98.2 , 99.4)
α = 9100
β = 0.031
δ = 0.0010
Reference 11-1 / 2
α = 9126
β1 = 3.073
β2 = 34.61
δ1 = 0.0623
δ2 = 0.7847
Fluorescentie / 1000
Afstand

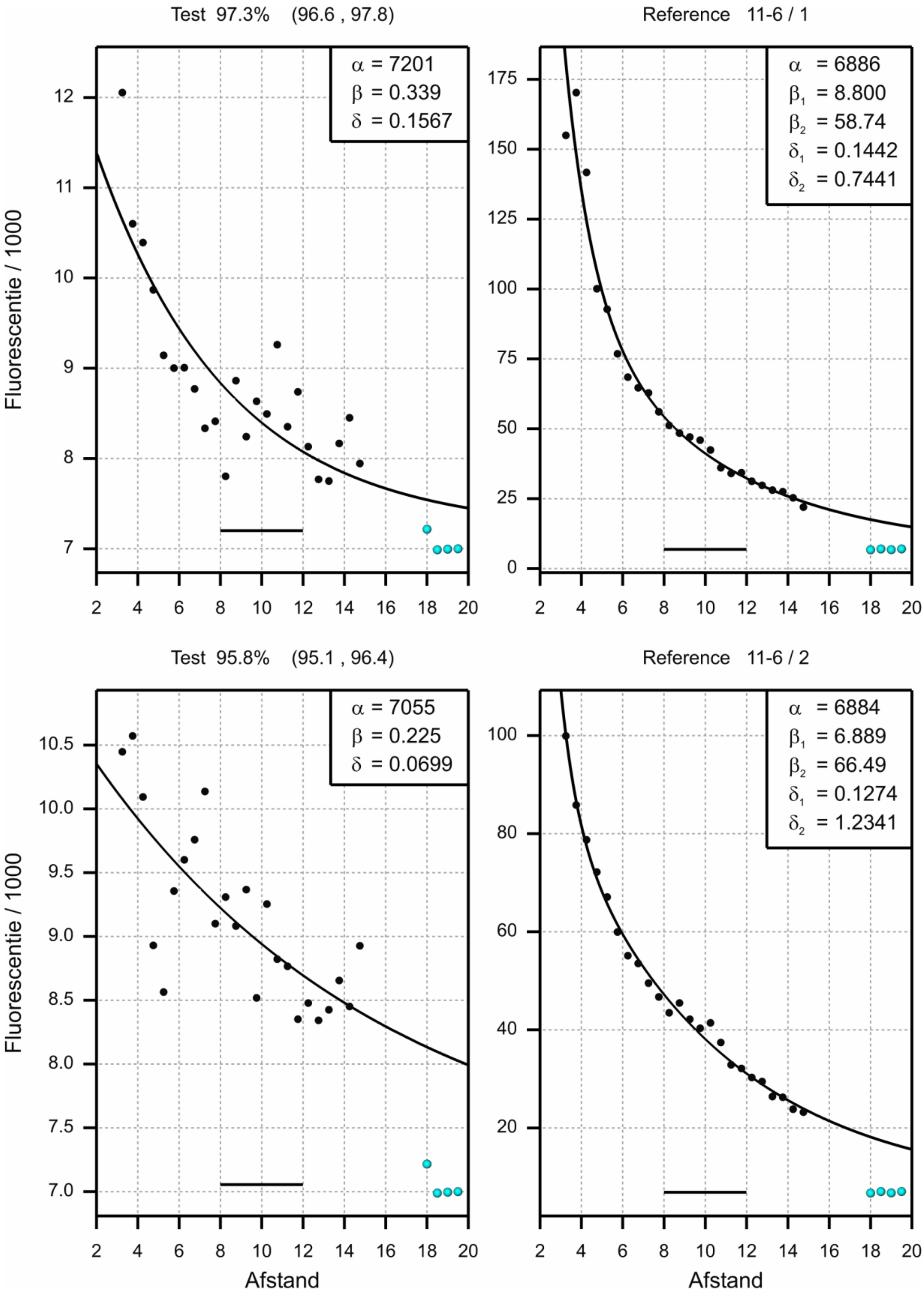

Test 100.0% (- , -)
α = 8763
β = -
δ = -
Reference 11-2 / 1
α = 8927
β1 = 1.792
β2 = 33.95
δ1 = 0.0372
δ2 = 0.7118
Test 98.9% (97.9 , 99.4)
α = 8687
β = 0.223
δ = 0.4193
Reference 11-2 / 2
α = 8935
β1 = 3.975
β2 = 2421
δ1 = 0.1091
δ2 = 2.0443
Fluorescentie / 1000
Afstand

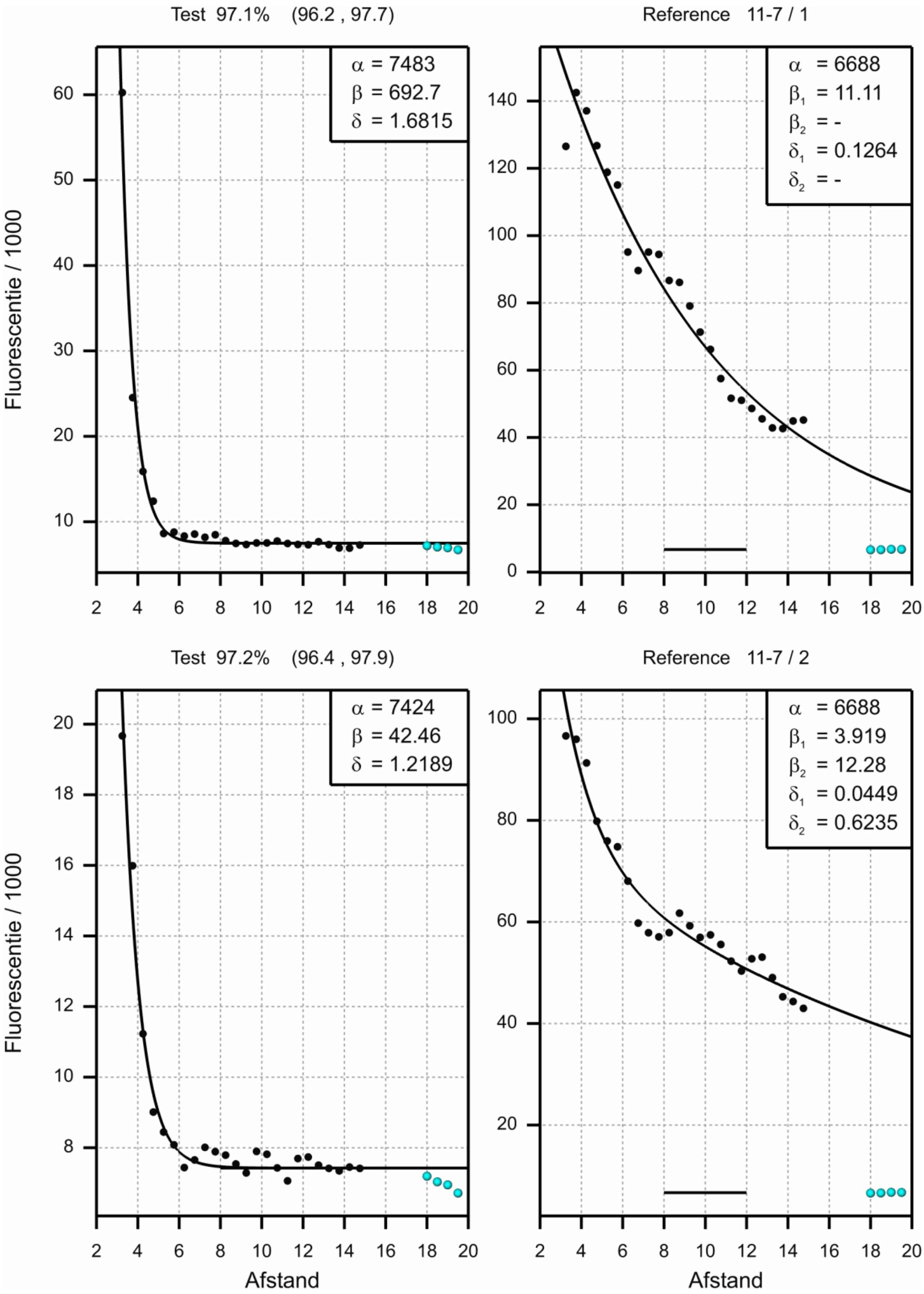

Test 99.4% (98.8 , 99.7)
α = 9273
β = 0.056
δ = 0.1320
Reference 11-3 / 1
α = 8845
β1 = 1.326
β2 = 43.20
δ1 = 0.0009
δ2 = 0.5010
Test 100.0% (0.0 , 100.0)
α = 9329
β > 10000
δ = 4.9996
Reference 11-3 / 2
α = 8844
β1 = 1.954
β2 = 11.63
δ1 = 0.0637
δ2 = 0.3744
Fluorescentie / 1000
Afstand


Test 99.6% (95.5 , 100.0)
α = 8258
β = 0.397
δ = 0.7436
Reference 11-4 / 1
α = 8460
β1 = 1.839
β2 = 83.25
δ1 = 0.0909
δ2 = 0.8397
Test 100.0% (- , -)
α = 8262
β = -
δ = -
Reference 11-4 / 2
α = 8450
β1 = 3.879
β2 = 272.2
δ1 = 0.1393
δ2 = 1.4087
Fluorescentie / 1000
Afstand

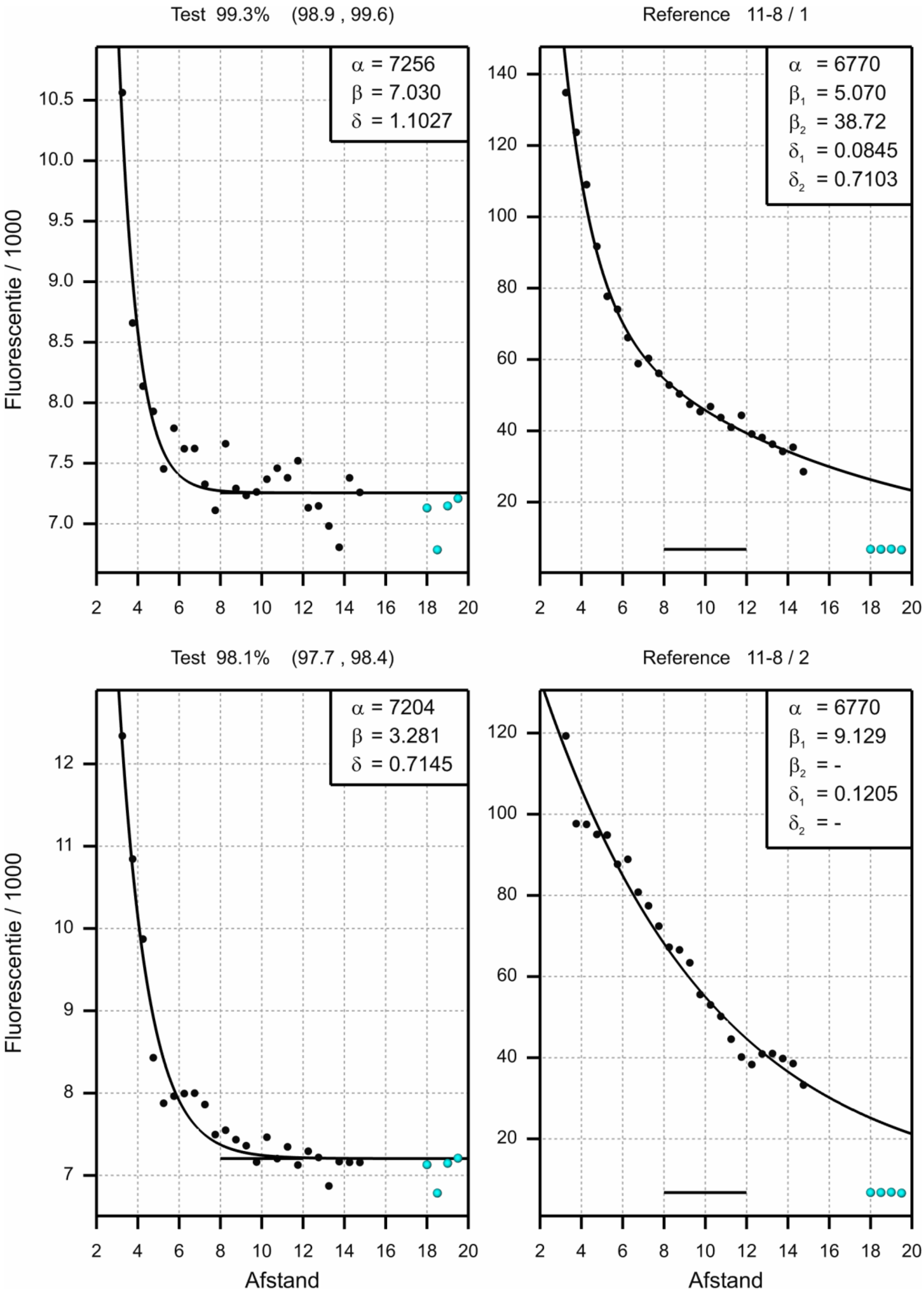


Test 99.2% (99.0 , 99.4)
α = 7303
β = 0.078
δ = 0.0769
Reference 11-5 / 1
α = 6044
β1 = 3.189
β2 = 42.46
δ1 = 0.0565
δ2 = 0.4481
Test 99.6% (98.7 , 99.9)
α = 7510
β = 0.613
δ = 0.7591
Reference 11-5 / 2
α = 6043
β1 = 2.973
β2 = 32.51
δ1 = 0.1066
δ2 = 0.6149
Fluorescentie / 1000
Afstand


Test 97.3% (96.6 , 97.8)
α = 7201
β = 0.339
δ = 0.1567
Reference 11-6 / 1
α = 6886
β1 = 8.800
β2 = 58.74
δ1 = 0.1442
δ2 = 0.7441
Test 95.8% (95.1 , 96.4)
α = 7055
β = 0.225
δ = 0.0699
Reference 11-6 / 2
α = 6884
β1 = 6.889
β2 = 66.49
δ1 = 0.1274
δ2 = 1.2341
Fluorescentie / 1000
Afstand



Test 97.1% (96.2 , 97.7)
α = 7483
β = 692.7
δ = 1.6815
Reference 11-7 / 1
α = 6688
β1 = 11.11
β2 = -
δ1 = 0.1264
δ2 = -
Test 97.2% (96.4 , 97.9)
α = 7424
β = 42.46
δ = 1.2189
Reference 11-7 / 2
α = 6688
β1 = 3.919
β2 = 12.28
δ1 = 0.0449
δ2 = 0.6235
Fluorescentie / 1000
Afstand



Test 99.3% (98.9 , 99.6)
α = 7256
β = 7.030
δ = 1.1027
Reference 11-8 / 1
α = 6770
β1 = 5.070
β2 = 38.72
δ1 = 0.0845
δ2 = 0.7103
Test 98.1% (97.7 , 98.4)
α = 7204
β = 3.281
δ = 0.7145
Reference 11-8 / 2
α = 6770
β1 = 9.129
β2 = -
δ1 = 0.1205
δ2 = -
Fluorescentie / 1000
Afstand

Appendix 2 Weather conditions during drift measurements

Mitterer VV Orchard sprayer:

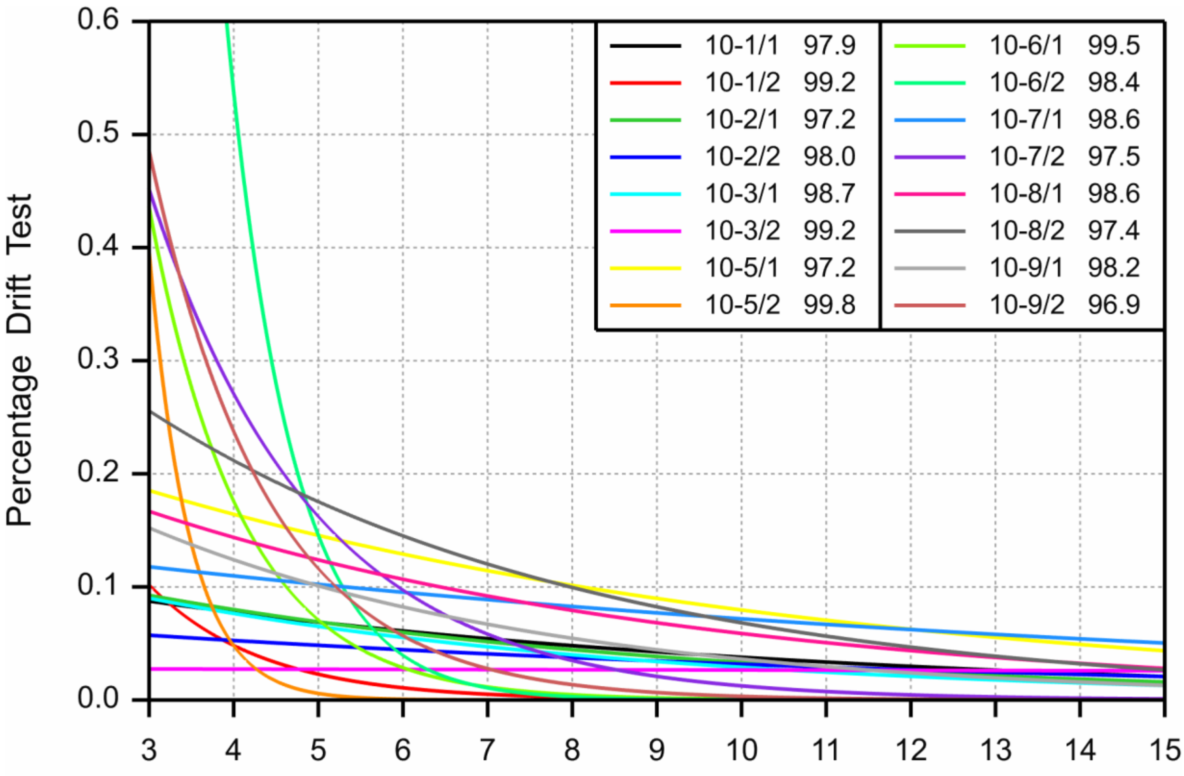
Technique	date		temperature [^{0}C] at		RH	Wind direction	windspeed [m/s] at				
		#	0.5 m	4 m	%	perpendicular=0^0	0.5 m	2 m	3 m	4 m	10 m
reference	14-oct-21	1	15.4	14.7	79	-19	0.9	1.9	2.6	3.1	5.0
	14-oct-21	2	15.0	14.9	75	-7	1.0	1.8	2.8	3.1	5.8
	15-nov-21	3	6.0	6.0	92	-3	0.5	1.1	1.5	1.9	3.3
	18-nov-21	4	11.7	10.0	71	-25	0.9	1.2	2.0	2.5	4.9
	19-nov-21	5	13.0	12.0	84	-14	0.7	1.1	1.9	2.2	3.8
	10-jun-22	6	21.2	20.3	61	-20	0.8	1.4	2.0	2.4	3.5
	10-jun-22	7	21.8	21.0	58	-15	1.0	1.5	2.1	2.5	3.9
	01-jul-22	8	21.2	19.7	44	-28	1.5	2.5	3.1	3.4	5.0
	25-jul-22	9	23.6	22.9	68	25	1.0	1.7	2.5	3.0	5.1
Miterer VV	14-oct-21	1	12.5	12.0	90	-26	0.8	1.4	2.0	2.4	3.7
	14-oct-21	2	14.0	14.0	78	-8	0.9	1.9	2.7	3.1	5.7
	15-nov-21	3	6.0	6.0	91	-28	0.6	1.0	1.5	2.0	3.5
	18-nov-21	4	11.2	10.8	68	-28	1.4	2.4	3.5	4.0	6.3
	19-nov-21	5	12.3	12.0	85	-5	1.0	2.0	3.1	3.8	5.8
	10-jun-22	6	22.2	20.8	59	-26	1.5	2.2	3.0	3.2	4.9
	10-jun-22	7	22.0	21.0	60	8	0.7	1.2	1.7	2.1	3.3
	01-jul-22	8	21.6	20.3	41	-7	1.1	2.0	2.8	3.3	4.8
	25-jul-22	9	24.6	23.6	56	17	0.6	1.1	1.6	1.9	3.1

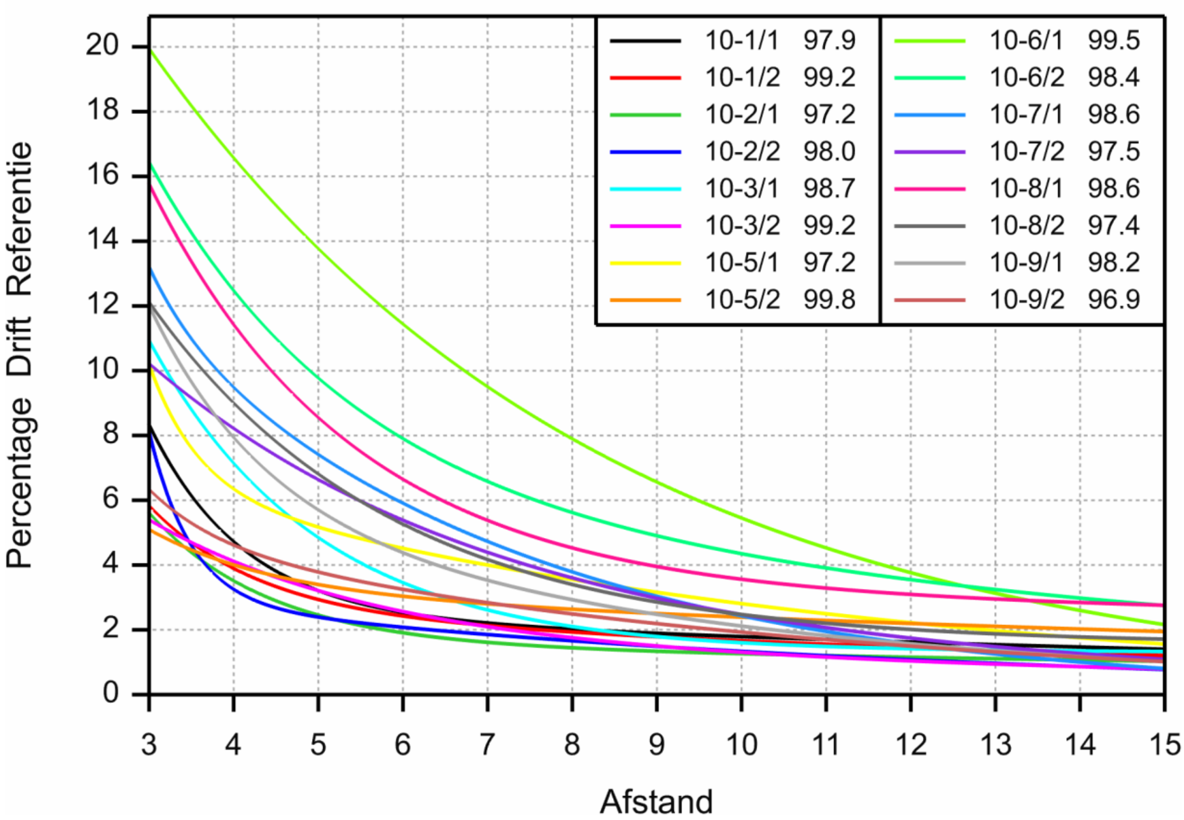
Mitterer VR Orchard sprayer:

Technique	date		temperature [^{0}C] at		RH	Wind direction	windspeed [m/s] at				
		#	0.5 m	4 m	%	perpendicular=0^0	0.5 m	2 m	3 m	4 m	10 m
Standaard	14-oct-21	1	15.4	14.7	79	-19	0.9	1.9	2.6	3.1	5.0
	14-oct-21	2	15.0	14.9	75	-7	1.0	1.8	2.8	3.1	5.8
	15-nov-21	3	6.0	6.0	92	-3	0.5	1.1	1.5	1.9	3.3
	18-nov-21	4	9.8	8.3	80	-29	0.8	1.6	2.4	2.8	4.4
	22-jun-22	5	26.8	24.8	29	-4	0.7	1.3	1.7	2.1	3.2
	25-jul-22	6	26.1	24.2	58	-7	0.9	1.8	2.5	3.0	4.8
	25-jul-22	7	24.3	23.3	56	0	1.3	2.4	3.4	4.2	6.6
	25-jul-22	8	25.3	24.0	47	10	1.3	2.3	3.5	4.0	5.9
Miterer VR	14-oct-21	1	15.0	14.0	81	-11	0.9	1.7	2.5	3.0	5.0
	14-oct-21	2	15.0	14.8	79	-17	0.7	1.3	2.1	2.6	4.4
	15-nov-21	3	6.0	5.0	91	-25	0.6	1.1	1.7	2.0	3.0
	18-nov-21	4	11.7	10.0	71	-25	0.9	1.2	2.0	2.5	4.9
	22-jun-22	5	27.2	25.3	30	-6	0.9	1.5	2.0	2.3	3.4
	25-jul-22	6	23.6	23.0	55	11	1.5	2.6	3.7	4.3	7.3
	25-jul-22	7	22.1	21.7	59	-4	1.1	2.3	3.3	3.8	5.4
	25-jul-22	8	24.8	23.4	50	-4	1.4	2.2	3.1	3.6	5.8

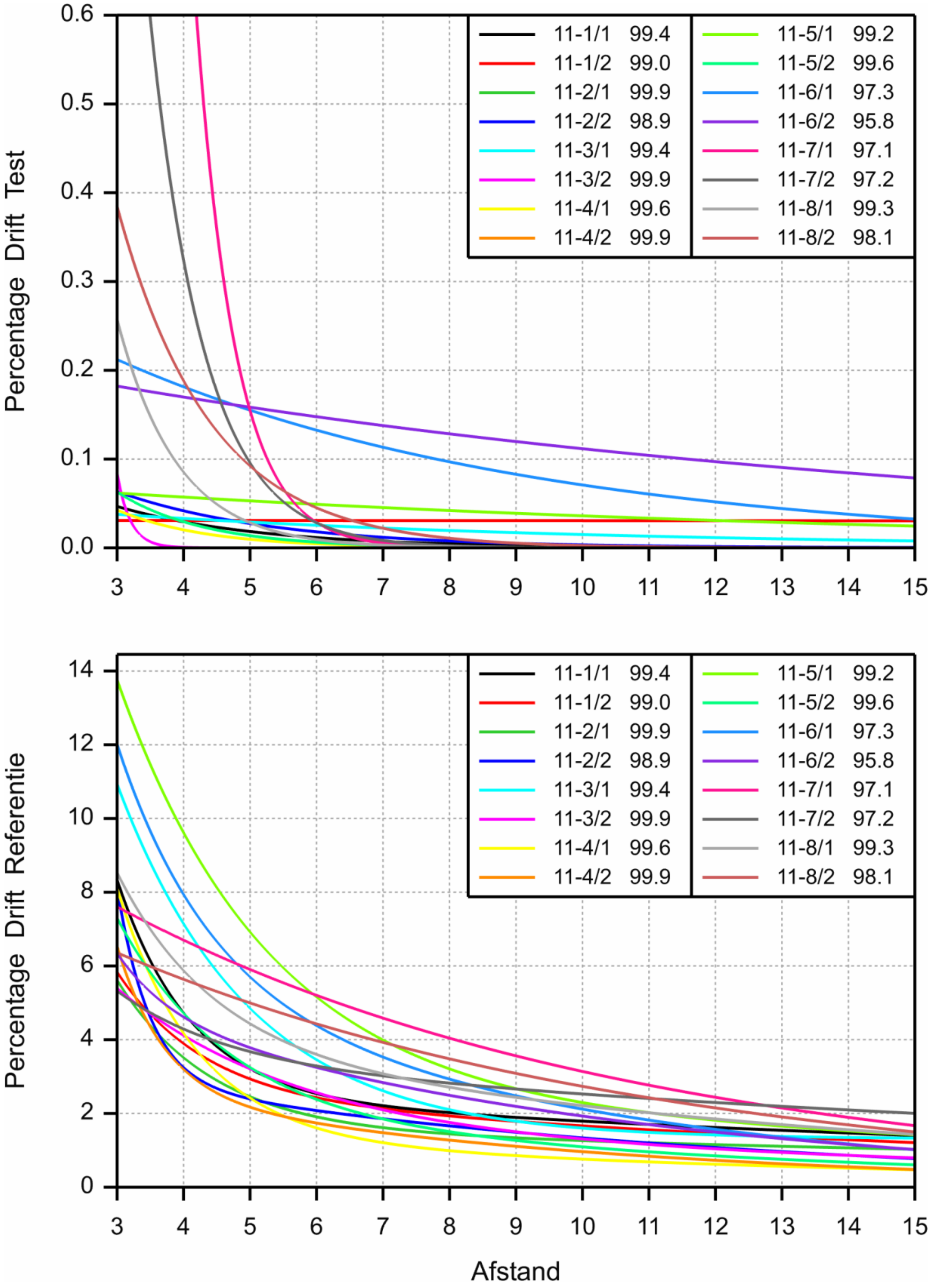
Appendix 3 Individual drift deposition curve fits

Mitterer VV:





Mitterer VR:



Percentage Drift Test
11-1/1 99.4
11-1/2 99.0
11-2/1 99.9
11-2/2 98.9
11-3/1 99.4
11-3/2 99.9
11-4/1 99.6
11-4/2 99.9
11-5/1 99.2
11-5/2 99.6
11-6/1 97.3
11-6/2 95.8
11-7/1 97.1
11-7/2 97.2
11-8/1 99.3
11-8/2 98.1
Percentage Drift Referentie
Afstand

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Report WPR-1182

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improve the
quality of life

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