

Smart Soybean Production in Brazil



Synthesis of four years of green-on-green weed detection in WP1

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Summary: During four years, green-on-green weed detection experiments were carried out on soybean, in a Public-Private Partnership between Brazilian and Dutch partners. The experiments were carried out with the Rometron WEED-IT sensor, and several algorithms were developed and tested to find weeds within the soybean crop for spot-spraying, with the aim of working more sustainably and saving herbicide. Weed detection algorithms look promising for driving and spraying within an angle towards the crop rows, as is common practice in Brazil.

Keywords: precision agriculture, weeding, spot spraying, green-on-green, fluorescence, herbicide, soybean, Brazil.

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Report WPR-1475

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Contents

1	Introduction and objective	5
2	Experiments in 2022, 2023 and 2024	6
	2.1 Methodology	6
	2.2 Finding optimal sensor height	9
	2.3 Finding and predicting rows using the data	10
	2.4 The Signal-to-Noise-Ratio	10
	2.5 Finding the frequency	10
	2.6 Developing a quantitative evaluation method	11
3	Results	12
	3.1 Results 2021-2024	12
	3.2 Algorithm parameters and performance	12
4	Discussion and conclusions	14

1 Introduction and objective

The objective of the work done in Work Package 1 was *to detect weeds in a soybean crop*. Experiments were done with the Rometron WEED-IT sensor. Since the WEED-IT sensor detects plants based on chlorophyll fluorescence, it is hard to distinguish weeds from crop plants, the method for detecting the weeds was based on the pattern of the crop rows. This approach is assuming there is a fixed distance between crop rows on a field.

In Brazil, driving in a slight angle from 30 to 45 degrees towards the crop rows is common practice (see Figure 1). Because of this angle, the pattern of the crop rows becomes visible in the signal of the WEED-IT sensor and can be used to detect crop rows and tell when a plant is not within a row. This principle was used to find weeds between the rows, analysing the WEED-IT signal.



Figure 1: Spray track in an angle towards the crop rows, common practice in Brazil. Santa Maria, RS, 2023.

2 Experiments in 2021-2024

2.1 Methodology

Plots of soybean were sown in the Netherlands and in Brazil, to facilitate for the measurements with the WEED-IT sensor. In the first and second year, 2021 and 2022, measurements were taken in Wageningen, NL, driving parallel to the crop rows and testing with angled driving.

- **In 2021**, soybean, maize and wheat were sown and measured in Wageningen, the Netherlands. The team experimented with small and big weeds (related to each other and the crop).
- **In 2022**, two soybean varieties were sown in Wageningen. Measurement were taken on five different days, driving parallel to the crop rows, with one test plot measured in an angle. Reflecting bars were placed next to the weeds as a reference, with an additional Go-Pro camera mounted next to the WEED-IT sensor.



Figure 2: Soybean crop with transplanted 'volunteer corn' on the first measurement day, 2022, Wageningen. On the left, the reflecting bars indicating 'weeds'. The crop was not well detected by the WEED-IT sensor on this day, as it just emerged.



Figure 3: Crop and test sprayer on the fifth measurement day in Wageningen. This crop stage was found to be too mature to successfully find weeds, as the canopy is almost completely closed.

In 2022-2023 and 2023-2024, angled measurements were performed in Brazil by Universidade Federal de Santa Maria (UFSM).

- **In the 2022-2023 growing season**, a soybean trial was planted and measured in Santa Maria, RS, Brazil. All measurements took place at a 30 degree angle towards the crop rows, as is common practice in Brazil. The measurements were performed on a quad with the WEED-IT sensor and a GoPro camera for reference footage on the weeds.



Figure 4: The quad measurement setup in Brazil. WEED-IT sensor (green) is hanging on the right.

- **In 2023-2024**, the last soybean trial in this project was measured in Santa Maria, RS, Brazil. Four different angles were tested this time: 0 , 15 , 30 and 45 degrees. The objective was to detect the location and angle of the soybean crop rows in the data, using Fourier analysis. To see if results can be improved, the sensor was mounted lower.

Note that natural field conditions were represented in the measurement data. Weather circumstances and foraging by wildlife caused the soybean crop to be uneven to very uneven at times, which is visible in the measurements. Although we consider it essential to measure under real conditions, these conditions made it more challenging to find a clear frequency in the signal.



Figure 5: Experimental fields on February 1st, 2024. Irregularity can be seen between the two locations and even within the images.

2.2 Finding optimal sensor height

In 2022 and 2023, the WEED-IT sensor was placed at a 110cm height above the soil; this height is recommended for spot spraying with the equipment. However, we found that when driving in an angle towards the crop rows at this height, the measurement beam was too broad to effectively detect anything *between* the crop rows, as the sensor is partly above a crop row most of the time.

So in 2024 we decided to halve the height of the sensor, measuring at 55 cm. This would increase our chances to find plants *between* the crop rows, which is our goal. Measuring at 55 cm will narrow down the measurement beam to half of its original width, giving us more measurements without crop rows.

To explain this into more detail, we define the term *distinctiveness* d .

"The distinctiveness of the setup is the fraction of soil measured in a channel, in which no part of the channel is above the crop. Distinctiveness is expressed as a number between 0 and 1, and calculated from the parameters below."

A higher distinctiveness equals a more precise detection of weeds, because it makes distinguishing weeds closer to the crop rows possible. Note that this means that the bigger the angle α , the higher the distinctiveness and the easier it is to detect weeds between the crop rows.

The distinctiveness D can be calculated as follows:

$$\begin{aligned} D &= (d - 2 \cdot sd) / d \\ &= 1 - SW \cos(\alpha) / a \end{aligned}$$

With:

- d : The *distance*, in the driving direction, between the foliage of the two crop rows;
- sd : Is the distance that the centre of the sensor has driven, while *a part of the sensor is above the crop row*. The higher sd , the lower the distinctiveness D ;
- SW : the *sensor width*, the width of the sensor beam (per channel). SW varies with the height at which the sensor is mounted (the width increases with the distance between sensor and the soil);
- a : the *distance* between the canopies of two crop rows. a is by definition smaller than the row distance, and further decreases as the plants grow and the canopy closes the area between two rows;
- α : the angle between the driving direction and the crop rows.

Note that D , d and sd depend on the driving angle α of the setup, distance a between the crop foliage, and sensor width SW .

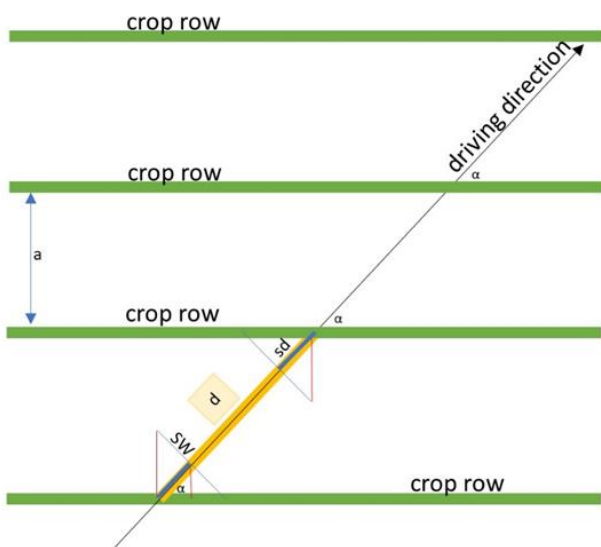


Figure 6: A schematic sketch of the crop rows and the sensor moving, illustrating the main parameters for the calculation of the distinctiveness D .

Note that D , d and sd depend on the driving angle α of the setup, distance a between the crop foliage, and sensor width SW .

Table 1 below shows the effect of four different driving angles on the distinctiveness (expressed in percent). The distinctiveness is computed with the assumption that the width of the crop row is 0. In reality, crop rows have a positive width (increasing over the season) and the distinctiveness is smaller.

Table 1: The distance d between the rows in the driving direction and the distinctiveness for each driving angle α .

Angle between crop rows and driving direction α	Distance in m between the rows in the driving direction d	Distinctiveness (%)
0	n.a.	n.a.
15	1.73	73
30	0.9	76
45	0.64	80

2.3 Finding and predicting rows using the data

All signals were analysed with a Fourier transform and time series analysis. GoPro footage was annotated to detect the weeds and then compared via timestamps.

A 'region of interest' was selected in the *frequency domain* for the Fourier filtering. This was done using frequencies that could be expected, based on the angle α and crop row distance. The distances between the crop rows in the driving direction determine an expected frequency: when the distance is d , the expected frequency is $1/d$. The region of interest was selected to be between $1/(d+0.2)$ and $1/(d-0.2)$. The distances in the driving direction can be found in Table 1 above.

It is desirable to predict the locations of the rows about two meters ahead. That is expected to be a workable distance for operating the spraying nozzles on a field sprayer in time.

Given the inverse Fourier transform and the dominant frequency, a prediction is made two meters ahead of the sensor and spray boom, by simply using a cosine function as prediction, extrapolating the dominant frequency two meters ahead, starting from the last peak found in the inverse-Fourier transform.

2.4 The Signal-to-Noise-Ratio

The angle between the crop and the driving direction will vary a bit during real field operations. Therefore, it is useful to detect crop rows after only a short period of driving. To do so, a measure is developed, the so called *signal-to-noise-ratio* (SNR).

With this SNR, the highest dominant frequency can be assessed with a relatively small amount of data. The SNR is a tool to determine the *real* driving angle α . When the SNR is computed for several angles, it will peak at the real angle. The longer the measurement (more rows, more data), the higher the peak and the more accurate the SNR.

The SNR was used to determine the quality of the frequency found. A minimal SNR was determined by visual assessment. An SNR of 3 or higher is considered enough to find the rows in a dataset.

2.5 Finding the frequency

To evaluate whether or not there is plant material under the sensor, we set a threshold value of 0.18 (WEED-IT signal). This threshold value was found by making histograms of the measurements. The value of 0.18 is a bit larger than the inflection point after the big peak with the datapoints corresponding to soil. This inflection point was found to be very stable.

2.6 Developing a quantitative evaluation method

We evaluated how many meters the setup has to measure to get a reasonable prediction for two meters ahead. We also evaluated how far the signal can be downsampled to still get good predictions.

For the downsampling, we assessed the data in terms of distance, because the speed was known. Tested downsampling rates were 1mm, 1cm, 5cm, 10cm, and downsampling was done by averaging. To determine the minimal and optimal driving distance predict 2 meter ahead, predictions were calculated based on different driving distances.

For evaluating the predictions, we took the amount of mm where the signal was higher than the threshold value of 0.18 (and thus considered plant material). This number is divided by the total amount and distance of mm < 10 cm from the peaks. The result is an indication of the quality of the prediction, which we will call *score*.

Scores were calculated on a signal downsampling rate of 1mm. See Figure 7 for an illustration on how this evaluation of the prediction works.

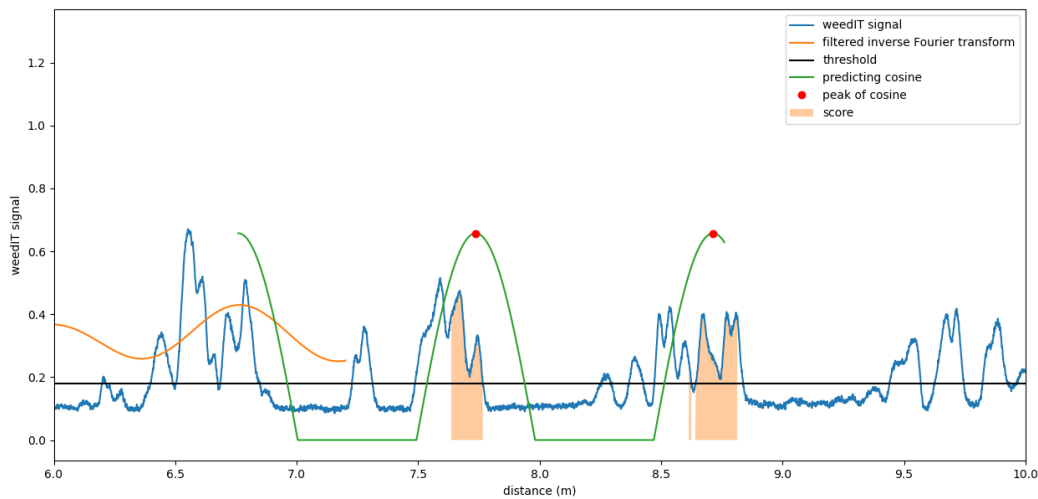


Figure 7: An illustration of how the score is defined. There are two peaks. The number of mm that the signal is larger than 0.18 around the first peak is 130, and around the second peak 183. The total number of peaks is two, so the score is $(130+183)/400 = 0.78$.

3 Results

3.1 Results 2021-2024

- **In 2021**, the team was able to detect large weeds in a small crop with threshold analysis. The team also concluded that threshold analysis and Fourier analysis were not sufficient to distinguish normal-sized weeds in a similar-sized crop when driving parallel to the crop rows. In 2021, there were problems with reference data (locations or detection of reflecting bars), causing a large loss in useable data. Predation caused loss in the soybean field, not leaving much crop material to detect.
- **In 2022**, the team found good potential for driving in an angle towards the crop rows, as the crop rows pass in a pattern below the WEED-IT sensor, showing a frequency. Driving parallel however did not yield promising results for distinguishing between rows and weeds. The team also found the optimum period for measurement. Right after emergence, the soybean crop cannot be detected well enough, and an almost fully closed crop canopy covers the soil surface too much, making it impossible for the sensor to detect weeds between the row (Figure 2 and Figure 3). Increasing the height of the WEED-IT sensor did not improve measurements in a fully grown crop. Measurements should therefore start at least two weeks after planting, depending on the weather. And measuring can stop when the soybean canopy closes.
- **In 2023**, all soybean was measured in a 30-degree angle, in Brazil. Two algorithms were developed: a Gaussian Mixture Model (GMM), detecting plant material, and a Fourier analysis for detecting the crop rows as they follow a pattern (frequency). When combined, the algorithms support a decision system: where Fourier finds no crop row, and the sensor (or GMM) detects plant material, there is a weed that can be sprayed. This method relies on a regular crop, and only works in the crop stages where the plant is detectable by the sensor and before the canopy closes (see Figure 2 and Figure 3). Since the Fourier model enables finding the crop rows, chemicals can be saved even if weeds are not detected precisely, as the model can avoid spraying in the crop row.

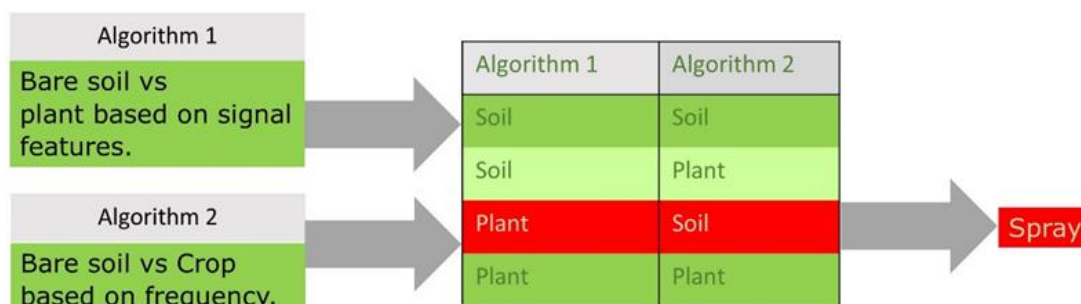


Figure 8: The 2023 algorithm rationale illustrated. In algorithm 1, the distinction between plant and non-plant material is made. In algorithm 2, the location of the crop rows is determined. When plant material is detected outside a row, this is considered a weed.

- **In 2024**, the objective was to detect the location and angle of the soybean crop rows, using Fourier analysis, and predict the location of the next rows of soybean. The extended results of the analyses are further described in the subchapters below.

Note that there is also an extended report on the methodology and results for each year of this Public-Private Partnership.

3.2 Algorithm parameters and performance

Optimal distinctiveness

The crop did not emerge well in 2024, making the rows difficult to distinguish. Also, the annotation of the weeds was not precise enough to be useful for weed detection. However, the differences in the angles between crop rows and driving direction are clearly visible in the plots.

The distinctiveness was higher in 2024 than in 2023, as was expected due to the lower height of the sensor. The expectation was that the distinctiveness of the measurements taken under a 45 degree angle would be higher than under 30 degrees, but that was not the case. Both 45 and 30 degrees had a higher distinctiveness than the 15 degrees.

Optimal 'look-back' distance for prediction

Our statistical analysis showed all calculations with different distances and downsampling rates. Unexpectedly, the analysis showed that a shorter distance leads to a slightly higher score for each downsampling rate. The number of times the $\text{SNR} > 3$ requirement was met, was substantially smaller for shorter measurement distances however.

We found that we can predict two metres ahead using the Fourier analysis to find the rows. Analysing three meters of measurement data backwards is sufficient for a prediction. Further backwards seems to lead to a higher SNR.

Row prediction quality evaluation

We designed a *score*, to validate the precision of the prediction of the row locations. The score was created so that it is independent of the signal strength and the dominant frequency found in the signal. The score is dependent of the width of the crop row however, since it is based on looking for plant material up to 10cm from the signal peak, at both sides of the crop row. This means that scores can be compared with other measurements that day (similar crop stage), but not with other days. This was taken into account when analyzing the data.

Downsampling rates

Predictions made using different downsampling rates did not significantly differ. This means that the averaging approach works well. Downsampling between 1mm and 10cm gives similar results. Downsampling further should be tested for quality before it is done.

4 Discussion and conclusions

During four years, field measurements were done in the Netherlands and in Brazil. The goal was to find weeds in soybean (or other crop) field using a fluorescence sensor (WEED-IT) on a spraying boom. Since the sensor can only distinguish between plant/no plant, alternative methods for finding the weeds had to be explored.

The result is a first exploration of a method to:

- Find an optimal sensor beam width of the WEED-IT sensor for finding weeds, adapting the height;
- Find crop rows in the data, when the sprayer is not driving parallel towards the rows (in an angle);
- Predict the next two meters ahead, using data from the past few meters;
- Determine the quality of the prediction with two quantitative parameters:
 - The Signal-to noise ratio; which indicates the dominance of each peak (row) found, compared with the rest of the signal (noise in this case). SNR should be higher than 3.
 - The Score, a score between 0 and 1, where 0 means that the predicting cosine peak covers no plant material at all (bad) and one means that the predicted cosine peak (+-10cm) is 100% over detected plant material (a row, which is good).
- Downsample the amount of measurement points used to an optimum, to avoid unnecessary data processing.

These results are a good start to elaborate on and to develop a realtime tool to detect and spray weeds between crop rows, when driving in an angle on a soybean field.

However, there are still challenges to detecting weeds in a crop with the WEED-IT sensor, that could be solved with more in-depth research:

- Driving angles can change regularly in real fields; a better real-time angle detection is needed;
- The score can be made into an even more powerful tool by taking the amount of data used to calculate it into account;
- The score and other quantifying methods in this research could be made completely independent of canopy width in the row, and thus crop stage;
- This is no solution for farming systems in which the sprayer drives along the crop rows and no frequency can be determined.

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