UNIVERSITY COLLEGE ROOSEVELT

Hailnets in the coastal regions of the Netherlands

A statistical analysis of the differences between hailnets and the correspondence to different locations in the Netherlands

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1/7/2014

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Version 1.1[2]

Abstract

Hailnets are becoming a prominent means for reducing the risk of hail damage. It is a big investment and the use should therefore be optimized. This research looks into different kinds of hailnets and their relation to light absorption, the leaf wetness and the soil moisture of the clay soil. The differences in light absorption between the nets, measured in a coastal region, are compared to the differences in light between the coastal and inland regions of the Netherlands. The difference between those regions is roughly 5.7%, which corresponds to the difference in absorption of a gray and black net or a crystal and gray net, compared to the inland region. The theoretical depreciation difference due to this extra light is also evaluated and it is concluded that the depreciation does not go 5.7% faster, but ranges between 3.3% and 4.3% depending on the net color. In general it can be concluded that it is justified to use a darker net in the coastal regions of the Netherlands to gain a cost advantage without incurring damage to the trees or fruits.

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[2] This paper is still being revised, with explicit focus on the used statistical test which does not take autocorrelation into account. This issue will be fixed in the next revision.

1. Introduction

The amount of hailstorms in the Netherlands and Belgium exhibits a growing trend [1] [2]. Due to the frequent occurrence of hailstorms an increasing amount of crops gets damaged. One option for the farmer to prevent huge and sudden profit losses is to insure his crop against hail damage. However, this has become more expensive due to the higher occurrence of hailstorms, especially for the vulnerable fruits apples and pears. Insurance companies require higher premiums to cover the same amount of crops, often also with a high deductible [3] . One alternative to these high premiums is preventing hail to damage the crops. Especially for fruits this can be done by using nets that catch the hail and absorb its momentum.

These so called hailnets prevent the crops from getting damaged but also have their drawbacks. The nets need to be set up above the trees and this requires a well-build structure that is able to support the weight of the nets and the hail [3]. This is a large expenditure and needs to be cheaper than the insurance premiums over time in order to be profitable. However, these nets also block a portion of the light that would have otherwise reached the trees [4]. The nets absorb the light, and the light slowly breaks down the material of the nets. Different materials absorb different amount of light and have a different sensitivity for the destructive power of the light [3]. Darker nets that block more light can be made of a sturdier material and are less sensitive to breaking down, so they last longer before they need to be replaced [4]. Studies approximating the exact amounts of light absorbed by the different nets have been done, but these numbers tend to deviate between the different researches [3] [4]. One of the causes for this could be that the percentage of light that is absorbed depends on the amount of light, as some studies suggest [3]. Again, different studies give different result on this issue, but especially since it is expected that coastal regions have more light this issue is relevant [5]. Therefore the light needs to be measured in one of the coastal regions in order to give an accurate result of the amount of light blocked for each net. However, the light is blocked by these nets is also necessary for the health of the trees, the flower bud formation of the year after and finally the growth and coloring of the fruit [5]. The retail price of the different nets regarded in this research are all roughly equivalent at €5500, but the write-off of the darker nets is lower than that of a lighter net [3]. It is thus profitable to know under which light circumstances a darker net does not damage the trees and fruits, resulting in a longer lasting and thus more profitable investment.

It is assumed by farmers in the Netherlands that there is more sunlight in the coastal regions than in the inland regions [5]. It is useful to see up to what degree this story holds true, and to determine how big the exact difference is between coastal and inland regions. A large enough difference in the amount of light could potentially allow darker nets to be used in the coastal regions, with the same amount of light under the nets as for a lighter colored net in the inland regions. This difference would then give the farmers in the coastal regions a cost advantage due to a lower write-off, resulting in a stronger market position and more competition. This research attempts to answer the following question: Is the amount of light in coastal regions significantly higher than in the rest of the Netherlands and is this difference high enough to compensate the loss in light due to the use of a darker and thus cheaper net.

The most used nets in the industry so far are black, gray, and crystal nets [3]. A black net absorbs the most light of these three nets, and has according to the producers a wear-down time of roughly 15 years [5]. However, so far these nets appear to be too dark to be used above light sensitive races as such as Conference pears in the Netherlands and surrounding countries [6]. A crystal (white colored) net blocks the least amount of light, but has according to the producers a wear-down time of roughly 10 years [3]. A gray net has properties of black and crystal nets and has according to the producers a wear-down time of roughly 12 years. So far there is no evidence yet of these claims being revolted, where the first researches started as early as 2007 [6]. Due to this difference in depreciation times the yearly write-off per hectare is roughly €90,- cheaper if a net one shade darker is used, based on a price per hectare per net of €5500,- [3]. Although these nets are around for several years already scientific research about their properties is scarce and not without error and ambiguity [3] [4] [6].

The exact amount of light under these nets needs to be known in order to correctly answer the research question. There is no consensus about the amount of light blocked by each type of net over a season under varying amounts of light; therefore, the amount of light is measured at a test location with the three types of light and a control sample without net, this all done in a coastal region. Although the main research question is about the amount of light, this research provided a valuable opportunity to determine whether the hailnets influence other properties such as the leaf wetness or soil moisture under a net in a coastal region. Sensors monitoring these variables were thus also used. Table 1 summarizes the hypothesized properties of all the variables under each net, together with their costs and depreciation time.

Table 1: The hypothesized differences between the different hailnets. Although darker nets are cheaper it is expected that they will also exhibit more negative properties compared to a lighter net.

Net type	Price per hectare	Approximate depreciation time	Yearly write-off	Amount of light blocked	Leaf wetness	Leaf wetness duration	Soil moisture
Crystal	€5500,-	10 years	€550,-	Low	Low	Low	Low
Gray	€5500,-	12 years	€458,33	Medium	Medium	Medium	Medium
Black	€5500,-	15 years	€366,67	High	High	High	High

The sunlight measured is not the full energy of a light beam, but only the part of the frequency spectrum that is relevant to the growth of plants and fruits. This part of the frequency spectrum between 400 and 700 nm is known as Photosynthetically Active Radiation or better known as PAR-light [7]. The unit of the measured PAR-light of the sensor is $\frac{\mu Mol}{m^2}$. More PAR-light implies more energy for the plant to make its fruits grow and make them sweeter, plus provides energy to perform well the next year. Both larger and sweeter fruits are more desirable and have therefore a higher retail price [3]. By reducing these properties, a too dark net could thus negatively lower the price of the fruit, easily negating the benefit gained by having a lower write-off. A second factor of interest is the health of the trees; if a darker net damages the health of the tree over time or makes it more susceptible to diseases the darker net is undesirable. One big factor influencing the susceptibility to diseases is the leaf wetness. When the leaves are wet, plants are more susceptible to infections, especially to scabies [3], which can then infect the entire orchard. It is thus also necessary to know if a darker net increases the average leaf wetness and leaf wetness duration. The soil moisture determines whether the plant has enough resources to grow properly. In general high soil moisture is preferable over low soil moisture, since trees deal better with moderate wetness than with moderate drought [5]. It is very well possible that a darker net causes higher soil moisture and this also needs to be tested.

It should be noted that this research does not attempt to absolutely determine which net to use at which location in the Netherlands. It does answer the same question in a relative manner however. The structure is as follows: If it is known that for a specific race a white/gray net is recommended in inland regions, this research proposes to use a gray/black net in coastal regions. The first part of this paper discusses the procedure of the data collection in the orchard. Thereafter this data is described and patterns in the data are discussed. External data from the KNMI describing the light circumstances in the rest of the Netherlands is then discussed and groups are formed to be able to discuss the data. The formal statistical analysis of both sections is done in the next section, after which the data of both is combined to draw conclusions about the light conditions in coastal regions. This part also discusses some other relevant issues, such as whether the amount of light per year is constant and if the absorbance by the hailnets is linear compared to the amount of light. After this a conclusion is given, where a comparison to earlier research is made.

2. Data collection:

The test location is located in the most south-west part of Zeeland, close to the village of Schoondijke. The most nearby coast is 6.5 kilometers away. The soil type is clay, which may influence the soil moisture and humidity. The measurements were performed in the middle of the parcel, close to a small road. The conditions are measured under 4 different circumstances:

i. A black net, which blocks the most light of all the nets.

ii. A gray net, which blocks less light than the black net, but still more than the white net.

iii. A crystal net, this net should block the least light of the nets tested in this research.

iv. Directly next to the nets, but far away enough that the nets do not influence the rain or soil moisture on this spot. This measurement is also used as a control group.

Figure 1 shows the layout of the nets. Every section is 5 rows wide, which corresponds to roughly 15 meters. Every section is at least 24 meters long, where the gray net is longer and continues till the end of the row. The nets are of course set up parallel to the rows of apples, which is in the NNW direction. The measurements are done by 2 stations, A and B, located under the black and crystal nets. Station A measures the conditions under the black (1) and gray (2) nets, where station B measures the conditions under the crystal (3) net and the control group (4).

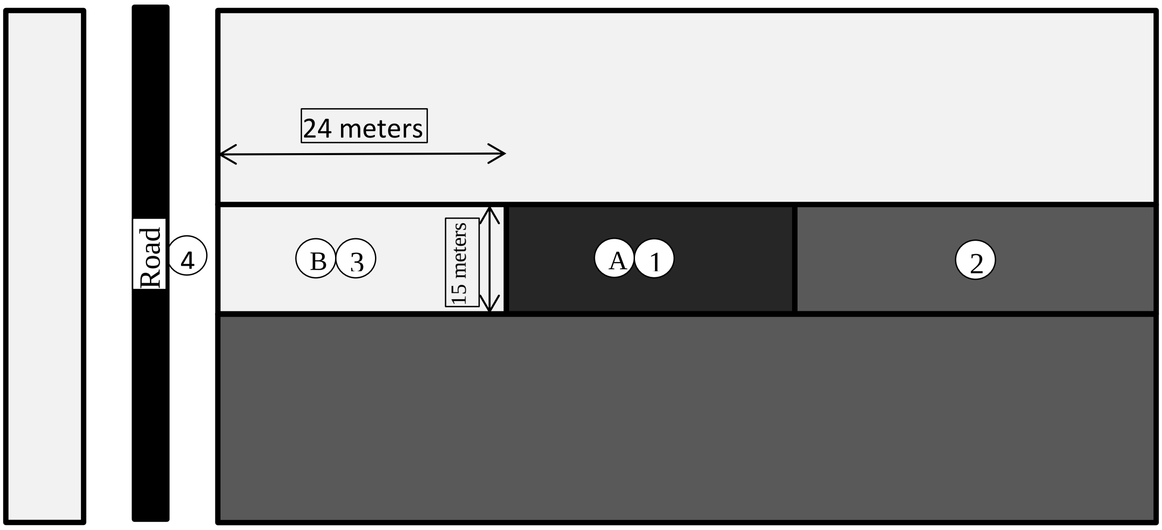

Figure 1: A visualization of the setup of the different nets in the orchard. The ordering of nets is not completely according to color, since that would have required more use of a darker net which might have damaged the other trees outside the test location.

The two stations measure for each of the four nets the PAR-light, the leaf wetness and the soil moisture using the sensors under the nets. The stations measure other variables at their own locations as well, but these are thus only known for the black and crystal nets. These variables are among others the temperature, the average wind speed and the humidity. Every 10 minutes the data from all sensors was sampled and saved.

The data was gathered over a period of roughly four months, starting the end of May and ending the end of September. After this period the nets were opened and another three weeks of measurements were obtained. These measurements were used as a control measure to see whether differences in the measured values are indeed due to the different hailnets and not to other external factors. Unfortunately, the data that was gathered before the end of May was not usable since the PAR-light sensors where not completely levelled properly. The PAR-light sensors are mounted on wooden poles that also support the weight of the trees. This causes the sensors to slightly shift during the growth period. During the mentioned period after the end of May the sensors were closely monitored and adjusted to ensure they remained properly levelled and clean. Unfortunately, malfunction of the sensors or stations caused also some data loss in this period, but after this a total of 12173 observations remained for analysis. Every observation corresponds to 10 minutes, so a total of roughly 84 days.

All sensors were placed according to the instructions of the manufacturer. The PAR-light sensors were placed on poles above the trees, with a distance of roughly 80 centimeters up to the net. This way the sunlight can only be blocked by the nets, limiting threats to internal validity. The leaf wetness sensors were placed at the height of the middle of a tree, roughly 120 centimeters, and close to the stem of the trees. However, afterwards it was realized that this placement may indeed produce the most accurate measurement of leaf wetness inside a tree, but also causes an extra source of bias, namely the tree it is closest to. However, since the condition of the trees is fairly constant this bias should be quite consistent over time, and the control period afterwards may be used to check for this. The soil moisture sensors were placed at a depth of 40 centimeters, measuring the long term soil moisture. However, the used soil is very heterogeneous and the structure of the clay may therefore influence the average values more than the nets do.

Other threats to the internal validity are:

i. The presence of wind and the road: The wind will be stronger closer to the road, since it is less obstructed here. This would not only cause the leaves to dry quicker, but the presence of the road itself may already alter the soil moisture.
ii. Although the exact same sensors are under each of the four different conditions bias might still be present. A subtle but consistent error may be present in each of these measurements. The control period when the nets are opened is used to check whether this bias is significant.
iii. The used net sizes of 15 by 24 meters are fairly small compared to an entire orchard. The regions under the surrounding crystal and gray nets may therefore influence the humidity, leaf wetness and soil moisture.

A few notes on the external validity also need to be made. There is no reason to assume that either soil moisture, leaf wetness or the humidity influence the PAR-light under normal conditions. The measured PAR-light is thus so far externally valid. However, the type of soil greatly influences the moisture level, which can again influence the humidity, which might influence the drying speed of a leaf. Every conclusion made in this paper regarding moisture levels is thus solely valid when a clay soil is present. A last factor that gives rise to bias is the wind speed. As stated before, wind is a great influence on all conditions except light, and the assumption that the wind speed is the same everywhere in the Netherlands can be easily rejected since the wind speed above the sea and in regions close to it is higher [8] [9]. Before a conclusion can be made about humidity or moisture for an arbitrary point in the Netherlands the average wind speed at that location needs to be known as well.

3. Data and methods:

The data section is divided into two parts: Data obtained from the measurements at the test location and external data gathered via the KNMI about the rest of the Netherlands. Originally one extra private source for external data was available, but of these PAR-light sensors it cannot be assumed that they are properly levelled. The bias caused by this misplacement corrupts the comparison, so this extra data source is not used.

a. Experimental data

All time series for the four different regions are obtained and treated in exactly the same way.

i. PAR-light

The time series of the PAR-light show a daily pattern which causes a high standard deviation. This pattern, together with the present noise can be seen in Figure 2 for the black net.

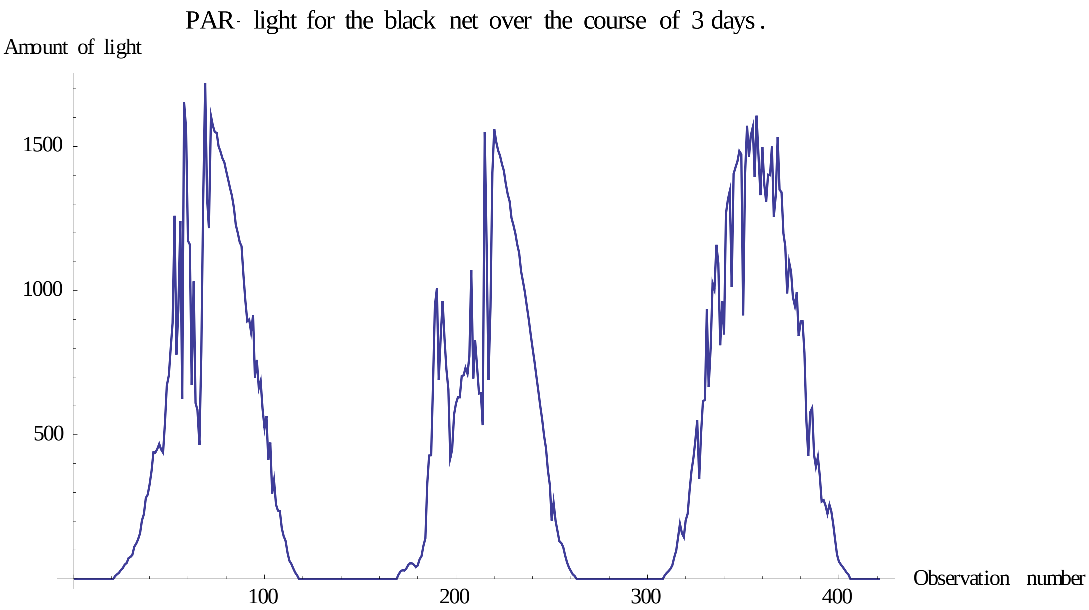

Figure 2: The amount per observation shown over the course of 3 days. It is clear that here is a lot of variation and that a lot of zeros are present.

The biggest part of this standard deviation is caused by the large amount of zeros in the time series. The distribution is by far not normal, as can be seen in Figure

6; the first histogram. A few methods for filtering this signal are used to reduce the standard deviation and to improve normality in a justifiable manner.

- The first procedure is deletion of the present zeros. All four signals have different amount of zeros at different locations. Deleting all zeros of every signal independently changes the length of the signals and biases the means since values close to zero are not deleted. Therefore an observation is deleted when the value of the control sample is zero. This corresponds roughly to dusk and dawn and reduces the standard deviation. The signals of the nets can thus still have zeros in them. The time series all have the same length after this modification. In total 4564 observations are dropped, which is 37.5% of the original signal.
- A second procedure is using a moving average filter, where every data point is replaced by the average of its neighbors. This indeed brings the standard deviation down, but is hardly justifiable statistically, since this is just artificially reducing all the standard deviation.
- An approach that suffers from neither of the problems above is normalized convolution. This method assigns a weight to every data point, where the zeros get a weight of zero. The signal is then smoothed using a Gaussian filter, taking the weight into account. The result is that this procedure interpolates all the data values that were previously close to zero based on the high-valued data points surrounding it, but it does not take other low values into account during this interpolation. This has a stronger effect on weaker signals, and will therefore bring the sample means closer together. *(For more information on normalized convolution, see* [10]*).* Normalized convolution mainly smooths

"unknown" or biased data and thus reduces the standard deviation in a more justifiable manner compared to a moving average filter.

Both the moving average filter and the smoothing kernel used in the normalized convolution have a width of 12 hours. The smoothing thus takes the 6 hours before and after into account to determine what the value of the data point should be. This way the situation during the night is interpolated regarding information from the day before and after, attaching more weight to the one that is closest. Figures 3, 4 and 5 show the original signal, the moving average signal and the convolved signal for each of the different nets. It is clear that, although there is a lot of standard deviation, there is a clear difference in light under the different circumstances.

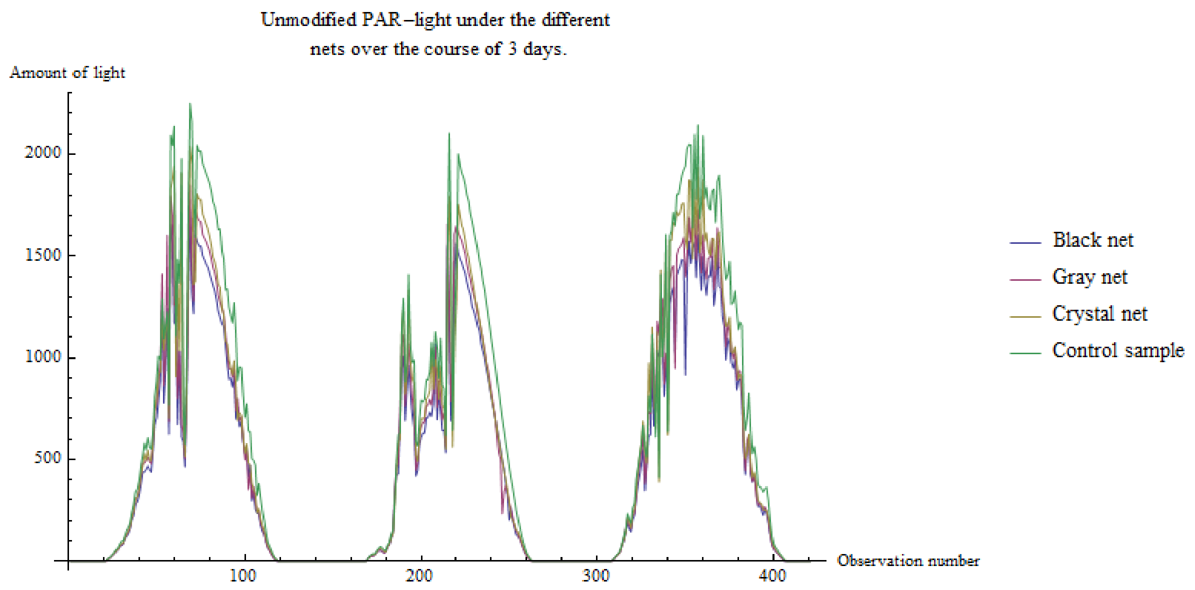

Figure 3: The original unmodified signal of the 4 nets for 3 arbitrary, consecutive days. It is clear that although there is a lot of standard deviation the difference between the nets is consequent.

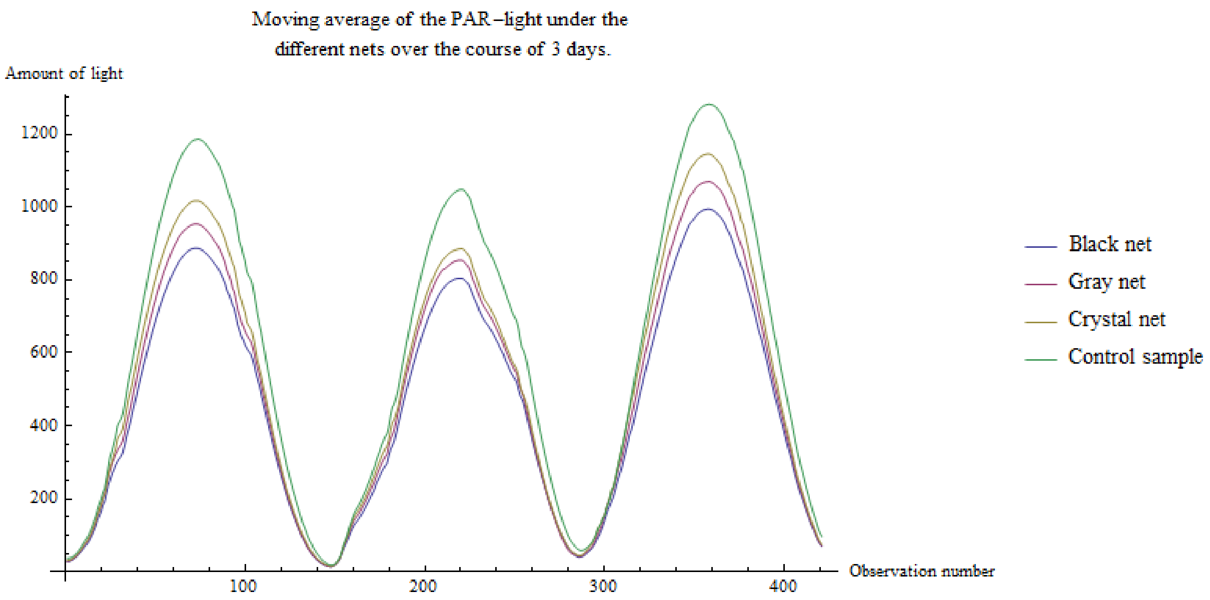

Figure 4: The moving average signal of the same three days as in Figure 3, but now it is more easily visible that there is a difference in light between the three different nets and the control sample.

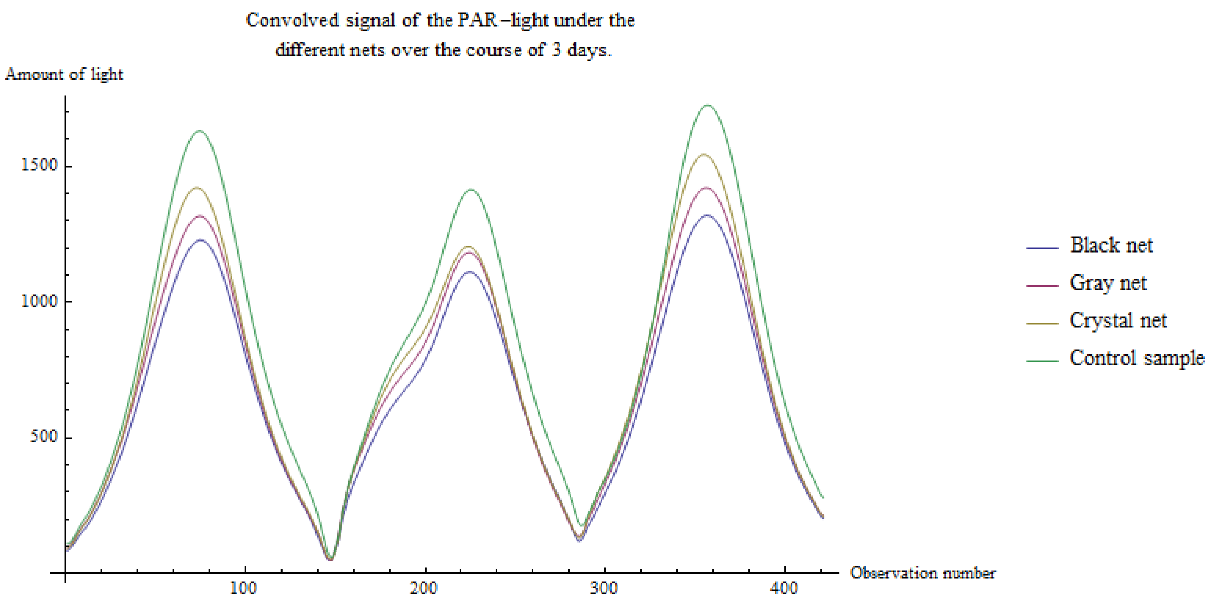

Figure 5: The convolved signal of the same three days as in Figure 3. The same distinction between the nets as in Figure 4 can be seen, but in general the signals have a higher value and relatively fewer observations close to zero.

Even after these modifications the data is not normal, as can be seen in the other histograms of Figure 6. However, it is visible that the convolution modification makes the data more normal, and using a wider filter indeed makes the distribution approximate a normal distribution better. For even a rough approximation this requires at least the double amount of filtering, which also biases the data. The non-normality of the data is thus taken as given, and tests for non-normal data are used. The means and standard deviations of every method applied on the data of the control sample net can be seen in Table 2. As a comparison the coefficient of variation is also given, defined as the standard deviation over the mean. A high coefficient of variation implies that it is hard to find significant differences between samples.

Table 2: The mean, standard deviation and the coefficient of variation are calculated for each of the modification methods applied on the signal of the control sample. A clear improvement over the methods can be seen, since the coefficient of variation decreases by roughly a factor 2 compared to the original signal.

Method	Mean	Standard Deviation	Coefficient of variation
Unfiltered signal	459.7	590.4	1.29
Zero-deleted signal	735.4	596.4	0.81
Moving average signal	456.8	363.1	0.79
Normalized convolution signal	668.25	432.0	0.64

The table shows that for each subsequent method the coefficient of variation goes down. More significant results are thus expected for each of these modifications. To obtain the amount of light the mean of each of PAR-light time series is calculated. This is done with the zero-deleted time series, since this is the only one that is fully unbiased, although noisy. The original time series have a lot of zeros in them, which lowers the difference between the nets. Normalized convolution artificially brings the means up and closer together, since it increases the on average lower signals more than a higher signal. A moving average filter crops the signal, deleting information, and includes zeros. The zero-deleted mean is thus the only unbiased estimator. The means of the different nets can be found in Table 3. It is again clear that the darker nets indeed block more light than a light or no net.

Table 3: The zero-deleted means and the differences in the zero-deleted means of PAR-light between the different nets, with the difference in percentage shown next to it.

Net	Mean	Percentage of control	Difference with lighter net
Control/No net	735.4	100%	-
Crystal	653.6	88.9%	-11.1%
Gray	608.7	82.8%	-6.1%
Black	578.69	78.7%	-4.1%

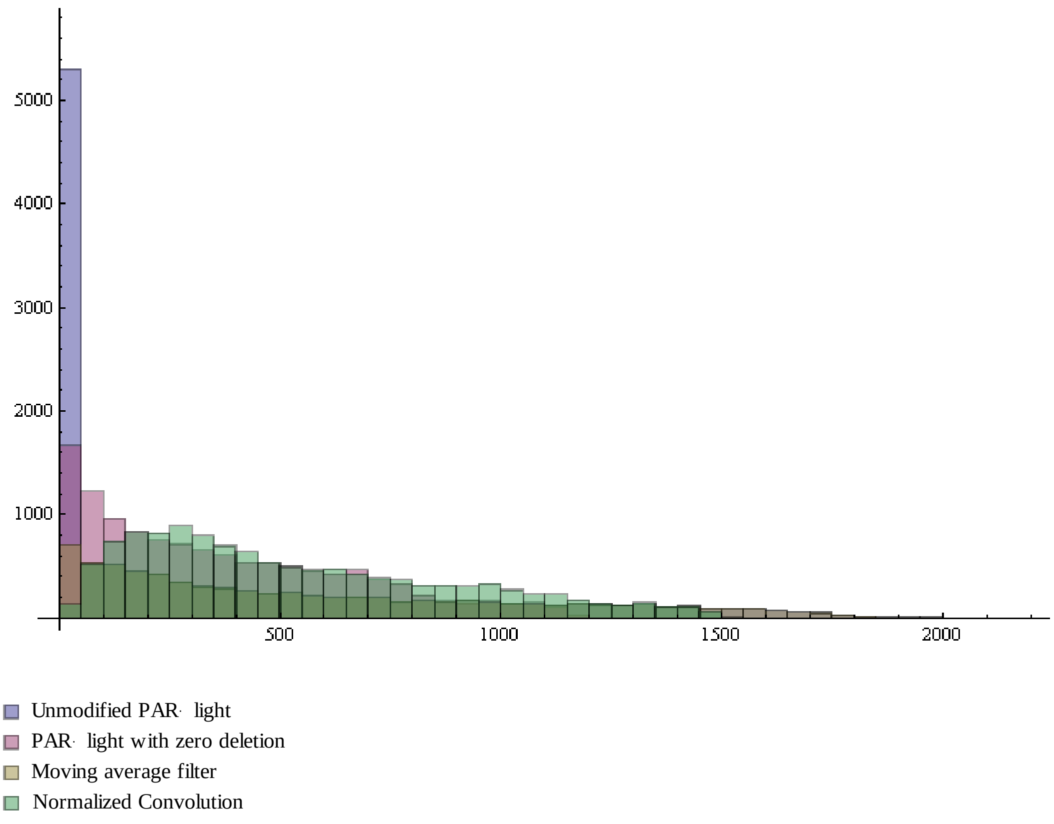

Figure 6: The histograms of the 4 different modification techniques applied on the signal of the black net. Each subsequent modification technique improves the approximate normality of the signal, but normality can still not be assumed.

ii. Leaf wetness

The leaf wetness shows partly the same pattern as the PAR-light. Due to temperatures below the dew point at some points during the colder nights a daily pattern rises. However, there are also longer periods in the summer where there was no rain or dew, where the leaf wetness is zero. This again increases the standard deviation, and should be taken care of.

The series is treated in roughly the same way as PAR-light: observations containing zeros are deleted separately for each sample, a moving average filter is applied and lastly normalized convolution is used.

The unmodified means and zero-deleted means, see Table 4, show no consistent pattern such as was present for the PAR-light. The only conclusion is that the mean under the nets is consistently higher, but this may also be due to the influence of the wind which is less under the nets.

Table 4: The means and standard deviation of the leaf wetness are given for each net. Although the standard deviation decreases if modification of the data is done, the same lack of a pattern is visible as in this table.

Net	Mean	Standard deviation	Zero-deleted mean	Zero-deleted standard deviation
Control/No net	4.21	4.98	8.26	4.20
Crystal	4.81	5.39	8.89	4.26
Black	4.56	5.11	8.49	4.12
Gray	5.22	5.41	9.42	3.92

iii. Duration of leaf wetness:

Light is one of the influencing factors on the drying speed of leafs. If there is more sunlight a leaf will dry quicker in general. Therefore the average duration of the leaf wetness per net was obtained. This data was again not normally distributed and had lots of outliers; there were very short periods of leaf wetness, which were so short that they were due to sensor inaccuracy. When the sensors are almost dry one small single drop can make the difference between a leaf wetness of zero or 0.1. This causes a sensor to think that the leaf wetness had a duration of only 10 minutes, while this is not true. All wet periods shorter than 30 minutes are for this reason deleted. Outliers of very wet periods also bias the result and are discarded as well. For this purpose, wet periods longer than one week are taken out. The means and standard deviations obtained from these modified measurements are shown in Table 5.

Table 5: The mean and standard deviation of the leaf wetness duration are given. No pattern is visible, except that on average the leaf wetness duration is higher under the nets than in the control group.

Net	Mean	Standard deviation
Control/No net	52.7	38.0
Crystal	53.3	39.6
Black	51.4	38.8
Gray	58.4	38.7

There is no immediate pattern in wetness duration visible. This data has also far less observations, at most 123 observations compared to a rough 12000 of the original data. It is visible however than under the nets where there is less wind the leaf wetness seems to be higher.

A last measure is to see whether there is a significant difference in the absolute changing speed of the leaf wetness under the different nets. The means and standard deviation of the absolute changing speed are given in Table 6.

Table 6: Mean and standard deviation of the absolute changing speed of the leaf wetness. There seems to be no pattern in this data which corresponds to net colors.

Net	Mean	Standard deviation
Control/No net	0.316	0.989
Crystal	0.346	1.071
Black	0.316	0.992
Gray	0.303	0.954

iv. Soil Moisture

The soil moisture seems to be hardly influenced by the presence of hailnets. All signals fluctuate around their mean, but this deviation is very small and the signals are clearly different. The means and standard deviations can be seen in Table 7. However, the means are unrelated to the nets above the sensors. Apparently the moist buffering effect of clay soil combined with the heterogeneity negates the possible effects the nets could have on the soil moisture.

Table 7: The means and standard deviation of the soil moisture under every net.

Net	Mean	Standard deviation
Control/No net	50.4	0.79
Crystal	49.0	0.96
Gray	51.4	0.67
Black	45.7	1.73

Other effects of the nets could manifest themselves in the speed of change of the soil moisture. Therefore the derivative is taken by differencing the data. The mean of this difference is almost exactly zero. Therefore the absolute value of these means is taken and these and the standard deviation are given in Table 8.

Table 8: Mean and standard deviation of the absolute changing speed of the soil moisture. A pattern is visible since the mean is on average higher below the hailnets, so it changes faster.

Net	Mean	Standard deviation
Control/No net	0.040	0.12
Crystal	0.058	0.09
Black	0.047	0.12
Gray	0.048	0.08

v. Other variables

The two stations themselves also gathered data, and a comparison of this data shows whether wind, temperature and humidity are the same under the nets. The means of each variable are shown in Table 9, where station B is the one closest to the border.

Table 9: The means of wind speed, humidity and temperature are given for each station. The wind speed is clearly higher near the border of the hailnets. For this location, the humidity and temperature are also slightly lower.

Station	Wind	Humidity	Temperature
A (below black net)	0.55	78.48	17.30
B (below crystal net)	0.99	78.14	17.22

This table shows that the average wind speed is indeed a lot higher closer to the edge of the nets. A simple, but untestable, hypothesis is that this higher wind speed affects the temperature and humidity by lowering them. This effect may not only be due to the wind, but this is at least one big influence on these variables.

vi. Absorption curve

Another important factor is whether the nets absorb an amount of light proportional to the intensity of the light. There is ambiguity in other research where some state that the absorption is independent on the amount of light and others say there is some dependency. To check for this, all four zero deleted samples are sorted, and then the proportional differences can be taken by dividing the samples of the nets by the control sample. These differences specify the absorption by each net and are then matched to the corresponding PAR-light value of the control group. All PAR-light values below 500 are dropped since this partly corresponds to sunrise and dawn, where the angle of the light on the nets is very sharp and thus more sunlight is blocked. The absorption curves are shown in Figure 7.

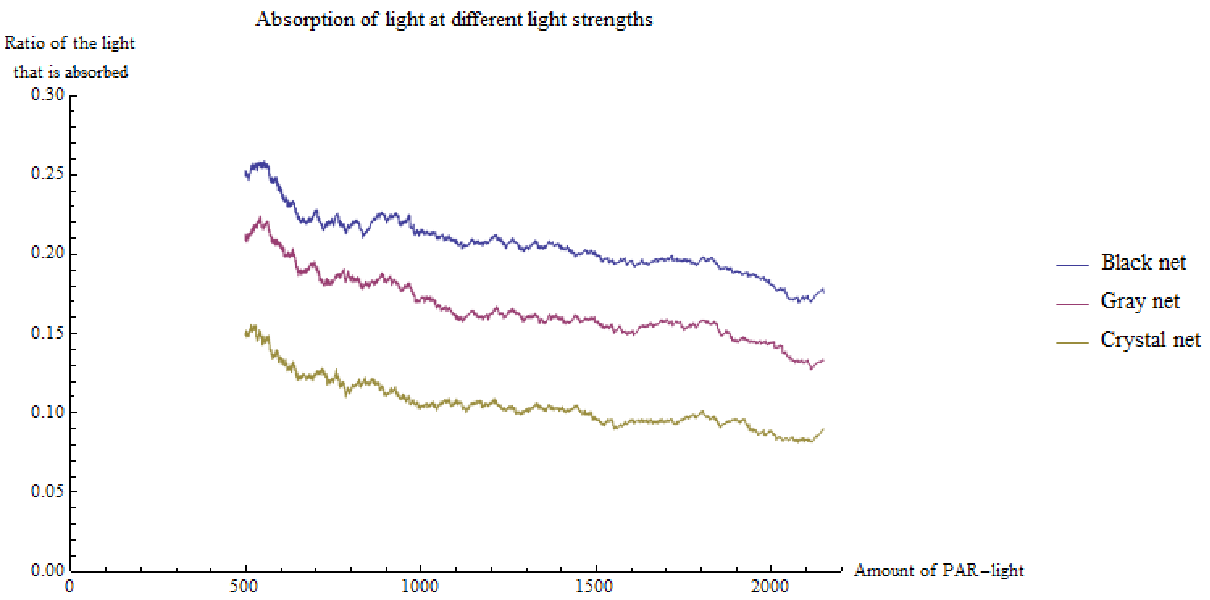

Figure 7: The absorption curves of each of the nets. It is clear that the nets absorb proportionally less light when there is more sunlight present.

According to the data, this absorption is not linear, but matches the physical phenomenon known as saturable absorption [11]. The higher the amount of light is, the less absorption occurs, and a roughly linear relationship seems to be present. The figure implies that a net absorbs proportionally less of the sunlight if the intensity is higher, since it is saturated already. Consequently, the deterioration of hailnets in the coastal regions does not go faster with the same proportion as of the proportional light increase compared to inland regions. If this would not be true, the extra amount of light would decay the material faster and the gain of using darker nets would not be beneficial, but just a requirement since all nets would deteriorate faster.

b. External KNMI data

The Royal Dutch Meteorological Institute or KNMI gathers data at 37 locations in the Netherlands, distributed relatively evenly over the entire country [12]. A 6 year old map containing the locations of the sensors at that time is displayed in Figure 8 [12]. This map is no longer fully up to date, since locations have changed, but the map still visualizes the distribution of the locations well. The data ranges from the year 2000 to the year 2014. Stations that had less than 3 years of data were not taken into account in this research. The full amount of weather stations that were taken into account is 33. All stations record the data every hour, resulting in a sampling frequency 6 times lower than the frequency used in the experimental data. From these stations all data before May and after October was deleted, since the nets are only open in the period between those months. Since the research question was whether there was more sunlight in the coastal regions of the Netherlands the country is for now divided into three regions: coastal, inland and far-inland. The lines displaying this distinction are also shown in Figure 8. For convenience, the lines divide the 33 stations in groups of exactly 11 stations each. These groups are mainly used as a visualization tool and not as an analysis technique. The main target is to be able to compare the stations (and groups) easily and find stations that not belong in their predefined group. The stations are set up professionally and monitored so it is safe to assume that their measurements are correct.

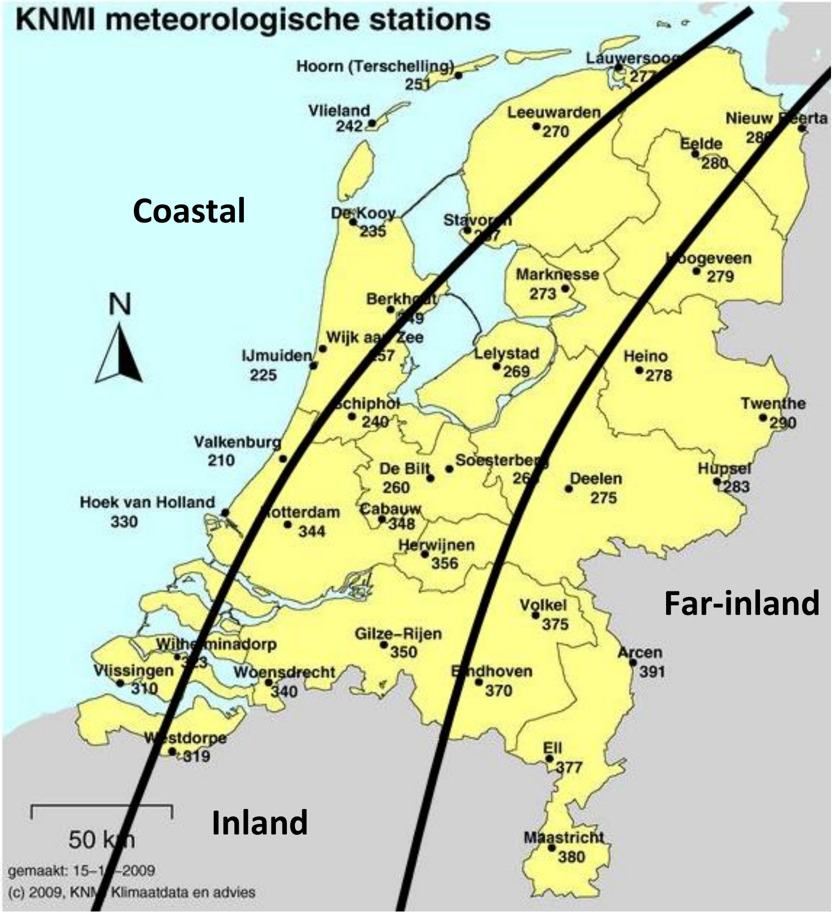

Figure 8: The map of the Netherlands with the measurement stations in the year 2009. Although stations have changed, this still gives a good idea of the distribution of the stations.

The means of all observations after zero deletion of the groups show on first sight a practically significant difference in the amount of light between them as can be seen in Table 10. One problem arises when it is noted that during the experiments the amount of PAR-light (in $\frac{mMol}{m^2}$) was recorded and that the KNMI stations record the amount of normal light (in $\frac{J}{cm^2}$). However, PAR-light is not more than the part of the frequency spectrum of normal light that is beneficial for plants [7]. In this research both are measured in energy per area. Assuming that there is one light source that illuminates the entire Netherlands and that air conditions above the Netherlands do not vary in how they filter the frequencies corresponding to PAR-light, the relationship between light and PAR-light is the same for the entire Netherlands. To show the distribution of light across the

Netherlands the mean of each station is calculated, and plotted on a map of the Netherlands. The radius of every circle is directly linked to the amount of light a station receives. The relationship is not linear however, so a circle with twice the size does not have two times more light! It is clearly visible in Figure 9 that the coastal region indeed has on average more light than the rest of the Netherlands.

Table 10: The means of light of every region, together with their standard deviation. A different unit is used compared to the experimental data, since this data is about normal light.

Region	Mean	Standard deviation
Far-inland	64.49	26.08
Inland	64.96	26.42
Coastal	68.02	27.38

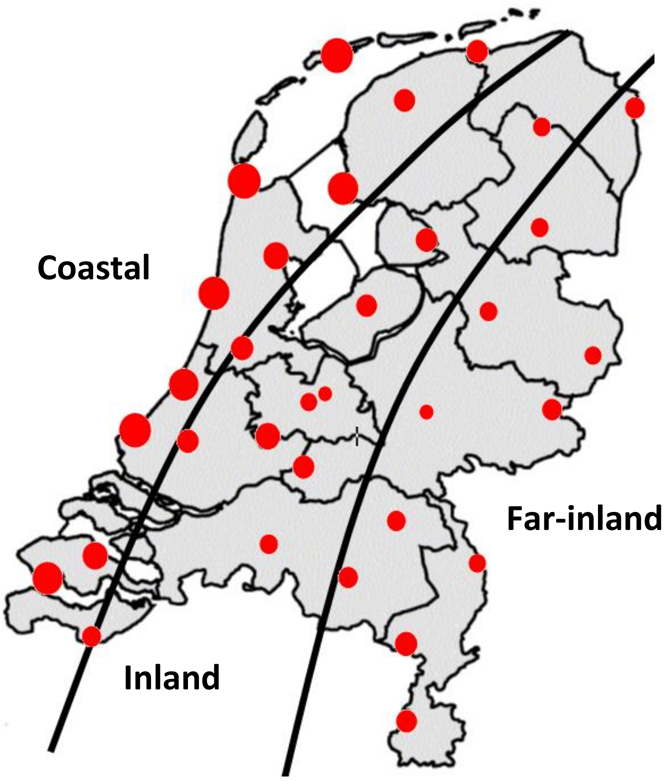

Figure 9: The map of the Netherlands with the lines displaying the different regions. All stations are visualized as red circles; with their radius describing the amount of light a station receives.

Due to the higher amount of data stretching over more years and the lower sampling frequency which introduces less variance there is no need to use advanced filtering techniques such as a moving average filter or normalized convolution. Only zero deletion is used to delete the values that biased the means and standard deviations. A boxplot of the distribution of the means in the different regions is shown in Figure 10. The boxplot shows clear overlap between the different regions. The lower quartile of the stations in the coastal region seems to correspond with the upper quartile of the inland region. This indicates that the categories as defined are not completely accurate and need to be altered later. The distribution of the light values is not normal for any of the stations.

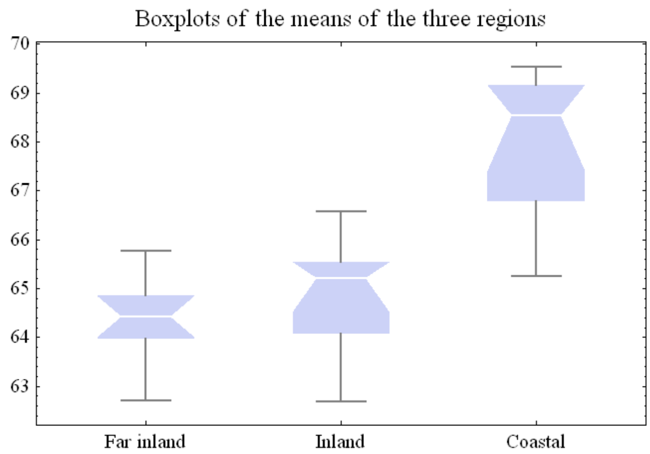

Figure 10: Boxplots describing the means of the separate locations of the three regions. There is clearly some overlap between the inland and the coastal region. This will be thoroughly checked in the analysis.

4. Analysis

Hardly any data in this research is distributed normally. Even approximately normal data is not available or requires too much filtering. A categorical test that does not require normality is therefore required. The program used to perform the statistical tests is Mathematica 9, which automatically assesses the data and performs the strongest test for which the assumptions hold. The Kruskal-Wallis one-way analysis of variance is the test that is suggested by Mathematica. This test does not need approximately equal sample sizes of the groups, nor does it require normally distributed residuals. However, it is an extension of the Wilcoxon–Mann–Whitney two-sample rank-sum test to more than two independent groups. This extension is not necessary, since only two samples are compared at once, so the Mann-Whitney test is used. The biggest assumption for this test is that the obtained samples are independent from one another. This is the case for all the cases in the different hailnets, since all results are due to the external effects of light, rain and wind. Logically, since it works under almost no assumptions this test needs more samples than for example a T-test to return the same P-value. This test assesses whether median values are different, instead of the means. If the P-value is small enough though, it is safe to assume that the samples will have different distributions and thus both different medians and means. Especially for the modified samples using normalized convolution the mean and median are close together. Throughout the analysis a P-value of $1 * 10^{-4}$ is assumed and it is noted whenever a different significance level is used. Every P-value that is below 10^{-6} will be noted as being zero, since the significance level is clearly higher than 99.99%.

a. Experimental data

i. PAR-light

The Mann-Whitney test is used to analyze all PAR-light data. The null hypothesis is that each combination of two nets has the same mean/median. For the unmodified PAR-light data this hypothesis is already rejected with almost 70%

certainty. The results of the tests are shown in Table 11, where all samples are compared, under a 99.99% certainty level.

Table 11: The P-values displaying the significance of the differences between the different samples for each modification technique. The significance level is $1 * 10^{-4}$ and it is denoted with an asterisk when a difference is significant.

Comparison	Unmodified	Zero-deleted	Moving Average	Normalized convolution
Black – Gray	0.3015	0.0051	0.0001	0*
Black – Crystal	0.0001	0*	0*	0*
Black – Control	0*	0*	0*	0*
Gray – Crystal	0.0048	0*	0*	0*
Gray – Control	0*	0*	0*	0*
Crystal – Control	0.0001	0*	0*	0*

Both zero deletion and a moving average filter bring the certainty level up, but neither to more than 99.9%. However, the test on the samples modified with normalized convolution is still significant for a P-value of 10^{-7}, where all samples are significantly different with more than 99.99% certainty. The null hypothesis that the means of all nets are equal is thus rejected. It is thus safe to assume that the differences in light absorption between the nets are significant, and correspond to the percentages in Table 3 in the data section. As a rule of thumb it is relatively safe to say that the light difference between two nets in a coastal region is roughly 5% of the full amount of light.

ii. Leaf wetness

The leaf wetness did not seem to have any correlation with the net color, so even if the samples are statistically significantly different the practical significance is virtually zero. The null hypothesis is again that the sample means are coming from the same distribution. The same test table as before is created for the signals, see Table 12. According to the moving average signal, the null hypothesis can thus be rejected with 99.99% certainty, but there is a catch. Almost the exact same filters as for PAR-light are used, but for some reason the zero-deletion and normalized convolution cannot find a fully significant difference for the comparison between black and control and for the comparison between gray and crystal. This inconsistency points indicates that certain parts of the variance that are altered by the filtering method determine the outcome of the tests. There seems to be thus another process influencing the leaf wetness. Although the conclusion that the leaf wetness is significantly different between the different samples with 99% certainty is still valid, nothing can be said about the cause of this difference. There is especially no significant correlation between darker nets having a higher leaf wetness. However, on average the leaf wetness under a net is 8% higher compared to the leaf wetness without a net.

Table 12: The P-values displaying the significance of the differences between the different samples for the different modification methods. The significance level is $1 * 10^{-4}$ and it is denoted with an asterisk when a difference is significant.

Comparison for leaf wetness	Unmodified	Zero-deleted	Moving Average	Normalized convolution
Black – Gray	0*	0*	0*	0*
Black – Crystal	0.162	0*	0*	0*
Black – Control	0*	0.2505	0*	0.4761
Gray – Crystal	0*	0.0427	0*	0.0117
Gray – Control	0*	0*	0*	0*
Crystal – Control	0*	0*	0*	0*

iii. Leaf wetness duration

The duration of the leaf wetness suffered from the same problem as the leaf wetness itself, it does not seem to be correlated to the colors of the nets. The null hypothesis is that all the samples have the same mean (or median) leaf wetness duration. The test results of unmodified and the trimmed samples comparison are shown in Table 13. The P-values for the trimmed samples are lower than for the normal sample, but this does not make a big difference. The null hypothesis can clearly not be rejected, thus the conclusion is that the average leaf wetness duration is not statistically different for different nets.

Table 13: The P-values displaying the significance of the differences between the different samples. The significance level is $1 * 10^{-4}$ and it is denoted with an asterisk when this difference is significant.

Comparison for leaf wetness	Unmodified	Trimmed
Black – Gray	0.94	0.18
Black – Crystal	0.50	0.79
Black – Control	0.81	0.91
Gray – Crystal	0.60	0.29
Gray – Control	0.88	0.23
Crystal – Control	0.66	0.90

The only noteworthy thing is that the average leaf wetness duration of the gray net is statistically different at the 70% level. The average leaf wetness for this net was the highest of all nets, but this is also the sample that comes from the sensor furthest away from the road and thus with the least wind. This suggests that the leaf wetness is higher further from the boundaries of the hailnets. Perhaps by gathering more data and eliminating wind as much as possible as a variable, by obtaining the measurements at the middle of the rows, it is possible to shed more light on this issue. On average the trimmed mean leaf wetness duration is 3% higher under the nets, but this is only significant with a certainty of little more than 60%. The comparisons of the absolute drying speed were all significant with 99.99% certainty, but this data had no practical implications. If only the negative values of the leaf wetness difference (thus drying) are taken into account, the difference between the nets is still statistically significant, but the practical significance is low, since there is hardly any correlation with the net colors.

iv. Soil moisture

The soil moisture samples have a very low variance, so a clear difference between the samples is expected. The null hypothesis is that the mean of all the samples is the same. Due to the low variance this hypothesis is easily rejected. For the unfiltered signal it is rejected with 99.99% certainty (P-values around 10^{-2500}). However, these means have no correlation with the net color, so this result has no practical significance. Therefore the absolute value of the rate of change is determined, to see whether there is a statistically and practically significant difference in those means. The test results are shown in Table 14. The null hypothesis that all samples have the same changing speed can be rejected with 90% certainty.

The average drying speed is higher under the hailnets and this significantly at the 99.99% level. This could be due to the slightly higher temperature under the nets [3]. However, the difference may also be due to the presence of the road, which could inhibit the drying process. More practically significant results may thus again be obtained by performing the measurements at the center of the orchard.

Table 14: The table displaying the test statistics for each of the different net combinations. The significance level is $1 * 10^{-4}$ and it is denoted with an asterisk when a difference is significant.

Comparison for soil moisture change	Unmodified signal
Black – Gray	0.00046
Black – Crystal	0*
Black – Control	0*
Gray – Crystal	0.07385
Gray – Control	0*
Crystal – Control	0*

v.

Other variables

So far the assumption is often used that the wind speed was higher closer to the boundaries of the hailnets. Although the means are different it is not shown yet that this difference is also significant. The null hypothesis is that for wind speed, temperature and humidity both stations have the same means.

The test results are shown in Table 15 and indeed show that null hypothesis for wind is rejected with 99.99% certainty. The wind is thus indeed a biasing factor in this research. The null hypotheses concerning humidity and temperature can only be rejected with 75% certainty. However, the mean difference between the samples is so low that it hardly bears any practical significance anyways.

However, it can be assumed that, due to the lower wind speed in the middle of the orchard, the temperature and humidity are higher on average compared to the boundaries of the orchard.

Table 15: The different test statistics for the comparison between the measuring stations. The means are again given to display what the practical significance as well. The significance level is $1 * 10^{-4}$ and it is denoted with an asterisk when a difference is significant.

Station	Wind	Humidity	Temperature
A (below black net)	0.55	78.48	17.30
B (below crystal net)	0.99	78.14	17.22
Test statistic	0*	0.249	0.123

vi. Absorption curve

The data for the absorption curve showed clearly that percentage of light that is absorbed is not constant when the amount of light changed. To see if this pattern is largely linear regressions are done on the curves. The fitted lines are shown in Figure 11. The functions for the absorption under every net are given as well. The physical phenomenon is not necessarily linear, but it gives a good approximation in this case, except when close to the limiting case that that absorption would be zero [11]. The high R^2 suggest that the linear approximation of the absorption hold fairly well, although a logarithmic approximation might even give a higher correlation.

$$Absorption_{Black} = 0.2564 - 0.000038\ light, R^2 = 0.920$$
$$Absorption_{Gray} = 0.2221 - 0.000043\ light, R^2 = 0.924$$
$$Absorption_{Crystal} = 0.1485 - 0.000033\ light, R^2 = 0.903$$

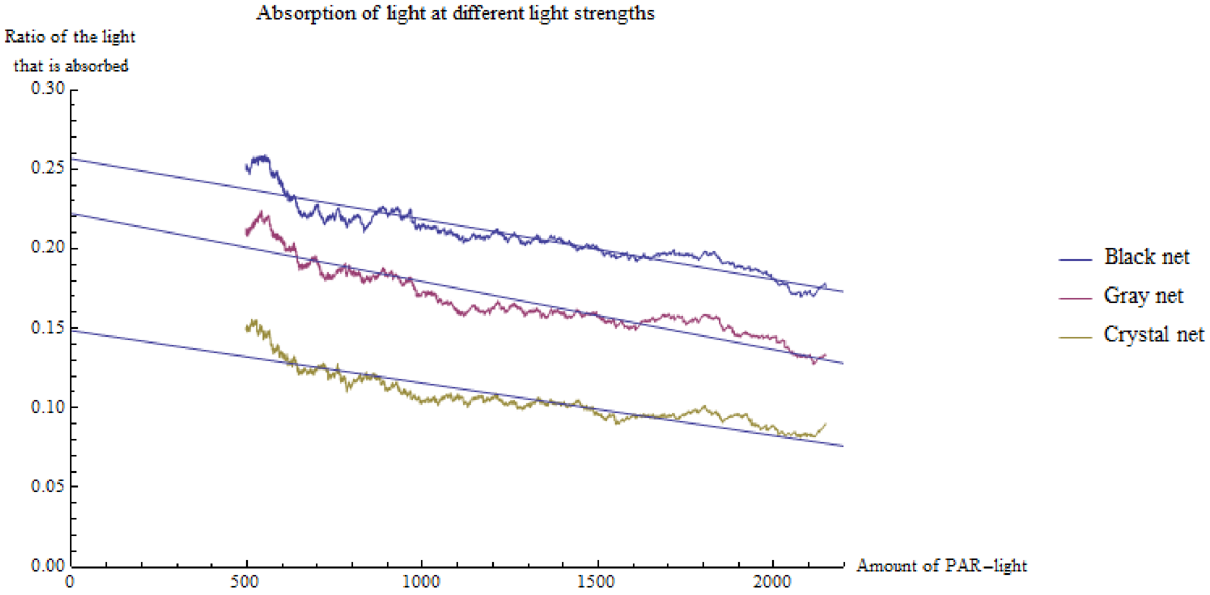

Figure 11: The fitted lines through each of the curves. For each line the slopes of the lines are fairly equal. The R^2 of each regression is high, indicating a good fit of the model.

Using the regressed functions the difference between a sunny day and a cloudy day can be approximated for each net. A sunny day is here taken to have an amount of PAR-light of roughly 1800 $\frac{\mu Mol}{m^2}$, where a cloudy day is roughly 800 $\frac{\mu Mol}{m^2}$. The absorption percentages for each net for the sunny and cloudy days are given in Table 16. The difference is clear, but the next question that rises is what the exact effects of more light in the coastal region are on the depreciation time of each net. The light difference between coastal and inland regions is roughly 5.7% (see section 4.c).

Table 16: The absorption on a cloudy and a sunny day. The difference is clear, and shows that for more light the absorption indeed goes down.

Net	Absorption on cloudy day	Absorption on sunny day	Absorption difference
Black	22.6%	18.8%	3.8%
Gray	18.8%	14.5%	4.3%
Crystal	12.2%	8.9%	3.3%

Under a few assumptions it is possible to calculate the increase in depreciation due to the extra light.

- A net solely absorbs and does not reflect, all the light that a net absorbs wears the net down.
- Depreciation is linearly dependent on the quantity of light absorbed; twice as much light absorbed implies twice faster depreciation.
- The difference in light between the coastal and inland regions is always 5.7% and is not dependent on the amount of light.

All values lower than 500 in the control sample are deleted, since the regressions did not take these values into account and they might introduce bias. This resulting time series is divided by the factor 1.057 to obtain the corresponding time series for an inland location. Of all data values of the both time series the absolute amount of light that is absorbed by each kind of net is calculated using the regression functions approximated before. This way the approximate total amount of light absorbed by each net in the coastal and inland region is obtained. The coastal total is divided by the inland total for each net to get the proportional increase in depreciation. The percentages and years with which the depreciation time decreases are given in Table 17. The extra amount of light does thus not reduce the depreciation time with the same percentage as the increase in light.

Table 17: The depreciation time decrease for each of the nets due to the on average 5.7% more light in a coastal region. All numbers are smaller than 5.7%, so the extra light actually gives a cost advantage.

Net	Proportional decrease in depreciation time	Decrease in depreciation time
Black	4.3%	0.62 years
Gray	3.7%	0.43 years
Crystal	3.3%	0.32 years

b. Control period of the experimental data

The control period of the data is used to check whether the means of PAR-light, leaf wetness, soil moisture, wind, humidity and temperature are still significantly different after the nets are opened. Exactly the same tests as the ones used on the experimental data when the nets are closed are performed on the control period data when the nets are opened. For the results of the analysis to hold, the means of this control period should not be significantly or practically different from one another.

i. PAR-light

The null hypothesis is thus that the means of the samples of the four different nets of the control period are the same. For each of the four different data modification methods no statistically significant differences were observed, not even for a P-value of 0.3. Most differences between the control samples were not even significant for a P-value of 0.7. The null hypothesis can thus not be rejected and the means of the indeed appear to be equal.

ii. Leaf wetness

The means of the leaf wetness of the experimental period did not show any significant pattern when the nets were closed, so the result seemed to be biased. The same pattern is still largely visible in the control period when the nets are opened. The null hypothesis that all the means of the control samples are equal can be rejected with 70% certainty. Some of the mean differences however can be rejected with 99% certainty. It thus appears as if there is an extra factor besides the nets. When the means of the experimental period are divided by the means of the control period a pattern rises. The results of this comparison are shown in Table 18. The leaf wetness was obviously higher during the experimental period, but the striking thing is that the proportional difference is almost the same for every net for every method apart. The nets were taken away, but apparently the proportionality did not change. This suggests that the leaf wetness is hardly dependent on the net that is above it. However, the difference, although small, is the biggest for the crystal net, then for the gray net and lastly for the black net. This suggests that a crystal net has slightly more influence on the leaf wetness than a black net, but this seems highly unlikely. This effect is probably due to the seasonal influences on the tree that cause a difference between the experimental and control period. In general there appears to be no difference in leaf wetness due to the net color. The mean difference in leaf wetness between no net and a net of 8% has a certainty level of 99.99% however.

Table 18: The differences in means between the experimental and the control period. The ratios for every signal are relatively close together, indicating that the color of the hailnets does not have a big influence on the data.

Method	Black net	Gray net	Crystal net	Control/no net
Original signal	1.35	1.37	1.43	1.37
Zero deletion	1.28	1.28	1.28	1.28
Moving average	1.34	1.36	1.42	1.35
Normalized convolution	1.36	1.37	1.47	1.36

iii. Soil moisture

The soil moisture is just as significantly different during the control period as during the experimental period. It seems unlikely that the difference in soil moisture is thus due to the nets. Heterogeneity of the soil seems to be a more likely cause of the differences.

iv. Other variables

Wind is still highly significantly different, with a certainty of more than 99.99%. However, the mean difference is smaller than it was before, so the opening or closing of the nets could have some influence. The concrete structure on which the hailnets rest plus the road close to the sensors did not change however and these are a major influence on the wind speed.

The humidity and temperature are still significantly different with 80% certainty. This supports the hypothesis that these factors are mainly influenced by the wind and to a lesser degree by the nets.

c. KNMI data

The null hypothesis that is tested is that for every pair of locations the means of their samples is equal. Due to the lack of normality the Mann-Whitney test is again used. The analysis of the separate stations is cumbersome due to the amount of stations that needs to be compared. Therefore a visualization of the P-values is used to show patterns in the groups and to find the eventual outliers which not belong in one group. For reference the locations belonging to each region are numbered in Table 19. The different locations of each region are compared to all locations of the other regions. The results of each test is displayed using a matrix-plot, where a black square indicates a P-value below 0.01%, indicating a difference in means with a certainty of 99.99% between two locations. The first comparisons are between region 1 and 3 and between region 2 and 3, where the columns indicate the locations of region 3. The results of the test are shown in Figure 12a and 12b.

Table 19: The table containing all the locations, their corresponding regions and their specific numbers in those regions.

Location number	Region 1 (far-inland)	Region 2 (inland)	Region 3 (coastal)
1	Deelen	Schiphol	Valkenburg
2	Heino	De Bilt	De Kooy
3	Hoogeveen	SoesterBerg	Berkhout
4	Hupsel	Lelystad	Terschelling
5	Nieuw Beerta	Marknesse	Wijk Aan Zee
6	Twenthe	Eelde	Stavoren
7	Eindhoven	Westdorpe	Leeuwarden
8	Volkel	Rotterdam	Lauwersoog
9	Ell	Cabauw	Vlissingen
10	Maastricht	Gilze-Rijen	Wilhelminadorp
11	Arcen	Herwijnen	Hoek van Holland

Most locations in the coastal region show a clear difference with the locations in the inland and far-inland regions. This difference is not present however for locations 7 and 8 of the coastal region, or Leeuwarden and Lauwersoog. Both locations are in Friesland, but almost all the other locations in the coastal region show a clearly higher mean compared to the inland regions. A third location that is less significantly different is location number 3, or Berkhout. Berkhout is located on the West side of the IJsselmeer. Those 3 locations also show significant differences compared to the rest of the coastal region. All significantly higher locations are located on the East side of the nearest big water, either the North Sea or the Ijsselmeer. According to the data, all locations in the three coastal provinces of Zeeland, Zuid-Holland and Noord-Holland that are within 20 to 30 kilometers on the East side from the nearest coast line are significantly higher. Other bodies of water such as the Ijsselmeer and the Westerschelde may have the same influence as the North Sea has, but only on to East side of those waters.

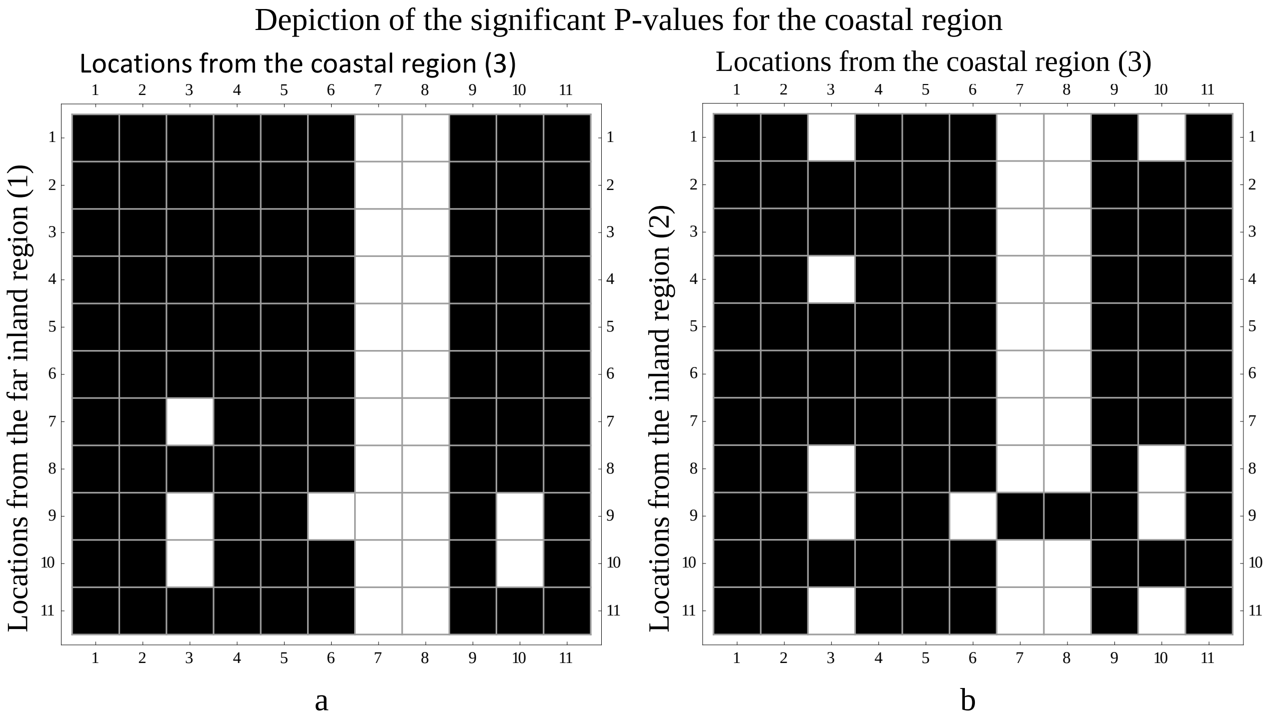

Figure 12: All locations of the coastal region are compared to all the other locations in the inland and the far inland region. A black square indicates a difference with 99.99% certainty. The locations can be referenced in Table 19. Location 7 and location 8 of the coastal region are clearly not significantly different compared to the other regions, location number 3 displays the same problem, but to a lesser degree. The same pattern holds for lower P-values as well, where those two locations show significant differences.

The same comparison plot is obtained for the comparison between region 1 and 2, the two inland regions. As can be seen in Figure 13, for the two inland regions the null hypothesis that the means are equal cannot be rejected with a 99.99% certainty and not even with a certainty of 75%. The means of both groups are almost exactly equal, and no clear distinction between the inland regions can be made. After merging the inland groups, and including the Leeuwarden and Lauwersoog in this group, the means of the coastal region and the inland region can be compared. This results in a highly significant difference of 5.7% between the inland and coastal region. This is well comparable with the difference between a black and gray net or the difference between a gray and a crystal net!

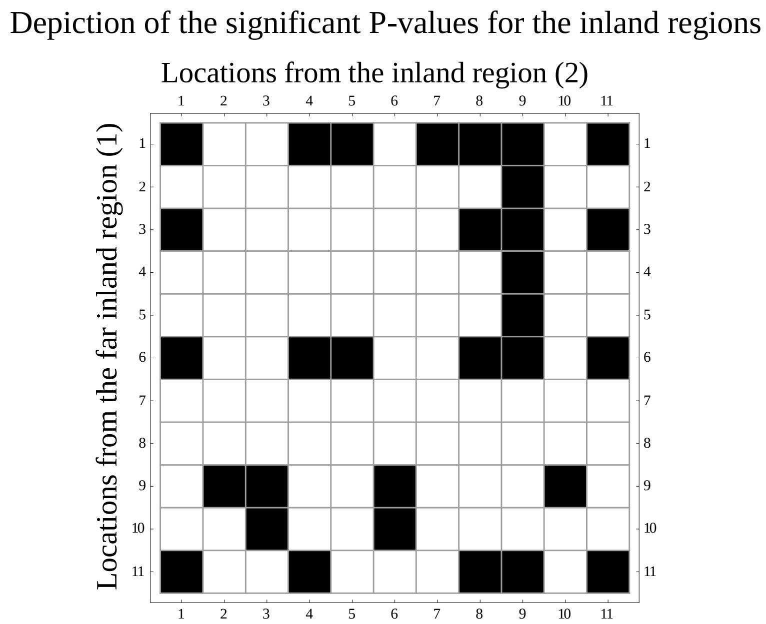

Figure 13: All locations of the inland region are compared to the locations of the far inland region. A black square indicates a difference with 99.99% certainty. The locations can be referenced in Table 19. The difference between the two regions is low and only present for some locations, but there is no clear pattern in this. The conclusion can be made that the two regions are approximately the same.

d. The amount of light over the years

It is possible that the amount of light changes over the years. Due to climate change the possibility rises that the amount of light will either increase or decrease the coming years [1]. Although more light is not a problem when using hailnets, lower amounts of light would impose a problem in the future. The expectancy of the Dutch climate scenarios suggests that due to climate change there will be more light in the future, but they talk about a period of 50 years, which is far longer than the depreciation time of a hailnet [1]. A regression of the means of each location over the years is performed to show a possible trend that could be relevant at the moment, the result shown in Figure 14. Over a course of 10 years the average amount of light in the Netherlands would decrease with roughly 0.2% of the amount of light in the year 2000. It would take 283 years before the amount of light has decreased with 5%, corresponding to one shade difference in net color. This is far longer than the life time of at most 15 years of the hail nets. The possible change of the amount of light over the years is thus irrelevant.

$$light = 68.634 - 0.0121year$$

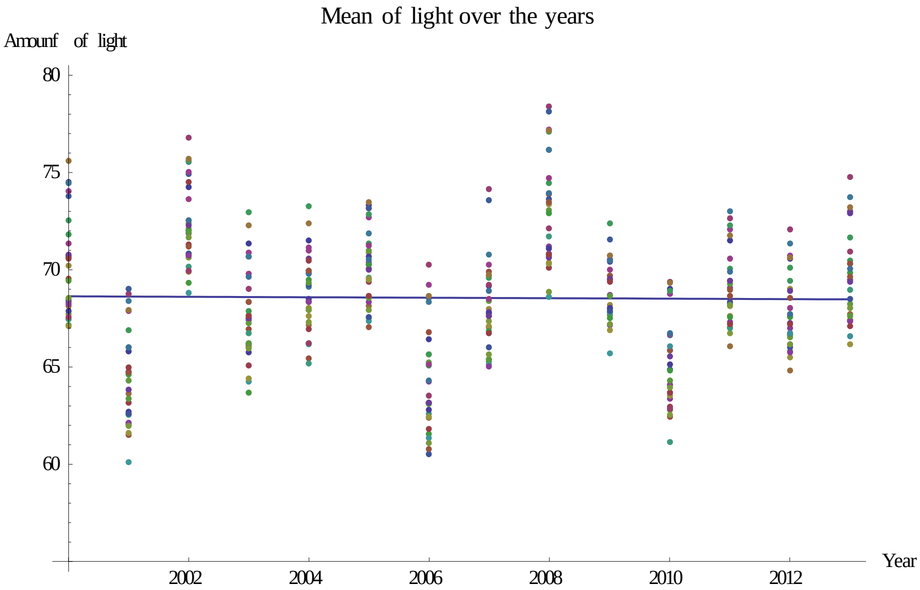

Figure 14: The regression on the means of light over the years, with the function describing the result above. There is no practically significant pattern present so far.

5. Conclusion

As stated in the analysis the light difference between the coastal regions and inland regions seems to be sufficiently high to compensate for the use of a net that is one shade darker, namely 5.7%. However, this is especially the case in a strip of roughly 20 to 30 kilometers wide next to the West coast of the Netherlands. This statement thus only holds for the provinces of Zeeland, Zuid-Holland and Noord-Holland and for the West side of Friesland, since only those are located on the East side of the sea/body of water. The map of the Netherlands with the means shown for every location is again given in Figure 15, but now with all coastal locations with a significantly higher mean colored green. The test location is added in blue, and also fits in to the pattern. However, different sensors were used to obtain the data compared to the KNMI, so the sensor was mapped onto the domain of light of the KNMI sensors. Therefore there may be a slight error in the size of this mean, but it gives a good indication nonetheless.

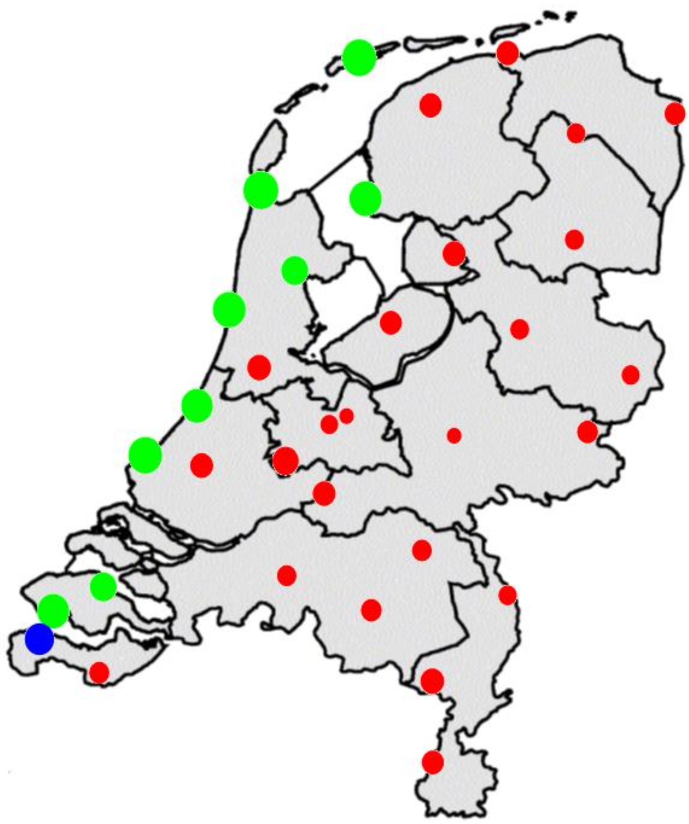

Figure 15: The map of the Netherlands with all the means of the stations shown. Green circles indicate a significantly higher mean of on average 5% in a coastal region. The blue location displays the mean and location of the test location, also being in the strip of 20 to 30 kilometers next to the sea.

This research provided no evidence that the color of a hailnet has either disadvantageous or beneficial effects on the leaf wetness or soil moisture compared to other colors of nets, although the data was biased due to the environmental effects. The only conclusion that can be made is that as well the leaf wetness as the duration of the leaf wetness are higher under a net but the statistical significance is not very high for the leaf wetness duration. The leaf wetness duration is at most 3% higher under a net compared to no net, where the average leaf wetness is at most 8% higher under a net. These effects correlate with the higher wind speeds at the boundaries of the hailnets. It also puts forward a claim that even without the bias the effects between different nets would probably not be practically significant, especially for the soil moisture in the clay. The only aspect that seems to be relevant when choosing a net is thus the amount of light that is desired under a net. Other research provides evidence as well that leaves are on average longer wet below a net, supporting the conclusions made here [3]. However, this other research does not distinguish between leaf wetness duration for different nets, nor are our own measurements able to make this distinction due to an experimental period with too few observations.

The differences in light under the different nets of 11.1%, 17.2% and 21.3% corresponds with other research, although the percentages appear to be on the high side sometimes [3] [6]. Blanke concluded that black nets can either be used in Southern Europe, or on apple races with good coloring, but this research extends this list to coastal regions of the Netherlands for races with lesser coloring as well [6].

The average amount of light does not seem to change over the years, so when deciding about what net color to use the average amount of light given in Figure 15 can be used as a guideline. For future investments in 15 to 20 years it may be wise to account for a higher amount of light and in 30 to 40 years even to light levels comparable to Southern Europe nowadays [1]. It is important to stress however that the nets get dirtier over the course of the years, and block more light. This blocking of light happens with all the nets, but there is no research yet whether this affects different nets differently. A last thing that was checked that was ambiguous in other research was whether the absorption of the light by the nets was linearly related to the intensity of the light [3]. The cost benefit would then be lost since a black net in a coastal region and a gray net in the inland region would have the same depreciation time and the same amount of light under the nets. It would simply be a requirement to use a darker net, since otherwise the costs would be higher in a coastal region. This is not the case and saturable absorption is present. This is again beneficial for the coastal regions, which have on average a higher intensity. The 5.7% extra amount of light in the coastal regions does thus not increase the wear down with the same percentage, but ranges between 3.3% and 4.3% depending on the net color.

This research has shown that coastal regions have indeed a clear benefit regarding the investment in hailnets than inland regions. For the price of €5500,- per net per hectare this results in a difference in depreciation costs of roughly €90,- per year or a little more than €1100,- over the total investment on average [3]. Especially for larger blocks this can easily make a difference of €10000 on the total investment, repeating every 12 or 15 years. The increase in depreciation of roughly 4% has hardly any effect on the yearly difference depreciation costs. Although the technology of the hailnets is rapidly advancing the core of the problem remains the same. Some properties of the nets will never change drastically, especially not the absorption percentage. Although nets that are currently developed already have a longer depreciation time [5], the difference always remains that in a coastal region a net with even a longer depreciation time can be picked, allowing the farmer to gain a better market position.

6. Acknowledgements

This research was supported by the knowledge/financial support of:

- Praktijknetwerk Optimalisatie lichtbenutting hagelnetten
- Rijksdienst voor Ondernemend Nederland (RVO)
- Europees LandbouwFonds voor PlattelandsOntwikkeling (ELFPO)
- VOF Fruitvallei
- University College Roosevelt (UCR)
- Zeeuwse Land en Tuinbouw Organisatie (ZLTO)
- VOF Flikweert, C.M. de Jager, Mts. de Jonge, Mts. Houtekamer
- R. van Wesemael BV
- Edudelta

Without their help this research would not have been possible and I would hereby like to thank them for their support.

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