SVERIGES
LANTBRUKSUNIVERSITET

1. Image processing for analysing spray deposits.

Procedure description

2. Deposit determinations in horizontal and vertical direction in a dense plant stand with the image analyser and the fluorimeter method

Per Eriksson (1)

Per Lagerfelt (2)

Institutionen för lantbruksteknik

Swedish University of Agricultural Sciences
Department of Agricultural Engineering

Rapport 128
Report

Uppsala 1988
ISSN 0283-0086
ISBN 91-576-3382-7

DOKUMENTDATABLAD för rapportering till SLU:s lantbruksdatabas LANTDOK, Svensk lantbruksbibliografi och AGRIS (FAO:s lantbruksdatabas)

Institution/motsvarande	Dokumenttyp	
Institutionen för lantbrukstekniK	Rapport	
	Utgivningsår	Målgrupp
	1988	F, R

Författare/upphov

1. Eriksson, Per
2. Lagerfelt, Per

Dokumentets titel

1. Image processing for analysing spray deposits. Procedure description
2. Deposit determinations in horizontal and vertical direction in a dense plant stand with the image analyser and the fluorimeter method

Ämnesord (AGROVOC)

Andra ämnesord

Image analyser, spray deposits, spray coverage, tracer,
Image processing, Qualitative deposits, Quantitative deposits, Sprayer

Projektnamn

Tillsatsmedel vid besprutning

Serie-/tidskriftstitel och volym/nr	ISBN
Rapport 128. Sveriges lantbruksuniversitet, inst. för lantbrukstekniK	91-576-3382-7
	ISSN 0283-0086

Språk	Sml-språk	Omfång	Antal ref.
Engelska	Engelska	24 s.	4 + 1

Postadress
SVERIGES LANTBRUKSUNIVERSITET
Ultunabiblioteket
Förvärvssektionen/LANTDOK
Box 7071
S-750 07 UPPSALA
Sweden

Besöksadress
Centrala Ultuna 22
Uppsala

Telefonnummer
018-17 10 00 vx
018-17 10 98
018-17 10 97

Telex
76062 ULTBIBL S

CONTENTS

ABSTRACTS

IMAGE PROCESSING FOR ANALYSING SPRAY DEPOSITS.
Procedure description

In the present studies, digital image processing equipment was used to make spray pattern analysis. A fluorescent tracer was mixed in the spray liquid to identify the spray deposit. The tracer, illuminated with UV-light in the analysis, makes the droplets white while the rest of the leaf becomes black.

Two different approaches have been made to document leaves. One approach is to photograph them with a normal 35 mm camera and make the analysis from the negatives. The other approach is to collect the images on a videotape.

To obtain good results of analyses when using negatives the image must be illuminated uniformly. This causes more work before an image is ready for analysis than when using video images.

In order to know the real size of a deposit, it must be related to something with known size. A ruler has therefore been put in the image for calibration.

Small area deposits will give a lower contrast than larger areas. The reason for this is unknown, but one theory is that small areas contain less tracer in proportion to their area than larger areas. Therefore small areas give poorer contrast than big areas.

It often happens that deposits are connected to each other and are thus segmented as one object. This is observed in the result when a small number of deposits is in the biggest interval which makes up 90-95 % of the total area. The reason for this is that the threshold is too high. This problem can be avoided by filtering the image. It requires that you can work with two fullsize images to avoid making the resolution worse.

DEPOSIT DETERMINATIONS IN HORIZONTAL AND VERTICAL DIRECTION IN A DENSE PLANT STAND WITH THE IMAGE ANALYSER AND THE FLUORIMETER METHOD

A preliminary investigation was made to investigate the possibility of minimizing the sampling procedure for deposit determination in field-and laboratory trials. Sample collection and analysis take up a great part of the time and work required. It is therefore important that this part of the research work can be rationalised with a preserved or even improved accuracy in the analytical values.

A suitable image analyser was procured during the spring of 1987 and interest was focussed on the relationship between coverage (obtained with the image analyser) and the deposition as per cent of spray per hectare (obtained with fluorimeter).

Spraying was carried out in a dense wheat crop after earing. Samples from nine different positions in the plant stand were collected.

Deposited spray in per cent of amount of spray per hectare (fluorimeter) was chosen as independent variable and coverage in per cent (image analyser) as dependent variable. The values were used to fit a linear regression model. It was found that the linear curve ($Y=0.734+1.538 \cdot X$, Y="coverage (%)" and X="recovery (%)") would give the best correlation.

The deposition studies revealed large differences in vertical direction and clearly emphasize the difficulty for droplets to penetrate dense crops. In addition, they also illustrate the very poor lateral spray distribution. Spraying with conventional nozzles in dense crops has a restricted possibility to give optimal results for pesticide control at deeper levels in the stand.

INSTITUTIONEN FÖR
LANTBRUKSTEKNIK

IMAGE PROCESSING FOR ANALYSING SPRAY DEPOSITS

PROCEDURE DESCRIPTION

Per Eriksson

POSTADRESS:
BOX 7033
750 07 UPPSALA

BESÖKSADRESS:
SÖDRA ULTUNA 12

TELEFON:
018-17 10 00

POSTGIRO:
1 56 67-9

INTRODUCTION

Until now it has been complicated to make quality decisions on spray patterns. However, the use of digital image processing now allows this to be done more easily. Earlier quantity decisions on spray patterns could only be made with, for example, the fluorimeter and droplet size had to be assessed visually. This was a fast method that was good as long there were big differences in droplet size in different samples and provided that the tests concerned relative estimations. For example, neither the average droplet size nor how many droplets there are in an interval can be assessed. When using digital image processing, on the other hand, this can be done since each droplet is handled individually. This is of great importance as it enables a quality decision to be made on the result. A quantity decision on the spray deposit can also be obtained by finding a relationship between the deposit area and volume.

PREVIOUS WORK

The visual method of Blinn & Lowell (1965) was used in one of the earlier studies to make quality investigations of the spray pattern. This method concerns the uniformity in spraying and relative deposits.

Carlton et al. (1981) used digital image processing equipment to establish the average spray pattern on the leaf surface. A fluorescent tracer was mixed with the spray liquid and the leaf was photographed. The analysis was made on the negatives.

To decide uniformity for areal spraying a transportable image processing system for pattern analysis was developed (Sistler et al., 1982). The aims were to be able to handle droplets individually, to decide surface coverage and to do statistical handling of data on droplets. The image was digitized in 320x240 pixels with 64 grey levels of light intensity.

Kranzler et al. (1985) used image processing equipment to decide droplet size and to make analyses of granular materials. The equipment used an image digitized in 256x256 pixels with 256 grey levels.

DIGITAL IMAGE PROCESSING EQUIPMENT

Hardware

In the present studies, digital image processing equipment was used to make spray pattern analysis (see Figure 1). The hardware consists of a PC/AT 640 kB RAM, a video camera (Sanyo VC 1900) and a monitor (Hitachi CM 1216 AE). From the video camera, signals are sent via an A/D-converter to an image memory. From the image memory, signals are sent to the monitor and the computer. A 90 mm macro lens was used on the camera. Since the camera was mounted on a camera-stand there were good possibilities to vary the part of the image wanted and thereby affect the resolution of the image. The objects were illuminated with two UV fluorescent tubes, Philips TLD 18W/08. Since there are only small areas (<1 dm^2) that will be illuminated and by directing the light, it is possible to get a uniform illumination all over the image.

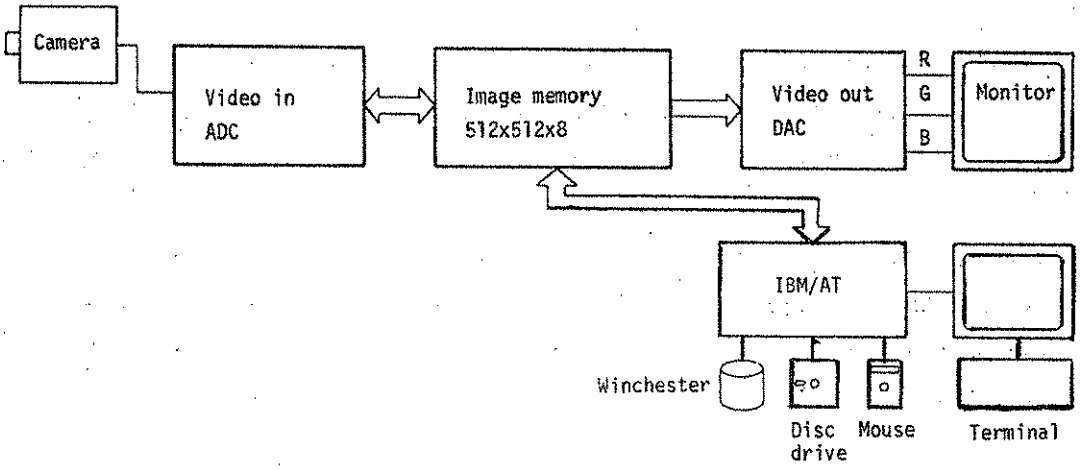

Figure 1. The hardware used for digital image processing of the spray deposits.

Program

The program works with a resolution of the image in 512x512 pixels with 256 grey levels. To make quality decisions of spray patterns the program has to handle the following:

- to count the number of droplets on the leaves,
- to measure deposit geometry (area, perimeter, etc),
- to retain information on the droplets for later statistical analysis,
- to make statistical analyses.

The program must be able to separate individual droplets to achieve this. The procedure for the segmentation is that the operator assigns the threshold that separates the objects from the background. That is interpreted like all pixels in the image with a grey level higher, or lower, than the threshold are parts of objects. After searching the image all objects are marked. Position, area, perimeter and form of objects are saved and can be analyzed later. If you are not satisfied with the result you can re-run the segmentation, possibly after improving the image. By separating the leaf and calculating its area the spray coverage can be decided.

ANALYSIS

A fluorescent tracer was mixed in the spray liquid to identify the spray deposit. The tracer, illuminated with UV-light in the analysis, makes the droplets white while the rest of the leaf becomes black. That makes a high contrast on the image and it is easy to separate the deposit from the background. To get a high contrast in the image a Kodak Wratten gelatin filter no. 2B was mounted on the objective. The filter removes shortwave light which enables the object to be illuminated with a higher intensity, thereby improving the contrast in the image.

If the result of the analysis is to be reliable, the leaves must be analyzed or documented fairly soon after the spraying. This is because the tracer breaks down when it is exposed to UV-light. If the leaves are left in sunlight, it results in the deposit rapidly becoming undetectable. To avoid this, the leaves are put in darkness immediately after collection until it is time to analyze or to document them. If the leaves are left in darkness for a long time, the leaves will wither. When this happens the leaf get lighter and that causes the contrast in the image to be worse since the tracer has poorer contrast on a light background. The tracer itself bleaches when the water in the spray

liquid evaporates. That means that the chances to get a good analytical result decrease the longer the time between spraying and analyzing. The results from the early analyses therefore cannot be compared to the later ones.

Documentation

There are several reasons for documenting the samples instead of analyzing them immediately. When documenting the samples you avoid the above mentioned problems because documentation of all samples is much faster than analyzing.

Thus more samples can be taken if you document them instead of analyzing directly. Thereby your results are more reliable. Since the samples are saved you do not have to analyze them immediately. This can wait until there is more time available. You also have an image you can return to and eventually do a new analysis. Documentation results in extra work. In analyses where it is important to get results quickly and where they are not going to be worked up afterwards, for example in measurements of area, there is frequently no point in documenting the results. This work can then be avoided. In more complex analyses it is useful to document all samples.

Two different approaches have been made to document leaves. One approach is to photograph them with a normal 35 mm camera and make the analysis from the negatives. The other approach is to collect the images on a videotape. Both techniques are discussed below.

An advantage in using the camera is that the hard copies allow an initial comparison to be made to see whether any analysis is meaningful. When the images are recorded on videotape this overview is impossible since only one image at a time can be studied. Making analyses from negatives requires more work than from videotaped images. When images are taken from video the images are exactly the same as they were recorded. There is no opportunity to change the grey scale in the image once it has been saved. When negatives are used you get a mirror image of the original and you have to adjust diaphragm and sharpness on the

video camera. To obtain good results of analyses when using negatives the image must be illuminated uniformly. This causes more work before an image is ready for analysis than when using video images.

The camera used has two exposure alternatives. The first is that you choose both diaphragm and shutter time. This means that you yourself ensure that the images are correctly exposed. The other way is to adjust the diaphragm yourself and let the camera decide the shutter time so that the image is correctly exposed. Of these two approaches the later is the easiest to handle and was therefore used here. Despite the images being illuminated in the same way with the same intensity, you can see that they are not exposed in the same way. It is not known whether this depends on a difficult illumination situation or whether the exposure meter in the camera was not good enough. Since the images are exposed differently the diaphragm selected must be changed in the analysis because the image will be either too dark or too light. Thus the same threshold in all images cannot be used, which means that a standard in the analysis is not possible as can be used with video images (if they are illuminated uniformly). Instead, a suitable threshold must be found in each image.

Threshold

It is up to the operator to decide the threshold. The operator colours the image so that each pixel above the anticipated threshold gets a different colour, for example red. In that way the operator finds the threshold by introducing some grey levels. It is a balance between getting as large a part of the deposit as possible and a minimum of noise. If the contrast in the image is not good enough, which makes it difficult to separate the deposit from the leaf, the contrast can be improved by the image processing functions available. But using this function causes problems because you must be able to work with two images at the same time and the system only allows you to work with one fullsize image (512x512 pixels). If you want to process the image you have to accept a decrease in resolution. Then you work with an 256x256 pixel image.

Segmentation

In the analysis two things must be separated in the image - the deposit and the leaf. To make the analytical work easier it is suitable to place the leaf on a dull, dark surface whereby the deposit will be lighter than the leaf (on hard copies) and the leaf will be lighter than the background. If a light background is used it is easier to separate the leaf from the background, but separation of deposit gets more difficult and more time-consuming. The light background will be separated as an object and will thus be classified as deposit.

If a light background is used when analyzing, there are two ways to avoid errors. You can avoid separating the background or avoid getting it in your result transcription. To avoid separation the operator has to darken the background so that its grey level is below the threshold. This require much work and great precision and is not suitable for large amounts of material. Instead, if the background is classified as a deposit this assumes that all parts of the backgrond (it can be segmented) are bigger in size than the largest deposit. All areas larger than the biggest deposit are then removed and thus the background is removed from the transcription. This is the fastest method and the one that affects the result least since the biggest deposit is generally only a fraction of the background area. This method is consequently often the best to use. However, it requires a viewing of the areas so that the limit between deposit and background can be decided correctly.

There are two ways of segmenting the image. One is to let the computer segment the image automatically and mark and measure objects that have been found. This is the method generally used because it is the fastest. A disadvantage is that there may be a lot of noise in the results, especially if the image is not illuminated uniformly. The other way is that the operator points at the objects and the computer does the marking and measuring. This method is suitable when there are few objects in the images and different thresholds on the objects are used. If the threshold is correctly chosen this method gives rise to a minimum of noise in the result since you have to point at a pixel that does not belong to an object to receive noise.

Calibration

In order to know the real size of a deposit, it must be related to something with known size. A ruler has therefore been put in the image for calibration. This provides flexibility in resolution since calibration with an object of known size may result in there being insufficient space for the object in the image or that the object is too small to give satisfactory precision in resolution. The ruler is very useful for sharpening the image since it is difficult to sharpen an image simply containing deposit.

Processing of results

After segmentation the results can be processed. The first step is to establish how much deposit there is in the result. The rest is removed. One filtering is almost always necessary, namely the one to remove noise. Then you decide the size of the area not to be classified as noise and remove all objects with an area less than that. This causes deposits with a small area to be removed but this is no problem because objects with such small areas can hardly be seen by man and therefore they are not identified as being removed. A further filtering may be necessary to remove big objects, for example when a light background has been used. When only objects of interest are left, they are sorted into classes and the result is written out, see appendix 1.

DISCUSSION AND CONCLUSIONS

Small area deposits will give a lower contrast than larger areas. The reason for this is unknown, but one theory is that small areas contain less tracer in proportion to their area than larger areas. Therefore small areas give poorer contrast than big areas. To avoid noise there is a risk that the threshold is chosen too high and small areas are missed. It would be of great help to improve the image contrast by filtering and thereby make it easier to find small objects. This, however, is not a good solution to the problem. To be able to filter the image the

resolution has to be reduced, which may cause the smallest areas to disappear and thereby remain unaffected by the filtering. Consequently, there is no point in filtering the image to more easily achieve small areas in the result. In order to utilize the filtering processes maximally, it must be possible to work with at least two fullsize images. It must be possible to add one image to another.

It often happens that deposits are connected to each other and are thus segmented as one object. This is observed in the result when a small number of deposits is in the biggest interval which makes up 90-95 % of the total area. The reason for this is that the threshold is too high. If it was lower then many deposits would be missed and the result would be wrong. This problem can be avoided by filtering the image. It requires, as mentioned above, that you can work with two fullsize images to avoid making the resolution worse.

It is difficult to get the illumination uniform all over the image. If the illumination is not uniform some of the deposits will be illuminated with a higher intensity and will reflect more light and thus become lighter than the other deposits. The background in the more strongly illuminated area is also higher than the surroundings and may cause trouble with noise during the analysis. There are more problems with uniform illumination when using negatives than when using video images. When negatives are used you must produce good illumination twice, first when documenting and later when analyzing. It would be useful to be able to compensate non-uniform illumination in the image afterwards by means of software.

Even if a uniform illumination of the object can be achieved it is not certain that the image on the monitor is illuminated uniformly. That depends on the influence of the diaphragm in the objective. When using a small diaphragm there will be an area in the middle of the image that is lighter than the rest. The bigger the diaphragm, the bigger will be the lighter area in the image. For the analysis this means that the threshold is affected by the diaphragm selected and that the quality of the analytical result is affected by the diaphragm. To avoid the problem of diaphragm choice, the area to be analyzed should be in the lighter

area. It is an advantage to make this area as large as possible. When documenting and analyzing, the biggest diaphragm is used. The normal function of the diaphragm will then be replaced by grey filters mounted on the objective.

When deciding on the deposit coverage of the leaf, the area of each deposit must be known. However, this provides no information on the droplet size in the spray. To find a correlation between the droplet diameter in the spray and the deposit on the leaf is difficult because it depends on many difficultly decided parameters, e.g., the surface tension of the liquid, the energy of the droplet when hitting the leaf, the nature of the cuticle, the angle of the leaf, etc.

LITERATURE

Blinn, R.C. & Lowell, J.B. 1965. A technique for observing spray pattern of Malathion and other organic phosphate insecticides using spray-deposit assessment cards. Journal of Economic Entomology 58(6), 1159-1160.

Carlton, J.B., Bouse, L.F., O'Neal, H.P. & Walla, W.J. 1981. Measuring spray coverage on soy beans. Trans. ASAE 24(5), 1108-1110.

Kranzler, G.A., DeVoe, D.R., Downs, H.W. & Stone, M.L. 1985. Agri-Mation 1. Proceedings of the Agri-Mation 1 Conference & Exposition, 136-141. St Joseph, MI:ASAE.

Sistler, F.E., Smith, P.A. & Rester, D.A. An image analyzer for aerial application patterns. Trans. ASAE 25(4), 885-887.

INSTITUTIONEN FÖR
LANTBRUKSTEKNIK

DEPOSIT DETERMINATIONS IN HORIZONTAL AND VERTICAL DIRECTION IN A DENSE PLANT STAND WITH THE IMAGE ANALYSER AND THE FLUORIMETER METHOD

Per Lagerfelt

POSTADRESS:
BOX 7033
750 07 UPPSALA

BESÖKSADRESS:
SÖDRA ULTUNA 12

TELEFON:
018-17 10 00

POSTGIRO:
1 56 67-9

DEPOSIT DETERMINATIONS IN HORIZONTAL AND VERTICAL DIRECTION IN A DENSE PLANT STAND WITH THE IMAGE ANALYSER AND THE FLUORIMETER METHOD

Per Lagerfelt
The Swedish University of Agricultural Sciences
Dept. of Agricultural Engineering
Box 7033
S-750 07 UPPSALA
Sweden

INTRODUCTION

A preliminary investigation was made to investigate the possibility of minimizing the sampling procedure for deposit determination in field-and laboratory trials. Sample collection and analysis take up a great part of the time and work required. It is therefore important that this part of the research work can be rationalised with a preserved or even improved accuracy in the analytical values.

During 1986 the idea occurred of acquiring an image analyser as a complement to the fluorimeter method. The fluorimeter gives the quantity of deposited spray in ug per collector (area) and/or the percentage of discharged spray. It gives no information about the droplet distribution on the collector, or how much of the collector that has been covered by spray. A substantial sample material and high accuracy of the analysis procedure are required for representative analytical values. The method is very labour-intensive.

A suitable image analyser was procured during the spring of 1987 and interest was focussed on the relationship between coverage (obtained with the image analyser) and the deposition as per cent of spray per hectare (obtained with fluorimeter).

LABORATORY EXPERIMENTS

Experimental plan

The experimental equipment consisted of a rail track with a two-meter long spray boom equiped with nozzles (TeeJet 110 01) mounted with 40 cm spacing. The liquid pressure was 4.0 bar which results in a volume median diameter (VMD) of 255 µm (Lagerfelt, 1987). The collectors were wheat plants (after earing) which had been dug up and replanted in a box (2x1 m). Boom height over the ears was 45-50 cm (Fig. 1).

After spraying, leaves from nine different positions in the plant stand were collected (Fig. 2). The sample position is indicated in horizontal direction as A - directly underneath a nozzle, B - 10 cm from the nozzle, C - in between two nozzles. The leaves were gathered from three levels, indicated as I, II and III. 12 leaves were gathered from each position. Of a total of 108 leaves collected 99 were analysed.

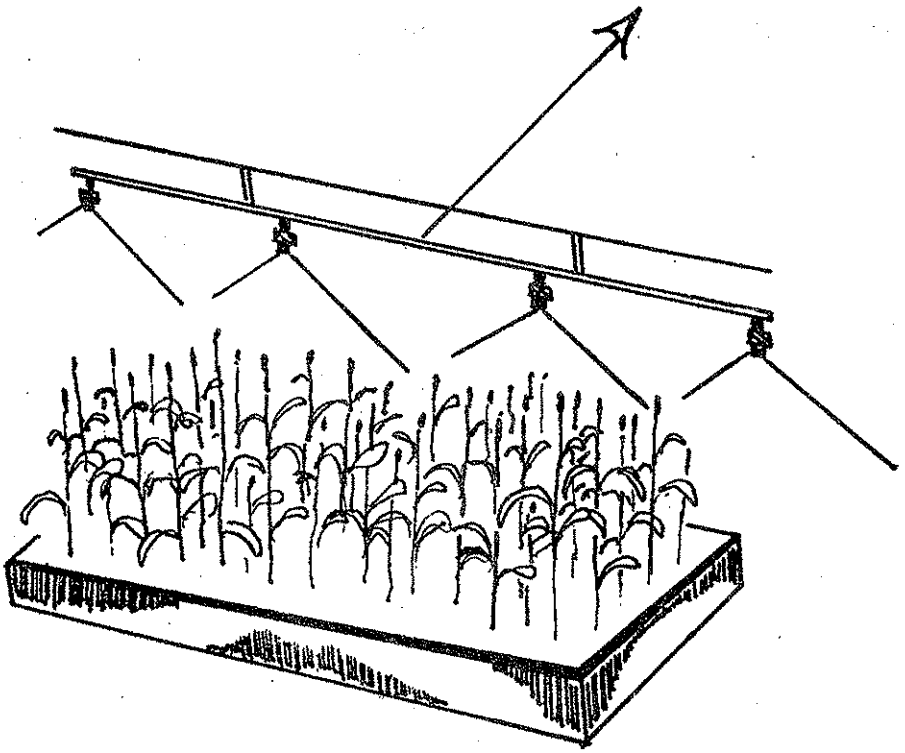

Figure 1. Spraying of a dense wheat crop after earing. Rail track with spray boom, nozzle spacing 40 cm and boom height 45-50 cm over the wheat ear.

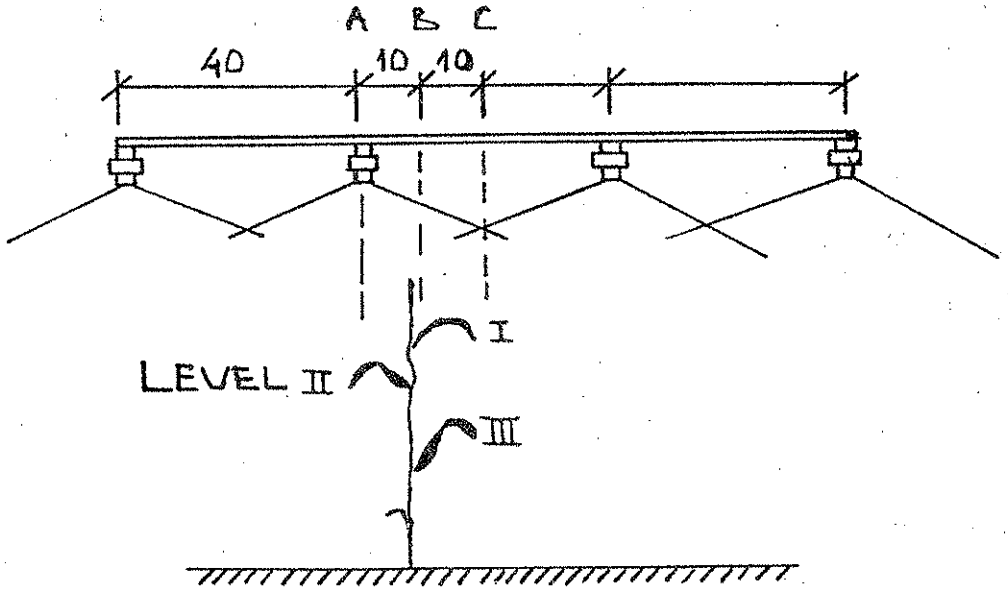

Figure 2. The sample positions in the plant stand indicated as IA, IIA, IIIA, etc. Roman numerals indicate the leaves' positions in vertical direction, the letters represent the leaves' positions in horizontal direction.

Analytical procedure

Image analyser

Each leaf was picked and analysed separately. A printout obtained from the work with the image analyser is found in app. 1, where the droplets are grouped in size intervals based on the drop spot diameter. The number of droplets in each interval and their combined area is indicated. Cumulative area expressed in mm^2 and as per cent is also given in the printout. To summarize the information, the total number of droplets on the leaf, the total leaf area covered and the leaf's total area (both sides) are given. In addition, the coverage in per cent as a result of total covered area times 100 divided by total leaf area is also given.

Fluorimeter equipment

To quantify the deposition, a fluorescent tracer was added to the spray liquid. In order to extract the fluorescent tracer the leaves were rinsed with an adequate volume of extraction solvent (carbon tetrachloride). The concentration of the fluorescent tracer was measured in the solution obtained. With known relationships between concentration, the wheat leaf area, amount of spray per hectare and extraction solvent, it was possible to calculate the percentage of deposition and the deposition in µg per collector. The deposition was calculated using the following formulas;

Deposition (Recovery) (%) = $(I \cdot V \cdot 10/D \cdot S)$

I = Fluorimeter reading (µg/l)
V = Volume (ml) of extraction solvent
D = Dose of fluorescent tracer per hectare (g/ha)
C = Collector area (cm^2)

Deposition in µg/collector = $I \cdot V/1000$

App. 2 shows a printout of the result from the analytical work with the wheat leaves gathered. In this example, 12 leaves from position IA have been analysed. It appears from the values in column "Recovery in %" that great differences in deposition exist between the examined leaves.

RESULTS

Correlation between coverage and deposited spray

Deposited spray in per cent of amount of spray per hectare (fluorimeter) was chosen as independent variable and coverage in per cent (image analyser) as dependent variable. The values were used to fit a linear regression model. It was found that the linear curve ($Y=0.734+1.538 \cdot X$, Y="coverage (%)" and X="recovery (%)") would give the best correlation (app. 3). Since great differences in deposition were found both in horizontal and vertical direction in the plant stand, fitting of sample values was also carried out separately for the various sampling positions. App. 4 shows a printout of the results of fitting sample values from position IA.

Tables 1 and 2 summarize the results from all computer runs. The quantitative deposit attained with the fluorimeter is given as X-values and data attained with the image analyser as Y-values. The greatest deposition was obtained at position IA. The deposition then declines rapidly with increasing lateral distance. The deposition regarding position IC is only 24% of the one recorded directly beneath a nozzle. For positions IIC and IIIC, 16 and 8% respectively are obtained in the same way. The differences in deposition in vertical direction are also very large. Beneath the nozzles at level I, approx. 16% of the spray was recovered and at level III approx. 11%. The difference in deposition midway between two nozzles is most striking, where at level I approx. 3.9% and at level III only 0.92% were recovered. At position IIIC the deposition was only 6% of what it was at position IA. A similar reasoning also applies to the coverage. Regression analyses were carried out for all data. Figure 3 depicts a 90% confidence interval for the deposition (measured with fluorimeter) as a function of coverage (measured with image analyser).

Table 1. Specification of computer runs for individual sampling positions. X-values indicate the measured deposition in per cent attained with the image analyser. The type of curve which best corresponded to the sample values is indicated with the correlation for that curve.

	Sampling position								
Mean value	IA	IB	IC	IIA	IIB	IIC	IIIA	IIIB	IIIC
X	15.95	7.71	3.90	12.70	5.51	2.04	11.39	3.51	0.92
ln(x)	2.70	1.75	0.99	2.52	1.25	0.38	2.22	0.49	-0.38
Y	25.45	14.03	6.05	20.87	10.61	2.44	16.86	5.47	2.77
ln(y)	3.12	2.27	0.99	2.98	1.81	0.004	2.55	-0.02	-0.39
Correlation	0.715	0.960	0.979	0.656	0.824	0.838	0.969	0.977	0.509
Chosen curve	pow	pow	lin	pow	lin	lin	pow	lin	exp

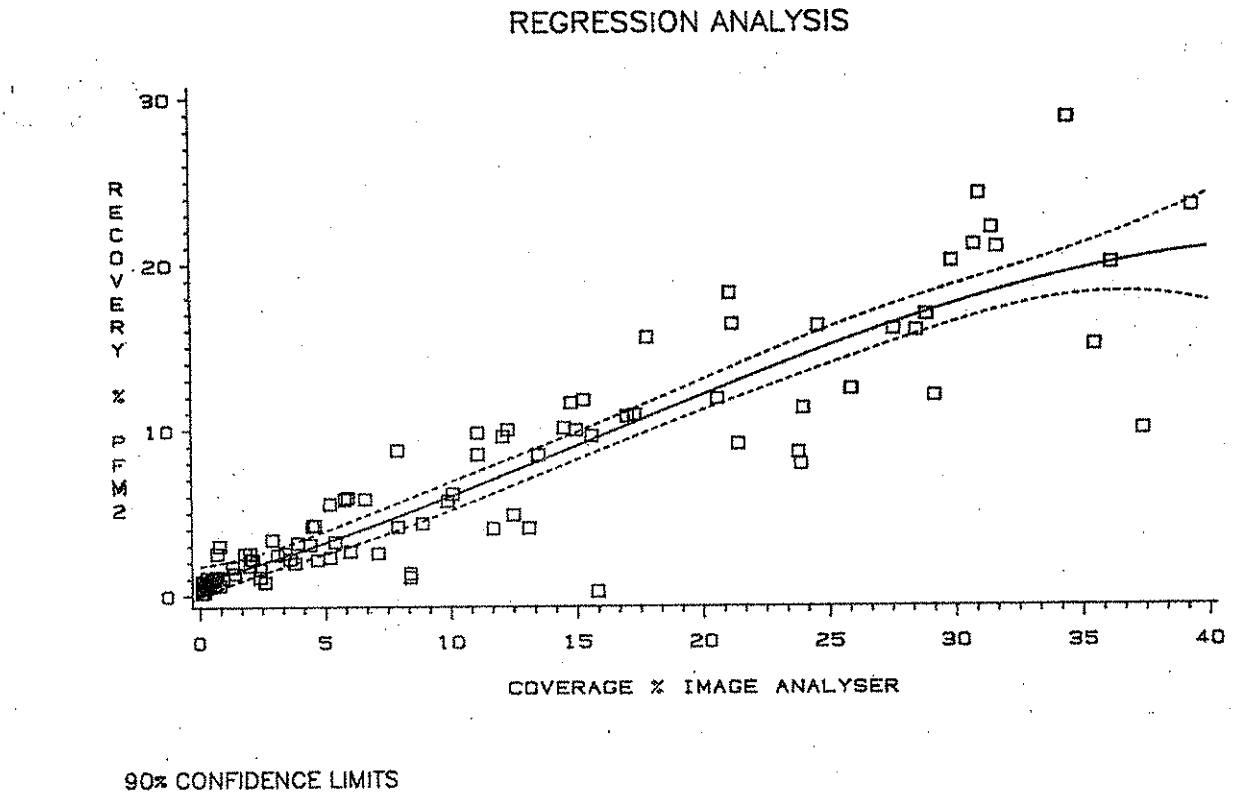

Figure 3 Regression analysis (90% confidence limits) was carried out for all experimental data on deposition as (measured with fluorimeter) a function of coverage (measured with image analyser).

Table 2 shows the equations found to give the best correlation with the observed values. Satisfactory correlation was found for positions IB, IC, IIIA and IIIB. The poorest correlation was found in IA, IIB and IIIC. As regards the deposition, these positions constitute extreme values. Positions IA and IIA received the largest deposit and position IIIC the smallest. Regarding the total area of droplets with a diameter larger than 4 mm (Table 2), this area is found to be decisive for the choice of curve with best correlation. When creating an empirical formula for the relationship between amount of deposited liquid and degree of coverage, the total area of droplets has to be taken into consideration in each specific droplet size interval, especially the interval with droplets larger than 4 mm in diameter. With the data and formulas obtained here it is not regarded possible to substitute the fluorimeter determination of the quantity with image analyzer determinations. However, the results imply that further work could create that possibility.

Table 2. Calculated equations for the various sampling positions. The X-value indicates the measured deposition in per cent with the fluorimeter, and the Y-value the degree of coverage in per cent. The total area of spots with diameter larger than 4 mm was measured with the image analyzer and gives the mean value of all analysed leaves for each position

Sampling position	Untransformed Equation	Transformed Equation	Area of spots with diameter >4,0 mm (mm^2)
IA	$Y = 1.691 \cdot X \hat{} 0.963$	$\ln(y) = 0.525+0.063 \cdot \ln(x)$	1339
IB	$Y = 1.402+X \hat{} 1.107$	$\ln(y) = 0.338+1.107 \cdot \ln(x)$	609
IC	$Y =-2.019+2.070 \cdot X$	$Y = -2.019+2.070 \cdot X$	222
IIA	$Y = 1.473 \cdot X \hat{} 1.031$	$\ln(y) = 0.388+1.031 \cdot \ln(x)$	1156
IIB	$Y = 3.429+1.304 \cdot X$	$Y = 3.429+1.304 \cdot X$	497
IIC	$Y =-0.191+1.290 \cdot X$	$Y = -0.191+1.290 \cdot X$	69
IIIA	$Y = 0.975 \cdot X \hat{} 1.161$	$\ln(y)= -0.026+1.161 \cdot \ln(x)$	1088
IIIB	$Y = 0.964+1.832 \cdot X$	$Y = 0.964+1.832 \cdot X$	220
IIIC	$Y = 0.245 \cdot e \hat{} (1.106 \cdot X)$	$\ln(y) = 1.405+1.106 \cdot X$	107

DISCUSSION AND CONCLUSIONS

The deposition studies revealed large differences in vertical direction and clearly emphasize the difficulty for droplets to penetrate dense crops. In addition, they also illustrate the very poor lateral spray distribution. Spraying with conventional nozzles in dense crops has a restricted possibility to give optimal results for pesticide control at deeper levels in the stand.

It is felt that there are great possibilities to minimize the number of samples without reducing the accuracy of the measurements. One condition is that the sampling position is known, especially in those trials where we are interested only in the relative deposit from one plot to another. In those cases, both the horizontal and vertical position of the sample in relation to where the nozzle is placed has to be recorded. This implies that a marker must be available during field experiments.

Figures 4 and 5 show that the differences in deposition are great both in horizontal and vertical direction. Decreasing deposition with increasing depth in the crop is not a major problem since utilization of the Crop tilter facilitates the penetration in dense crops. The great differences recorded in horizontal direction are more alarming. In spite of careful control of the spray distribution on a spray patternator the result obtained is unacceptable. The explanation could be that the droplets had varied angles of incidence. The spray from adjacent nozzles overlap each other and consequently the plants underneath the nozzle will be subjected to droplets from above but also from the sides, while plants situated in between two nozzles will only be subjected to droplets from the sides. The relationship influences the deposition and offers great potential for reducing the amount of fungicides and insecticides

in crops at a late stage of development. Best results could probably be attained if it were possible to have the same volume of droplets with the same angle of incidence at each specific point. However, a narrower nozzle spacing would most probably be a simple and adequate measure.

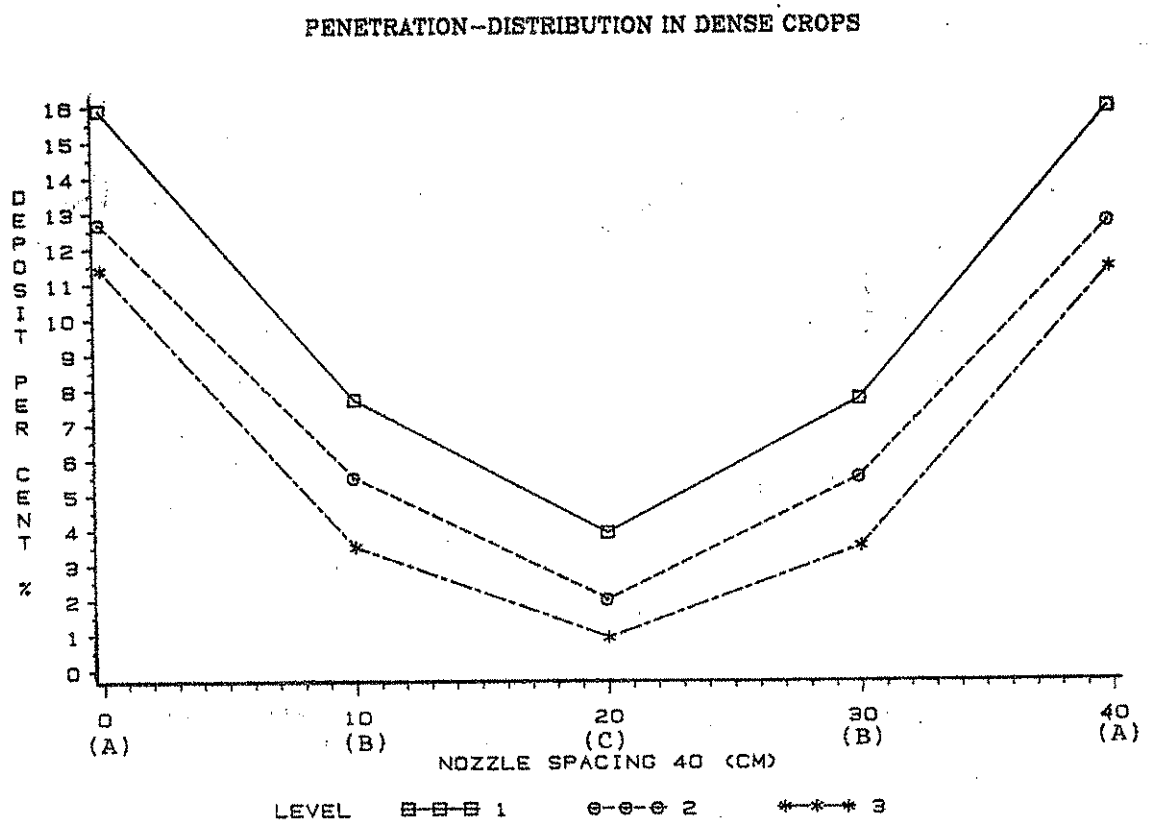

Figure 4. The spray distribution in horizontal and vertical direction in dense plant stand. Quantitative deposit (% of spray per hectare) determined with fluorimeter.

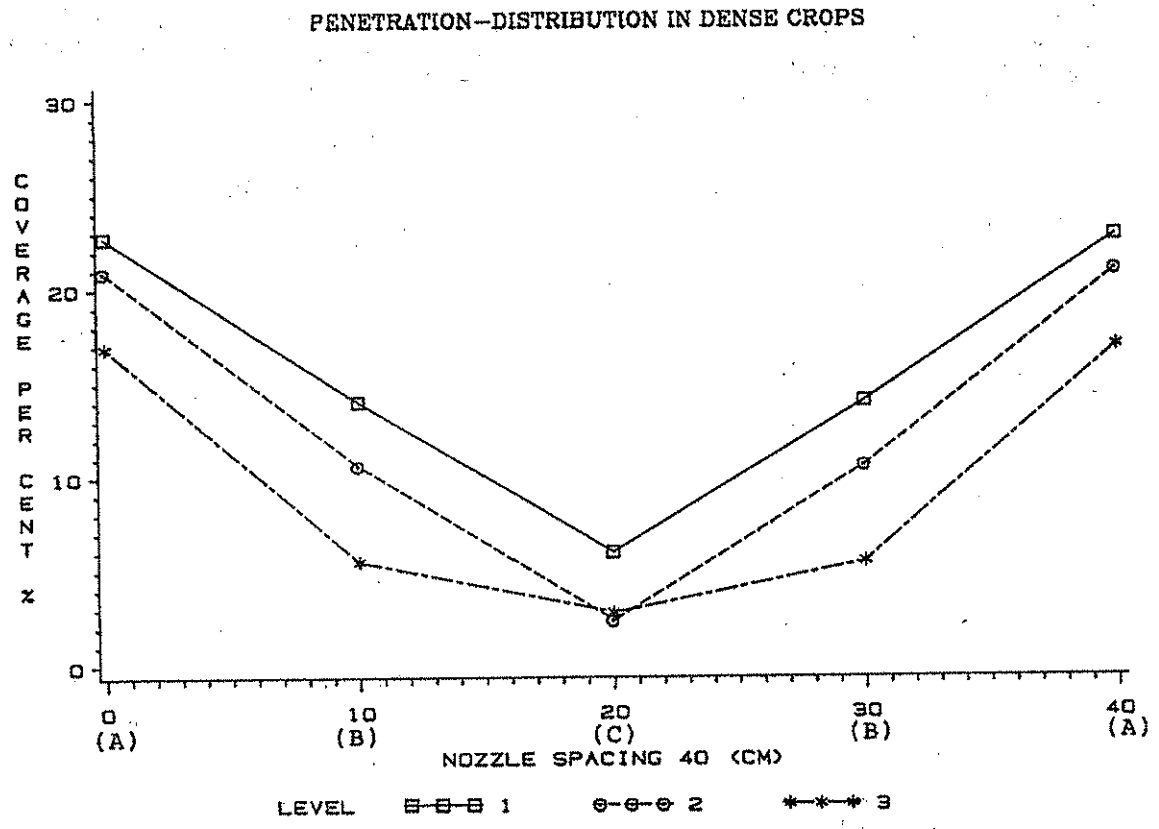

Figure 5. The spray distribution in horizontal and vertical direction in dense plant stand. Qualitative deposit given as degree of coverage (% of covered leaf area).

LITERATURE

Lagerfelt, P. 1987. Influence of Quality and Adjustment of Spray Equipment on Working Environment and Spray Drift. The Swedish University of Agricultural Sciences, Dept. of Agricultural Engineering. Report 115. Uppsala 1987.

APPENDIX 1

Interval (mm)	Number	Area (mm^2)	Cum. area (mm^2)	Cum. area (%)
<=0.20	92	10.096	10.096	0.8
0.20 - 0.40	51	14.836	24.931	1.8
0.40 - 0.60	25	12.674	37.605	2.8
0.60 - 0.80	22	15.530	53.134	3.9
0.80 - 1.00	17	15.312	68.445	5.0
1.00 - 1.20	13	14.142	82.587	6.0
1.20 - 1.40	5	6.605	89.191	6.5
1.40 - 1.60	9	13.309	102.499	7.4
1.60 - 1.80	3	5.098	107.597	7.8
1.80 - 2.00	5	9.600	117.196	8.5
2.00 - 2.20	5	10.611	127.807	9.2
2.20 - 2.40	3	6.982	134.788	9.7
2.40 - 2.60	1	2.579	137.366	9.9
2.60 - 2.80	5	13.388	150.754	10.9
2.80 - 3.00	1	2.857	153.610	11.1
3.20 - 3.40	1	3.214	156.823	11.3
3.40 - 3.60	3	10.473	167.295	12.1
3.80 - 4.00	2	7.934	175.228	12.6
>=4.00	18	1217.432	1392.660	100.0

Total number: 281
Total covered area: 1392.660 mm^2
Total leaf area: 3928.000 mm^2
Degree of coverage: 35.5 %

APPENDIX 2

WHEAT LEAVES

Observation	Recovery in %	Deposit in µg/collector	Fluorimeter Reading
1	15.039	1.992	284.6
2	9.959	2.640	660.0
3	23.414	4.201	525.1
4	21.089	4.931	493.1
5	16.898	3.764	376.4
6	20.959	5.785	578.5
7	28.710	4.055	405.5
8	9.604	1.748	174.8
9	9.750	1.949	194.9
10	9.798	2.521	252.1
11	15.541	3.642	364.2
12	11.600	3.029	302.9
Mean	15.947	3.355	384.3
Stand dev	6.443	1.264	153.8
Variance	40.406	37.676	40.0

IA1-IA12

DETERMINATION OF EQUATION FOR COVERAGE-RECOVERY.

DATE FOR TRANSFORMATIONS TO LINEAR REGRESSION FORM

	Variable 1	2	3	4	
	Variable X	ln(X)	Y	ln(y)	
Observation		Variable Value			Sample
1	15.039	2.711	35.500	3.570	IA 1
2	9.959	2.298	37.400	3.622	2
3	23.414	3.153	39.400	3.674	3
4	21.089	3.049	30.800	3.428	4
5	16.898	2.827	28.900	3.364	5
6	20.959	3.043	31.700	3.456	6
7	28.710	3.357	34.500	3.541	7
8	9.604	2.262	15.600	2.747	8
9	8.750	2.169	7.900	2.067	9
10	9.798	2.282	11.100	2.407	10
11	15.541	2.743	17.800	2.879	11
12	11.600	2.451	14.800	2.695	12
13	8.586	2.150	23.800	3.170	IB 1
14	2.656	0.977	6.000	1.792	2
15	18.755	2.931	41.500	3.726	3
16	20.118	3.002	29.900	3.398	4
17	4.127	1.418	7.900	2.067	5
18	6.117	1.811	10.100	2.313	6
19	8.471	2.137	13.500	2.603	8
20	2.442	0.893	3.100	1.131	9
21	1.797	0.586	2.000	0.693	10
22	8.494	2.139	11.100	2.407	11
23	3.220	1.169	5.400	1.686	12
24	2.998	1.098	0.800	-0.223	IC 1
25	0.643	-0.442	0.800	-0.223	2
26	11.267	2.422	24.000	3.178	3
27	1.037	0.036	0.600	-0.511	4
28	1.602	0.471	2.400	0.875	5
29	2.206	0.791	3.600	1.281	6
30	5.711	1.742	9.900	2.293	7
31	2.551	0.936	3.400	1.224	8
32	2.520	0.924	1.800	0.588	9
33	11.851	2.472	20.600	3.025	10
34	3.069	1.121	4.400	1.482	11
35	1.328	0.284	1.400	0.336	12

DETERMINATION OF EQUATION FOR COVERAGE-RECOVERY.

DATE FOR TRANSFORMATIONS TO LINEAR REGRESSION FORM

	Variable 1	2	3	4	
	Variable X	ln(X)	Y	ln(y)	
Observation		Variable Value			Sample
36	12.003	2.485	29.200	3.374	IIA 1
37	12.424	2.520	25.900	3.254	2
38	15.923	2.768	28.500	3.350	3
39	18.209	2.902	21.100	3.049	4
40	10.778	2.378	17.000	2.833	6
41	9.973	2.300	12.300	2.510	7
42	9.573	2.259	12.100	2.493	9
43	7.883	2.065	23.900	3.174	IIB 1
44	4.839	1.577	12.500	2.526	2
45	2.150	0.765	4.700	1.548	3
46	1.306	0.267	8.400	2.128	4
47	0.500	0.693	0.300	-1.204	5
48	1.091	0.087	8.400	2.128	6
49	16.326	2.793	21.200	3.054	7
50	5.814	1.760	6.600	1.887	8
51	2.529	0.928	0.700	-0.357	9
52	3.369	1.215	2.900	1.065	10
53	4.051	1.399	13.100	2.573	11
54	16.216	2.786	24.600	3.203	12
55	1.087	0.083	2.400	0.875	IIC 1
56	0.799	-0.224	2.600	0.956	2
57	4.349	1.470	8.900	2.186	3
58	5.531	1.710	5.200	1.649	5
59	0.860	-0.151	0.400	-0.916	6
60	0.503	-0.687	0.100	-2.303	7
61	0.856	-0.155	0.100	-2.303	8
62	4.208	1.437	4.500	1.504	9
63	2.539	0.932	2.000	0.693	10
64	0.916	-0.088	0.500	-0.693	11
65	0.834	-0.182	0.200	-1.609	12

DETERMINATION OF EQUATION FOR COVERAGE-RECOVERY.

DATE FOR TRANSFORMATIONS TO LINEAR REGRESSION FORM

	Variable 1	2	3	4		
	Variable X	ln(X)	Y	ln(y)		
Observation		Variable Value			Sample	
66	22.124	3.097	31.500	3.450	IIIA	1
67	16.003	2.773	27.600	3.318		2
68	9.109	2.209	21.400	3.063		3
69	5.797	1.757	5.800	1.758		5
70	10.869	2.386	17.300	2.851		6
71	24.207	3.187	31.000	3.434		7
72	3.170	1.154	3.900	1.361		8
73	10.092	2.312	14.500	2.674		9
74	2.198	0.788	2.100	0.742		10
75	11.775	2.466	15.300	2.728		11
76	9.962	2.299	15.000	2.708		12
77	4.021	1.392	11.700	2.460	IIIB	1
78	19.977	2.995	36.200	3.589		2
79	1.954	0.670	3.800	1.335		3
80	0.786	-0.241	0.300	-1.204		4
81	1.707	0.535	1.300	.262		5
82	0.434	-0.835	0.023	-3.772		6
83	4.261	1.450	4.600	1.526		7
84	5.913	1.777	5.900	1.775		8
85	0.752	-0.285	0.200	-1.609		9
86	1.120	0.113	0.700	-0.357		10
87	1.047	0.046	0.900	-0.105		11
88	0.179	-1.720	0.016	-4.135		12
89	0.198	-1.619	0.200	-1.609	IIIC	1
90	2.544	0.934	7.100	1.960		2
91	2.294	0.830	5.200	1.649		3
92	0.629	-0.464	0.200	-1.609		4
93	0.552	-0.594	0.400	-0.916		5
94	0.812	-0.208	0.400	-0.916		6
95	0.615	-0.486	0.600	-0.511		7
96	1.064	0.062	0.300	-1.204		8
97	0.657	-0.420	0.100	-2.303		9
98	0.208	-1.570	15.800	2.760		10
99	0.509	-0.675	0.200	-1.609		12

Type of Curve	Correlation Function	Result	Untransformed Equation	
Linear	Corr(1,3)	0.912	Y=A+B*X	
Exponential	Corr(1,4)	0.745	Y=A*e^(B*X)	(A>0)
Logarithmic	Corr(2,3)	0.817	Y=A+B*ln(X)	
Power	Corr(2,4)	0.880	Y=A*X^B	(A>0)

The "best fit" straight line corresponds to the linear curve:

	Untransformed Equation	Transformed Equation
Equation	Y=A+B*X Y = 0.734 + 1.538 * X	Y=A+B*X Y = 0.734 + 1.538 * x
X=Recovery Y=Coverage		
Intercept	A = 0.734	A = 0.734
Slope	B = 1.538	b = 1.538

RECOVERY = FLUORIMETER READING, COVERAGE = IMAGE ANALYSER READING

TEEJET 110 01 PRESSURE 4.0 BAR

DETERMINATION OF EQUATION FOR COVERAGE-RECOVERY.

DATE FOR TRANSFORMATIONS TO LINEAR REGRESSION FORM

	Variable 1	2	3	4
	Variable X	ln(X)	Y	ln(y)
Observation		Variable Value		
1	15.039	2.711	35.500	3.570
2	9.959	2.298	37.400	3.622
3	23.414	3.153	39.400	3.674
4	21.089	3.049	30.800	3.428
5	16.898	2.827	28.900	3.364
6	20.959	3.043	31.700	3.456
7	28.710	3.357	34.500	3.541
8	9.604	2.262	15.600	2.747
9	8.750	2.169	7.900	2.067
10	9.798	2.282	11.100	2.407
11	15.541	2.743	17.800	2.879
12	11.600	2.451	14.800	2.695
Mean value	15.947	2.696	25.450	3.121

CORRELATIONS RESULTING FROM TRANSFORMED CURVES

Type of curve	Correlation Function	Result	Untransformed Equation	
Linear	Corr (1,3)	0.664	Y=A+B*X	
Exponential	Corr (1,4)	0.677	Y=A*e ^(B*X)	(A>0)
Logarithmic	Corr (2,3)	0.688	Y=A+B*ln(X)	
Power	Corr (2,4)	0.715	Y=A*X ^B	(A>0)

The "best fit" straight line corresponds to the power curve:

	Untransformed Equation	Transformed Equation
Equation	Y=A*X ^B (A>0)	ln(y)=ln(a)+b*ln(x>)
	Y = 1.691 * X ^ 0.963	ln(y) = 0.525 + 0.963 * ln(x)
X=Recovery Y=Coverage		
Intercept	A = 1.691	ln(a) = 0.525
Slope	B = 0.963	b = 0.963