Smart Soybean in Brazil WP4
WEED-IT fluorescence sensor and NDVI for end-of-season variable rate soybean desiccation

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This document collects the reports on the experiments carried out in the context of work package 4. The goal of these experiments was to investigate the usage of WEED-IT to vary the dessicant dosage in end-of-season dessication in Brazil

1. **Executive summary report synthesis**
   This document syntesize the results of experiments 2,3,4 aimed at the parameterization of a rule for variable rate end-of-season desiccation of soybean using as input either NDVI or WEED-IT observations.

2. **2023 and 2024 Brazil experiment on WEED-IT for end-of-season soybean desiccation year**
   This experiment was carried out for over two seasons in Rio Grande Do Sul-Brazil with the goal of establishing a rule to vary diquat dosage for end-of-season desiccation in soybean in Brazil.

3. **2022 Brazil experiment on correlation between NDVI and WEED-IT**
   This experiment was the first experiment carried out in Brazil in the context of work package 4 and was aimed at evaluating the correlation between NDVI and WEED-IT in soybean.

4. **2022 Dutch experiment on soybean for end of season desiccation**
   This experiment was carried to study the effect of different dosages of diquat on soybean canopy desiccation and investigate the relationship between NDVI (a robust proxy of canopy biomass) and fluorescence as measured by the WEED-IT sensor.

5. **2021 Dutch experiment on WEED-IT to predict canopy biomass in potatoes**
   This experiment was carried out in work package 4 to evaluate the use of WEED-IT to estimate canopy biomass. Since the results were positive for potatoes (the only crop that we could investigate in the first year given the short time intercurring between project start and growing season) in 2022 we extended this investigation to soybean.

Smart Soybean in Brazil WP4 - Executive Summary Report

WP 4 desiccation team

2024-10-30

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1 Introduction

Farmers in Brazil apply desiccant containing the active ingredient diquat to defoliate soybean before harvest as a preparation for a second crop in the season that is typically corn. The objectives of desiccation are the following:

1. Speed up the desiccation of the bean and anticipate harvest
2. Remove weeds for the next crop
3. Reach an homogenous desiccation of the bean

Diquat is a contact desiccant that inhibit photosystem I and thus photosynthesis leading to the death of the target plant, by interrupting the electron transport chain. Diquat was widely used as a potato haulm kulm desiccant in the Netherlands until an EU-wide ban was fully enforced in 2020. A consistent body of literature exists on using variable rate of diquat for desiccation of haulm killing of Potatoes in the Netherlands, part of this research was made actionable through an app on Farmmaps for variable haulm killing in potatoes (Kempenaar et al., 2017). Kempenaar et al. (2017) estimated that variable rate of haulm-killing could save 68 euro/ha in 2017. In Brazil the desiccant paraquat was banned in 2020. As a result most research over the past decade focused on the comparison of alternative herbicides (Albrecht et al., 2024, 2022; da Silva et al., 2022) and the timing of application (crop stage development) (Finoto et al., 2017; Albrecht et al., 2022; Zagonel, 2005). These studies generally concluded that desiccation should be carried out at stage R7.2 and that diquat or glufosinate are adequate substitute for paraquat. Different rates have been tested for example Finoto et al. (2017) tested diquat at a rate of 400g a.i./ha, whereas Zagonel (2005) and Albrecht et al. (2022, 2024) tested it at a rate of 200 g a.i./ha. However to the best of our knowledge less attention has been paid to the effect of different dosages of diquat,for example da Silva et al. (2022) evaluated the effect of different dosages of various products (including diquat) on pre-harvest defoliation, however they did not find any significant differences between 200, 300, and 400 g a.i. /ha of diquat on canopy desiccation nor on grain moisture.

1.1 Goals

The goal of these two experiments was to define a rule for variable spraying of end-of-season diquat desiccant in soybean thorugh experiments carried out in Rio Grande do Sul, Brazil. The rule will be parameterized separately both for NDVI (for example collected from drone or satellite) and for WEED-IT. WEED-IT is a variable rate spraying system composed of chlorophyll fluorescence sensors and pulse width modulation (PWM) solenoids. The rule we are parameterizing is:

$$Diquat(mg/ha) = \begin{cases} if(\ biomass\_proxy < \mathbf{threshold})\{0\} \\ else\ \{\mathbf{a} + biomass\_proxy * \mathbf{b}\} \end{cases}$$

The biomass_proxy can be either vegetation indices from remote sensing (e.g. drone, satellite) or the biomass index produced by WEED-IT itself. To identify the parameters *threshold* (the threshold below which it is not necessary to apply the desicant), and *a* and *b* we setup an experiment where different rates (including no spraying) of diquat (a popular desiccant for soybean) were applied to 6x8 m plots in a soybean field. The purpose of the study was to identify the parameters *threshold*, *a* and *b*, assuming that harvest would take place 7 days after spraying.

1.2 Differences between the experiment in 2023 and 2024

1.2.1 Methodology

In 2023 the experiment consisted of 50 plots and these were harvested for more variables (biomass partitioning, bean moisture) than in 2024 we only focused on miosture of beans and pods. In 2024 we measured total abovegroud fresh biomass but not dry matter content of leaves and stems. Values of NDVI, WEED-IT and crop variables (biomass, bean moisture, ...) are averaged per plot. Plots were sprayed uniformously based on WEED-IT measured less than 24 hours prior the experiment.

1.2.2 Desiccation moment

In 2023 the plots were desiccated on March 27, whereas in 2024 the plots were desiccated on April 19. In 2024 the soy had been planted very late (8th of January) because of the rainfall affecting soil workability. In 2024 the plots was harvested at a slightly earlier stage (and slight earlier NDVI). The distribution of NDVI at the moment of spraying is showed in Figure 1. The reason for the earlier spraying in 2024 was to test whether a variable rate (still within the label dosages) has an effect on bean moisture if applied at an earlier stage (i.e. on a greener crop). In fact in 2023 we had observed that all spraying rate were sufficient to reach the desired soil moisture content.

1.2.3 Weather

The weather was substantially different between the 2 years, the week following desiccation in 2023 was sunny and dry whereas in 2024 it was humid and cloudy (Figure 2). This – together with a higher NDVI at spraying time – had an impact on the result causing the bean to not dry to the desired moisture (in 2024 bean moisture was >13%).

1.3 Results

1.3.1 Comparison NDVI-WEED-IT

The comparison between NDVI and WEED-IT generally gave good results, with an r^2 of 0.77 and a non linear relationship, that may indicate that WEED-IT signal does not saturate as soon as NDVI when used as a proxy for to biomass content 3.

1.3.2 Efficiency and homogeneity

The efficiency is reported in Figure 5 where the mg/ha of diquat used for the treatment are reported next to the bean moisture. The figure shows that in 2023 the crop did not actually need spraying whereas in 2024 despite spraying the desired desiccation was not achieved.

1.4 Relation bewteen bean moisture before and after spraying

The relationship between bean moisture at spraying and 1 week after spraying was generally weak.

1.4.1 Identifying curve

In 2024 it was not possible to clearly identify a curve for desiccation since almost no plot had reached a DM of 13%. The threshold that we derived was obtained from Figure 6 where data from 2023 and 2024 were combined to calculate the value of the proxy (ndvi or WEED-IT) for which we can expect that after a week without desiccation we can expect a bean water content of 13%. Where a and b parameters where derived from the fact that the low rate reached the lowest moisture, despite this was not sufficient in 2024. Thus the low treatment provided the most savings and we do not have evidences that higher rates would provide drier beans one week after the treatment in agreement with da Silva et al. (2022). The final equations are reported in Equation 1 for ndvi and Equation 2 for WEED-IT. Such equations are also plotted in Figure 7

Final spraying rule using NDVI

$$Dose = \begin{cases} if(\ x < \mathbf{0.55}\ )\{0\} \\ else\ \{\mathbf{140.945}\ + x * \mathbf{148.003}\ \} \end{cases} \tag{1}$$

Final spraying rule using WEED-IT

$$Dose = \begin{cases} if(\ x < \mathbf{51.82}\ )\{0\} \\ else\ \{\mathbf{181.286}\ + x * \mathbf{0.67}\ \} \end{cases} \tag{2}$$

1.5 Backcalculation of savings in 2022 soybean field

We backcalculated the savings that would have been obtained if this equation was applied to the experimental UFSM field in 2022. If the Equation 1 was applied to that field the average Diquat application rate over the field would have been 154.47 mg/ha which represent a saving of 41 % compared to an average blanket application rate of 260 mg/ha. If the same equation was applied to the field of 2023 the application rate would be 103.18 which represents a saving of 60 % compared to 260 mg/ha blanket application. The maskmap generated by applying the Diquat equation is reported in Figure 9.

If instead of a spot+VR approach as described in eq. 1.1 we were to use a spot-spraying approach where only the spots higher than the threshold are sprayed with a dosage of 200 mg/ha we would save 52 % in 2022 and 67 % in 2023. Such taskmap using NDVI as biomass proxy is reported in Figure 10.

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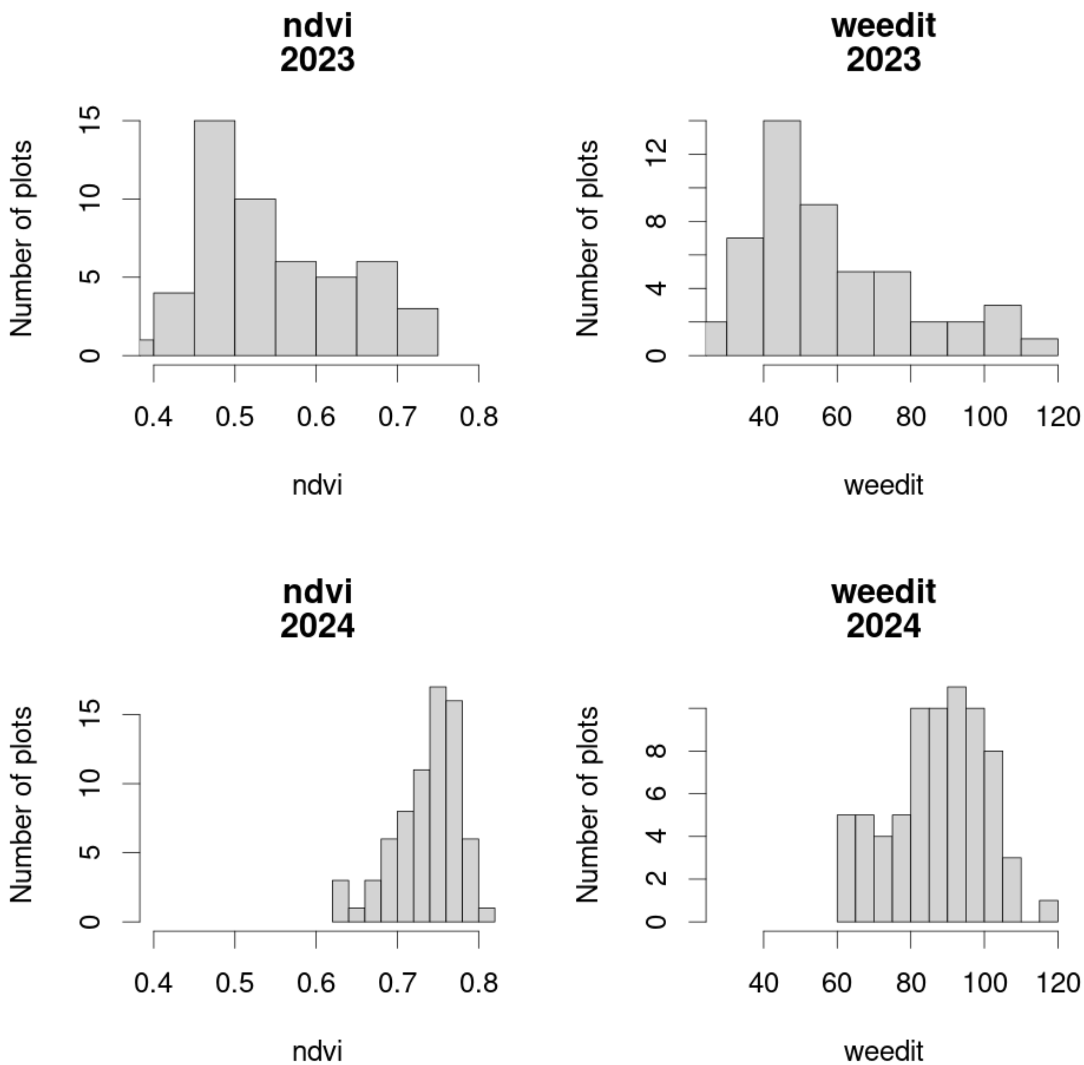

Figure 1: NDVI distribution in the plots in 2023 and 2024 before spraying

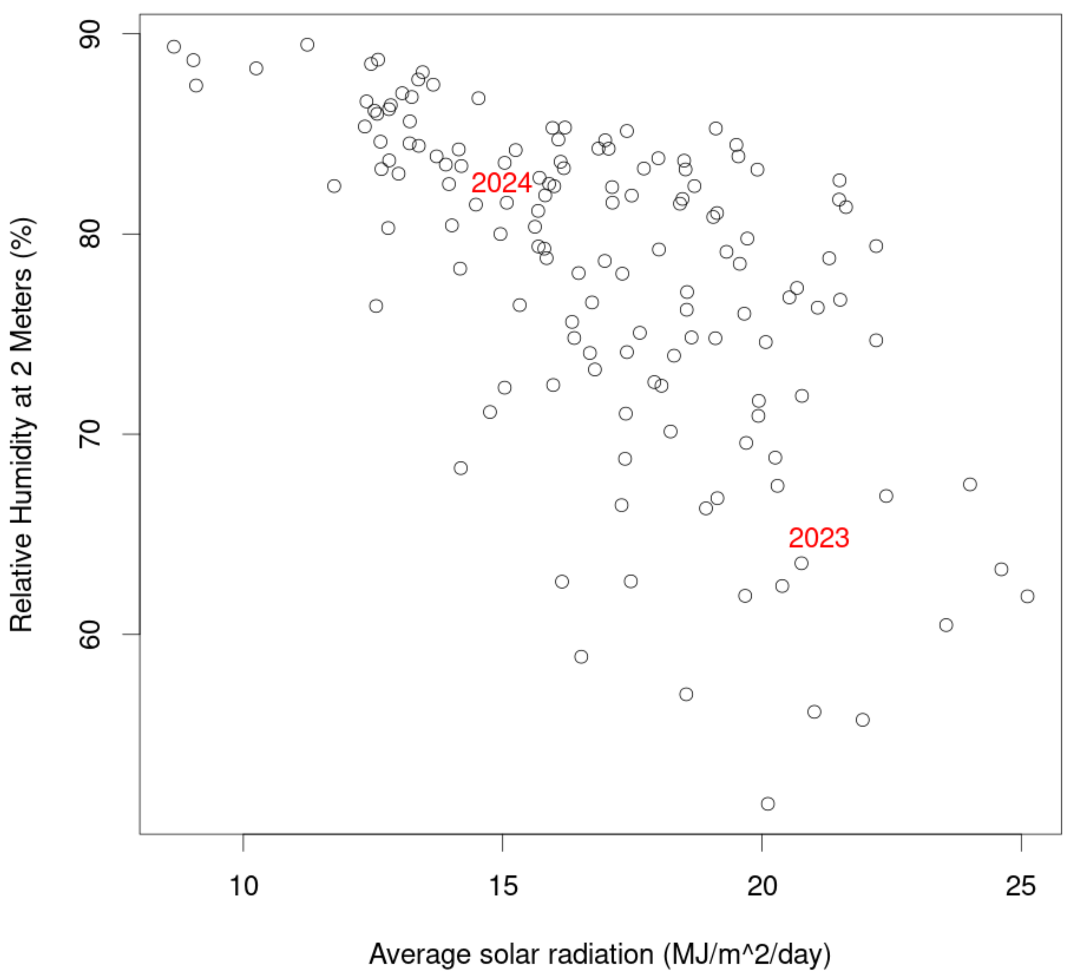

Figure 2: Difference in weather between the two years of the experiment. Each dot represent a week in the period March-April for the last 10 years. On the y axis is the cumulative rainfall and on the x axis the temperature.

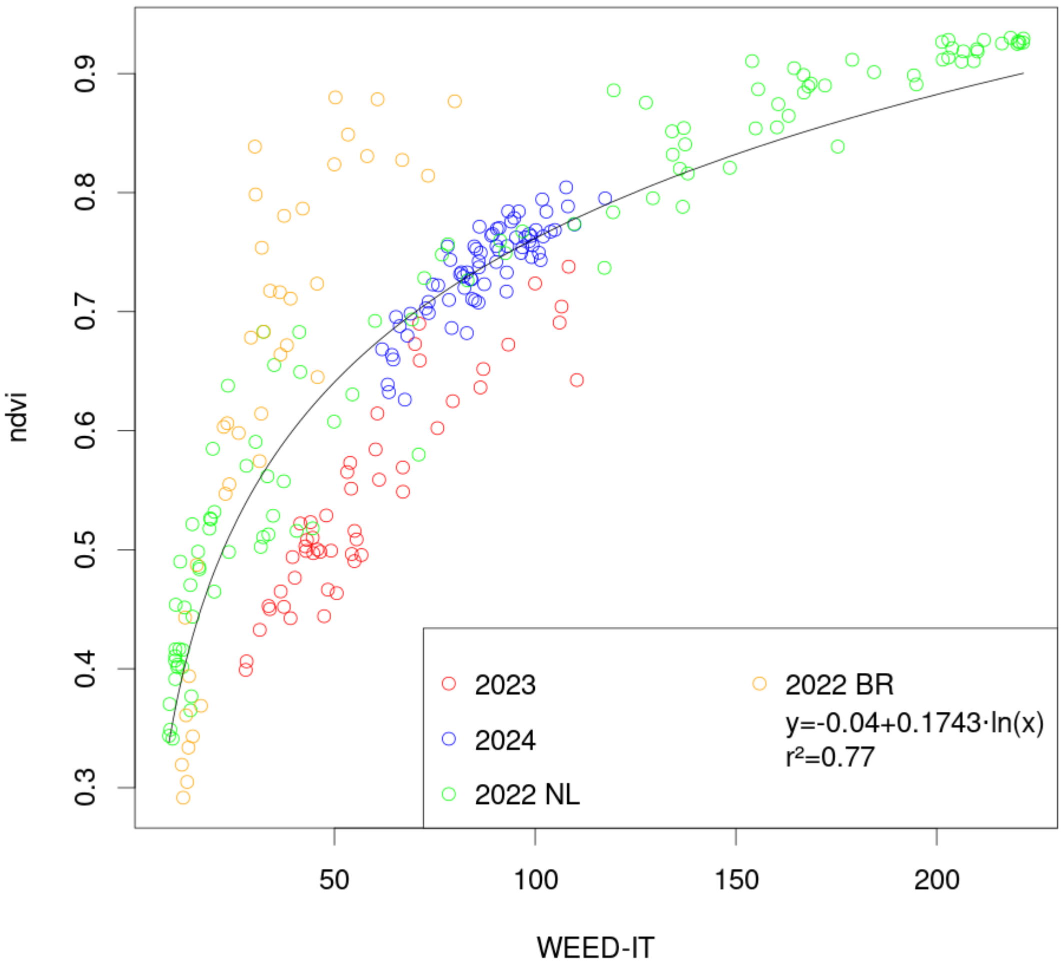

Figure 3: Comparison between NDVI and WEED-IT , by date and year. In 2022 two experiment were conducted one in the Netherlands and one in Brazil.

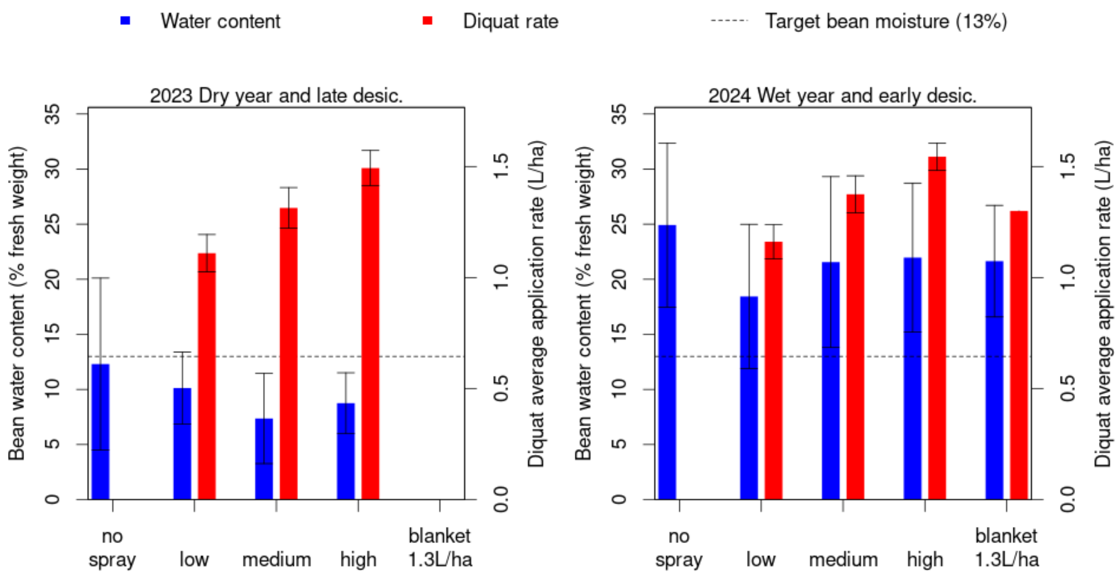

Figure 4: Efficacy of desiccant use by treatment and year. The error bars represent the 75% confidence interval (each side of the error bar is 1 σ).

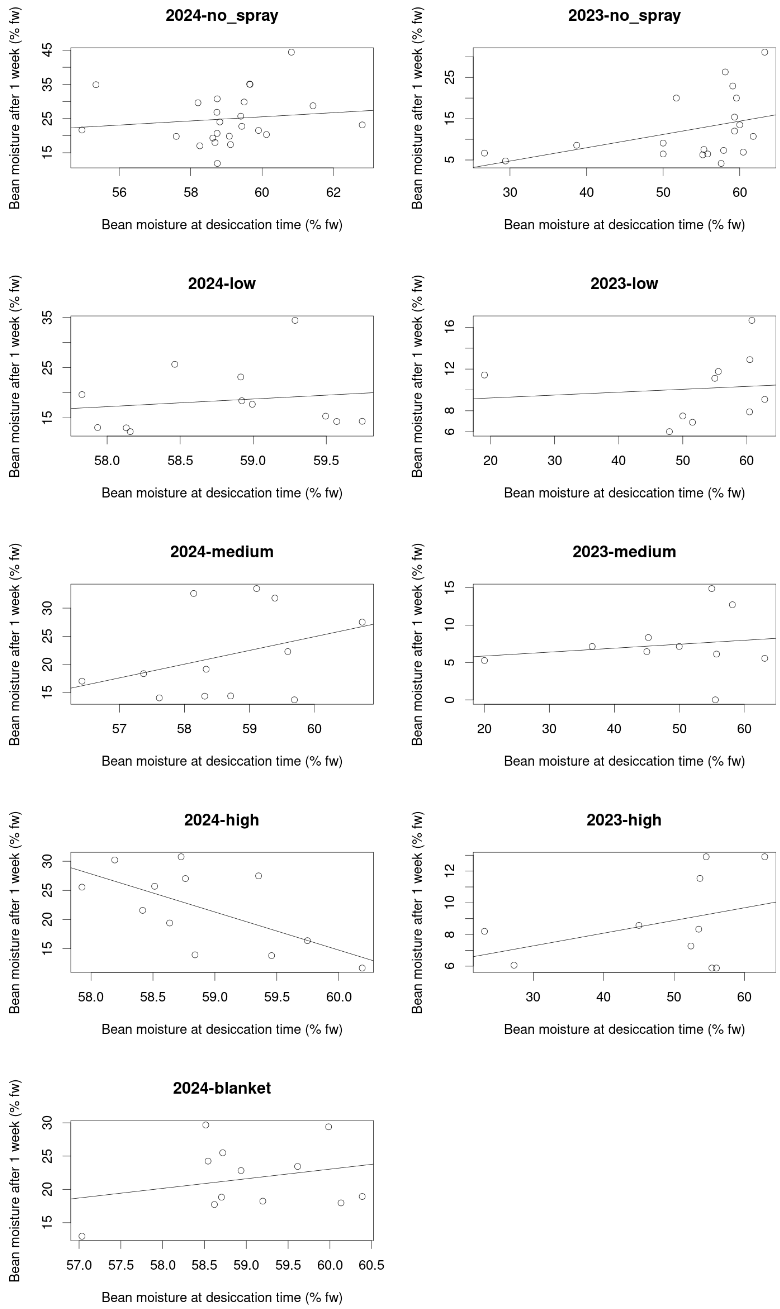

Figure 5: Relationship between bean moisture measured on the day of spraying and 1 week after by year and treatment. Bean moisture is expressed as percentage of fresh weight

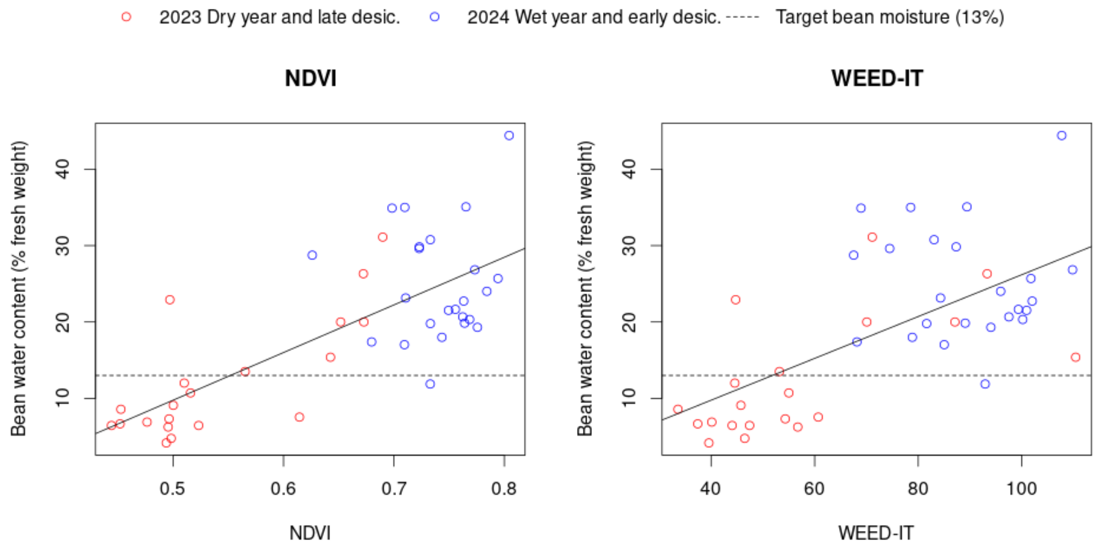

Figure 6: Threshold for Equation 1.1 reporting on the x axis NDVI or WEED-IT before spraying and bean moisture after spraying.

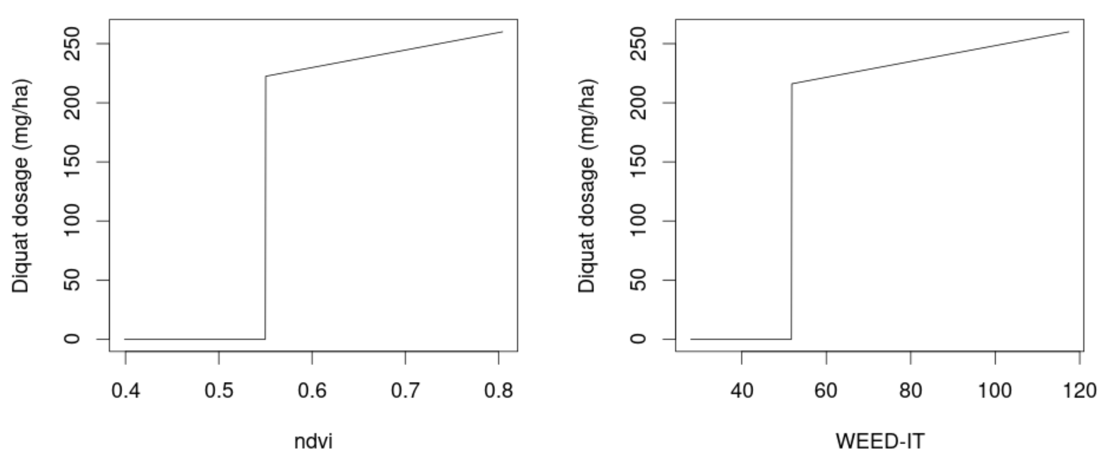

Figure 7: Plotting of final equation as reported in Equation 1 and 2.

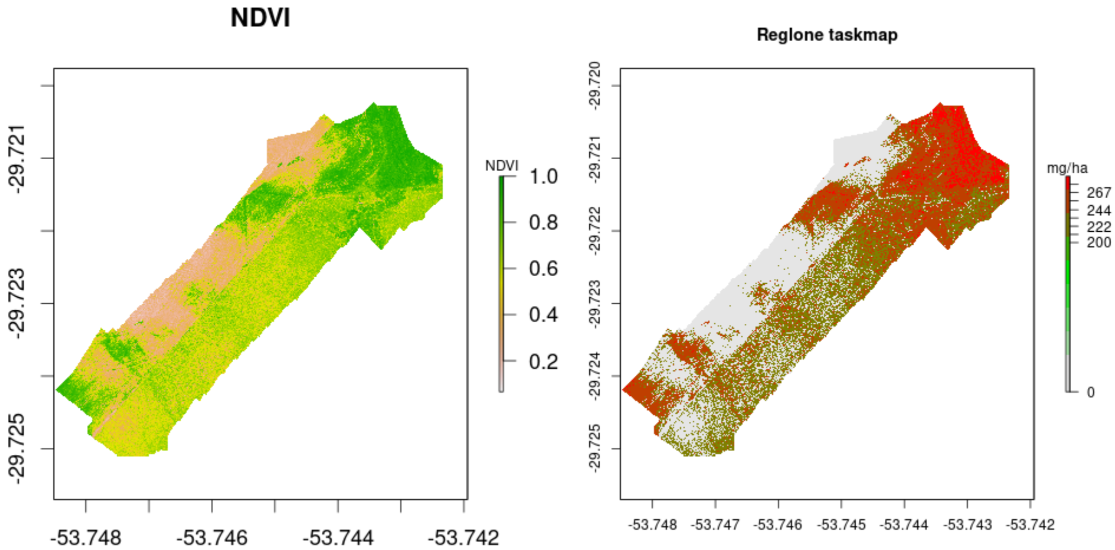

Figure 8: Taskmap generated by applying 1.1 to the field of 2022 experiment (measured on March 5, 2022).

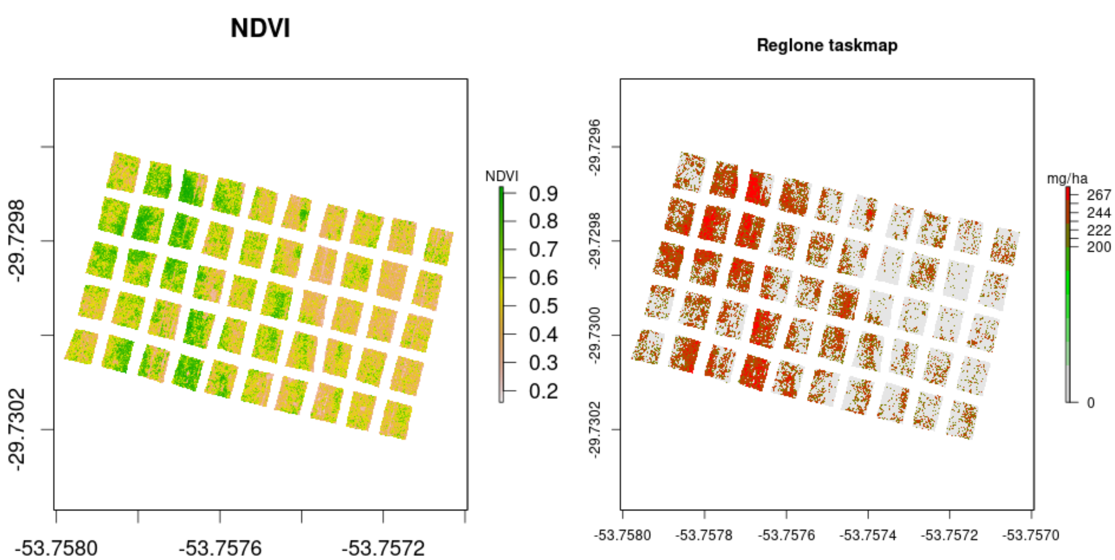

Figure 9: Taskmap generated by applying 1.1 to the field of 2023 experiment.

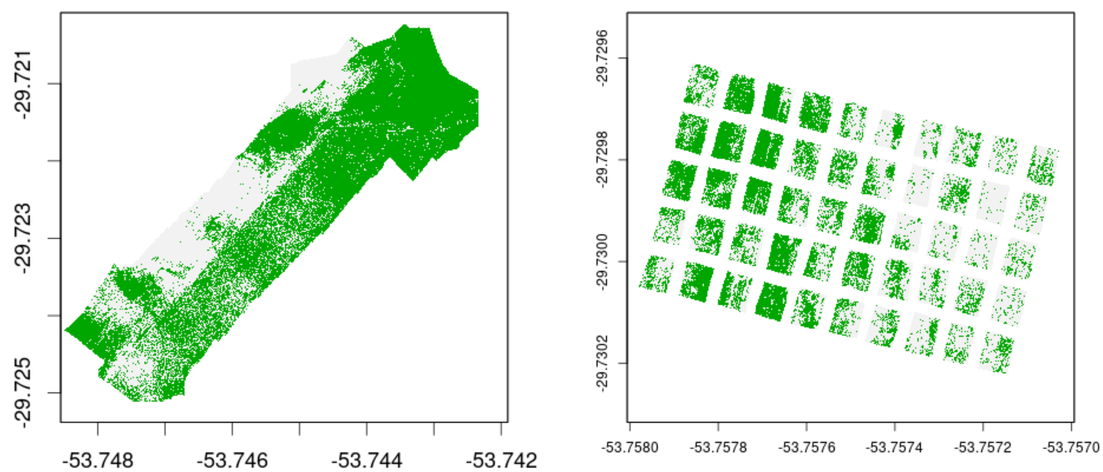

Figure 10: Taskmap generated by using a spot only approach (no variable rate). The green pixels indicated the areas where the crop is sprayed.

Smart Soybean in Brazil WP4 - Soybean Desiccation Dosage 2024 Santa Maria experiment

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1 Introduction

Soybean desiccation is a common practice in Brazil to anticipate the harvest by a few days and the second crop of the season (typically corn) can be planted earlier. WEED-IT is a variable rate spraying system composed of chlorophyll fluorescence sensors and pulse width modulation (PWM) solenoids. We believe that major savings in herbicide for end-of-season desiccation can be reached if WEED-IT is used to distribute the herbicide based on the amount of alive biomass present in the canopy. To reach this goal we need an algorithm that defines the amount of desiccant to be sprayed. For such purpose we identified the following algorithm that combines spot and VR spraying:

$$diquat(mg/ha) = \begin{cases} if(\,biomass\_proxy < \textbf{threshold})\{0\} \\ else\;\{\mathbf{a} + biomass\_proxy * \mathbf{b}\} \end{cases}$$

Such algorithm was defined in the 2023 experiment and the same experiment was repeated in 2024. This document describes only the experiment from 2024. The biomass_proxy can be either vegetation indices from remote sensing (e.g. drone, satellite) or the biomass index produced by WEED-IT itself. To identify the parameters *threshold* (the threshold below which it is not necessary to apply the desicant), and a and b we setup an experiment where different rates (including no spraying) of diquat (a popular desiccant for soybean) were applied to 6x6 m plots in a soybean field. The purpose of the study was to identify the parameters *threshold*, a and b, assuming that harvest would take place 8 days after spraying. The parameter *threshold* is identified as the value of NDVI below which we estimate that 8 days after NDVI observation soybean grains will have a moisture content lower than 13% even without spraying. To identify this parameter we related NDVI and WEED-IT before spraying and beans moisture 8 days after spraying. The results are presented in section 3.6

2 Materials and methods

2.1 Field and destructive measurements

The weather at the time of the experiment in 2024 was much wetter than 2023, in fact at desiccation time the weather was very rainy. Two days after the end of the experiment the area was completely flooded by a tragic flooding event that was reported on international media, however the flooding has not affected the measurement as it occurred after the last sampling date. The experiment took place in a soybean field in Santa Maria in Rio Grande Do Sul, we set up 72 plots organized in 6 blocks. The plots had a size of 6 (approximately 13 rows) x 6 meters. A subplot from each of the 72 plots was harvested prior spraying (same day, 19/4/2024), two days after spraying (22/4/2024), and eight days after spraying (27/4/2023). The subplots had a size of 0.5 x 0.9 m and occupied the area of two rows, as row distance was 45cm. The plants were harvested, partitioned between leaves, stems, and bean and pods. A subsample of pods was then opened to estimate the proportional weight of beans and pods. The samples and subsamples (bean and pod) were separately dried at 70 degree C for 72 hours. After the last harvest (8 days after desiccation) the pods have been drying for one week as it was not possible to access the lab because of the flooding. The water content of soybean (without the pod) in the field was calculated as:

$$watercontent = \frac{(bean_{fresh} - bean_{dry})}{bean_{fresh}} * 100$$

2.2 Treatments

We tested the following different variable rate treatments. The no spray treatment had a double amount of plots since these are used to determine the threshold of spot-spraying. Spot-spraying is a spraying technique where some parts of the field are sprayed and parts aren't depending on the crop status (e.g. only the greenest parts of the field are sprayed).

Treatment	Lowest dosage (mg/ha)	Max dosage (mg/ha)	N. of plots
No spray	0	0	24
Low	200	260	12
Medium	260	300	12
High	280	340	12
Blanket	260	260	12

The treatments were applied using a linear interpolation based on the measured values of biomass index (cdd) calculated from the WEED-IT sensor measured in the afternoon of April 18 2024, so that the lowest spot would receive the minimum and the max spot would receive the max treatment, with a linear interpolation for the plots in between.

2.3 Equipment: WEED-IT and sprayer

A six meter boom sprayer was retrofitted with a WEED-IT (Figure 2) sensor system connected to PWM solenoids, in order to apply variable rate and measure green biomass index. The WEED-IT sensors were

Table 1: Drone flights during the experiment

date	Res. x (cm)	Res. y (cm)	file
2024-04-06	2.80	2.80	raw_data//drone/Flight3_20240406/NDVI_Rxx_Fly3_06042024.tif
2024-04-17	2.83	2.83	raw_data//drone/Flight4_20240417/NDVI_Rxx_Fly4_17042024.tif
2024-04-18	2.84	2.84	raw_data//drone/Flight5_20240418/NDVI_R6_Fly5_18042024.tif
2024-04-19	2.90	2.90	raw_data//drone/Flight6_20240419/NDVI_R6_Fly6_19042024.tif
2024-04-20	2.96	2.96	raw_data//drone/Flight7_20240420/NDVI_Rxx_Fly7_20042024.tif
2024-04-21	2.99	2.99	raw_data//drone/Fligth8_20240421/NDVI_Rxx_Fly8_21042024.tif
2024-04-22	2.83	2.83	raw_data//drone/Fligth9_20240422/NDVI_R7_Fly9_22042024.tif
2024-04-23	3.01	3.01	raw_data//drone/Fligth10_20240423/NDVI_Rxx_Fly10_23042024.tif

placed approximately 1 m over the crop, and an embedded logging system was used to record the WEED-IT signal, generate a map of the WEED-IT signal and execute the task map – that is uploaded to the WEED-IT cloud system and automatically downloaded on the WEED-IT physical system – and record an as_applied map. The WEED-IT biomass index was mapped two days before spraying in the morning and in the afternoon. The spraying of the desiccant occurred on April 19 2024 at 2 PM. The biomass maps captured by WEED-IT one day prior spraying (19 April) are reported in Figure 1. The plots were identified on the WEED-IT biomass maps and a shrinking buffer of 1 m was applied reduce border effect when calculating average WEED-IT signal per plot. There was a problem in the georeferentiation of the maps produced by WEED-IT since plots did not align between themselves nor with NDVI, possibly due to a problem with RTK signal. As a result the spraying was not correctly applied over the whole plot. To solve this problem we only sampled within the portion of plot that was sprayed (this was clearly visible) and we delineated plots borders (i.e. we created a new plot shape file) so that only the portion of the plot that were effectively sprayed (it was possible to identify such area in the NDVI maps) were sampled.

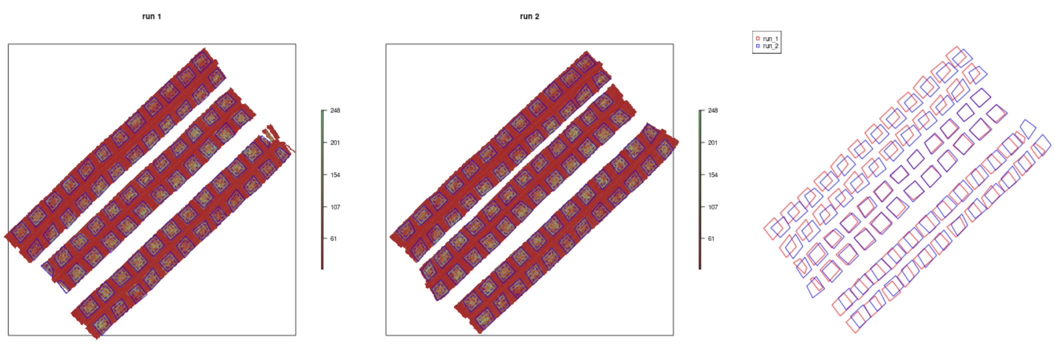

Figure 1: WEED-IT biomass measured using WEED-IT sensor. The figure on the right shows the poor alignment of the two WEED-IT measurements

2.4 Drone flights

Over the course of the experiment a drone was flown regularly to monitor the crop. The resolution was approximately 3 cm (see Table 1). The NDVI images of the drone flights are reported in Figure 3. The plots were identified on the NDVI maps and a negative buffer of -1 m was applied to reduce border effect when calculating average NDVI per plot. Subplots used for destructive samplings were not identifed in the NDVI images. NDRE images were also captured but since the correlation with bean moisture was worse with NDRE than with NDVI we present only NDVI.

Figure 2: Sprayer (6m boom) being tested with the WEED-IT mounted on it.

3 Results

3.1 Grain and abovegroud biomass

The results on the fresh biomass partitioned among pod,bean, and stem and leaves as reported in table 2. This is different from 2023 where we also partitioned between stem and leaves and measured their water content, in 2023 we opted for dropping the partitioning between stems and leaves in favour of more plots.

3.2 Comparing biomass proxies

We compared WEED-IT and NDVI against the actually measured aboveground fresh biomass (figure 4) at the moment of spraying. The correlation between destructive samples and remote sensing samples was poor. As observed already in the Dutch experiment, at the end of the season the determination of biomass is difficult because there is a great mix of dead and alive biomass.

3.3 Execution of the task map

The task map was correctly executed and recorded by the WEED-IT system. The *as applied* map and the correlation between prescribed task map and executed is presented in figure 5. Please note that in this case the as_applied map produced by WEED-IT is only indicative of the the correct communication between task-map reader and the solenoids, it does not reflect actual flow measurements through the solenoids.

Table 2: Results of destructive sampling aggregated by organ, diquat dosage (2024-04-19), and sampling date. Leaves and stem (in 2024 leaves and stems were not partitioned whereas this was done in 2023) are reported as fresh ton/ha, pods and beans are reported as dry ton/ha, water content is reported as percent of fresh weight and refers to the water content of beans. Standard deviations of the sample are reported in brackets.

	blanket	high	low	medium	no_spray
stem_and_leaves_fresh					
2024-04-19	12.85(2.47)	13.9(2.36)	13.8(2.34)	16.06(4.26)	14.41(2.98)
2024-04-22	7.98(2.19)	8.49(2.28)	7.79(2.34)	8.49(1.96)	9.51(3.58)
2024-04-27	3.42(0.84)	3.75(0.85)	3.39(0.56)	3.59(0.92)	3.44(1.13)
bean					
2024-04-19	5.39(0.8)	5.64(0.93)	5.81(0.87)	6.07(1.37)	5.67(1.02)
2024-04-22	5.42(0.88)	5.67(1.1)	5(0.74)	6(0.9)	5.68(1.3)
2024-04-27	5.49(0.96)	5.55(0.66)	5.55(0.8)	5.39(0.71)	5.45(1)
pod					
2024-04-19	1.74(0.18)	1.75(0.23)	1.77(0.31)	1.95(0.47)	1.8(0.34)
2024-04-22	1.76(0.33)	1.75(0.3)	1.55(0.25)	1.97(0.38)	1.72(0.43)
2024-04-27	1.75(0.25)	1.87(0.21)	1.78(0.29)	1.81(0.28)	1.76(0.32)
watercontent					
2024-04-19	59.03(0.91)	58.9(0.66)	58.79(0.67)	58.62(1.18)	59.01(1.62)
2024-04-22	49.46(5.22)	47.75(6.03)	49.48(6.38)	48.4(6.98)	49.55(4.6)
2024-04-27	21.64(5.06)	21.96(6.77)	18.44(6.55)	21.56(7.75)	24.92(7.44)

3.4 Reproducibility of CDD maps

We tested the reproducibility of biomass index maps generated using WEED-IT. We generated two WEED-IT biomass index maps on the same day running two consecutive WEED-IT measurements on the 18 April 2024. In 2023 the two runs were done one in the morning and one in the afternoon. We then extracted the values by averaging the pixels by plot, and compared them in Figure 6. The results indicate a good reproducibility, the plots have been redrawn for each measuremnt to overcome the problem in spatial alignment.

3.5 Effect of diquat Dosage on NDVI

We measured daily the NDVI drop compared to before-spraying NDVI for the first 4 days after spraying (Figure 7). We observed an effect of diquat on NDVI (i.e. a difference between no-sprayed and sprayed),however we did not observe a difference in NDVI between the plots that received different levels of diquat on any of the measured dates after spraying (1,2,3,4), suggesting that only based on NDVI it was not possible distinguish the effect of dosage on defoliation.

3.6 Identifying equation parameters

When no diquat was applied, there was no correlation between ndvi and WEED-IT measured flourescence before spraying and bean moisture measured 7 days after (figure 8) and only one sample out of 24 had reached a moisture lower than 13% , thus we could not use these data to derive a threshold for the equation. The reason for this was that the weather was too wet and the crop too green when sprayed. The different spray levels (low, medium, high, blanket) had a different effects on soybean moisture one week after spraying depending on the biomass index (NDVI or WEED-IT). The correlation between pre-spraying biomass index (WEED-IT or NDVI) and bean moisture one week after spraying varied depending on the dosage rate (figure 9). The most positive correlation (greener canopy resulting in more moist bean) was found for the blanket and high application. The low treatment resulted in the following unexpected relationship: plots with the highest ndvi had a lower moisture content after 8 days). Whereas the medium treatment was ensuring the most homogenous bean water content. However in almost no case the seed were dry enough (13%), thus we cannot derive equation parameters from these data.

Table 3: Parameters of a linear model of type: $y = (Intercept) + trt + (b + x : trt) * x$ where y is the bean moisture 7 days after spraying the predictor x is either WEED-IT (morning measurement) or NDVI, b is the slope of predictor if treatment is low, x:trt is a slope modifier if treatment is low, medium or high.

	Estimate	Std. Error
	NDVI	
(Intercept)	-46.056	41.753
x	89.736	55.292
trthigh	-16.276	58.394
trtlow	108.045	50.455
trtmedium	55.103	56.878
x:trthigh	28.077	79.411
x:trtlow	-149.411	67.512
x:trtmedium	-72.721	76.219
	WEED-IT	
(Intercept)	2.545	11.84
x	0.209	0.128
trthigh	-10.326	17.396
trtlow	44.147	17.359
trtmedium	13.363	16.48
x:trthigh	0.157	0.202
x:trtlow	-0.538	0.195
x:trtmedium	-0.145	0.183

3.7 Short-term increase in moisture with spraying

Contrarily to what was observed in 2023 we did not observe a short-term increase in bean moisture following spraying (Table 2).

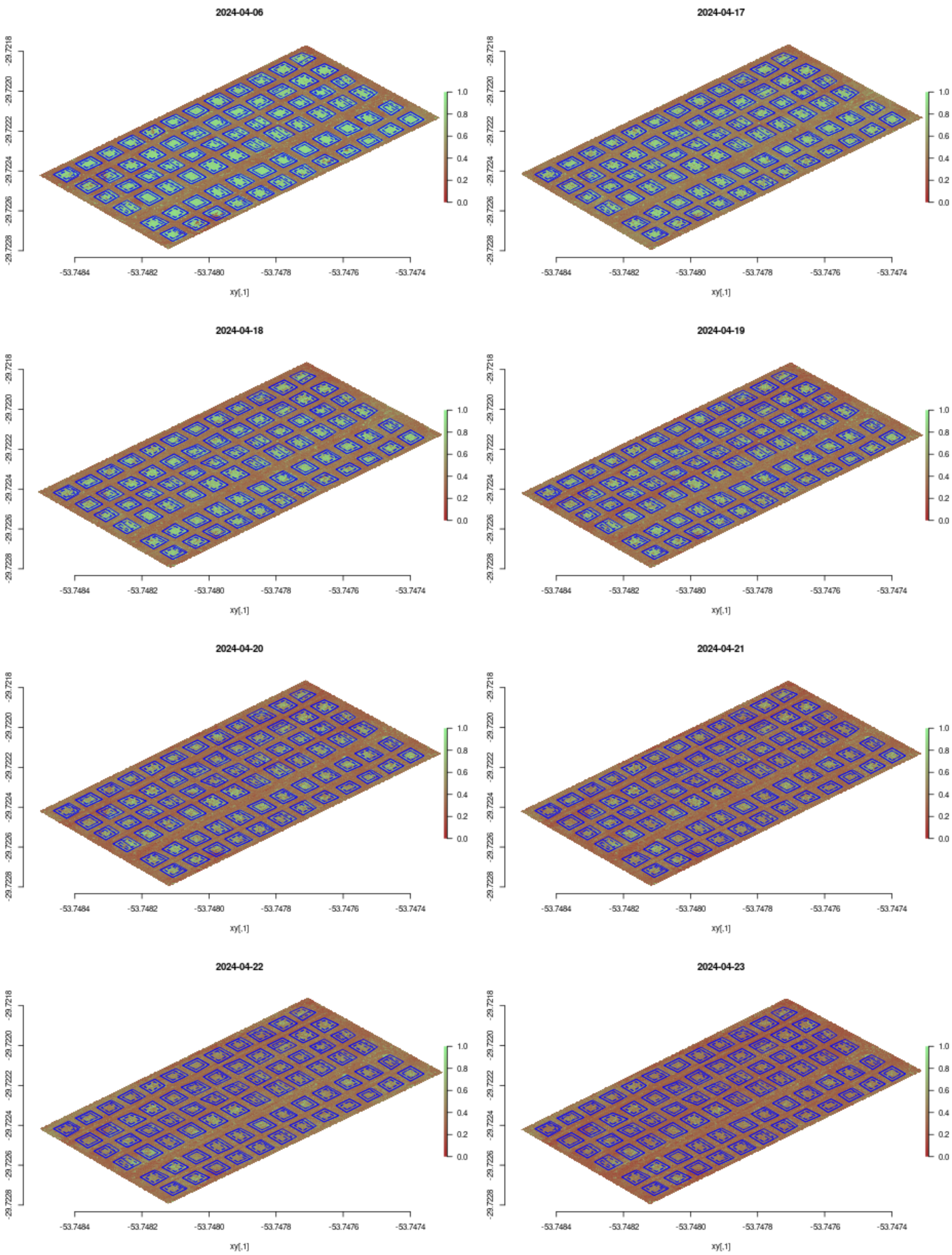

Figure 3: NDVI measured in drone flights

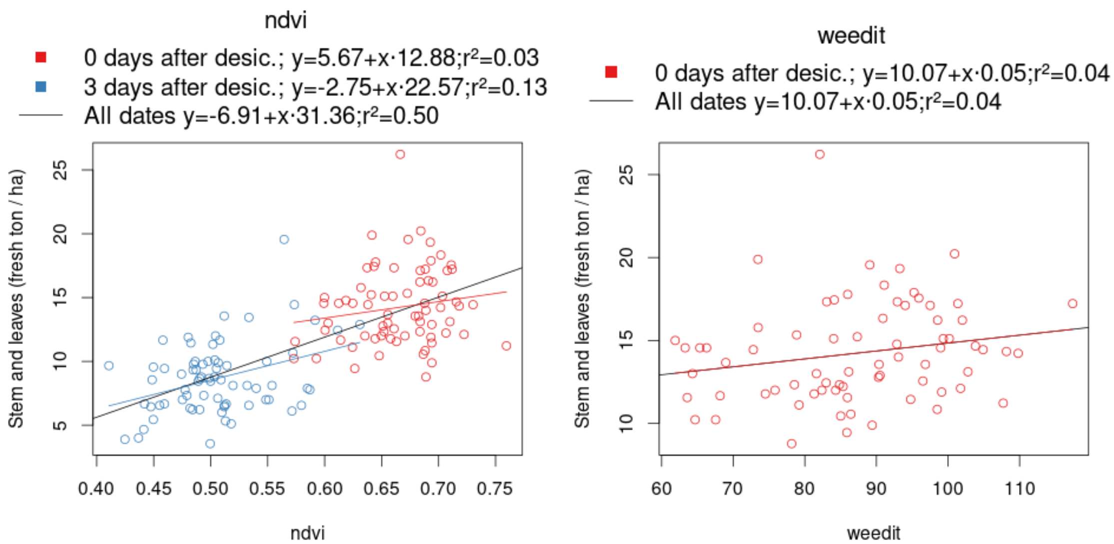

Figure 4: Comparison of biomass proxies used in this experiment, including actually measured biomass.

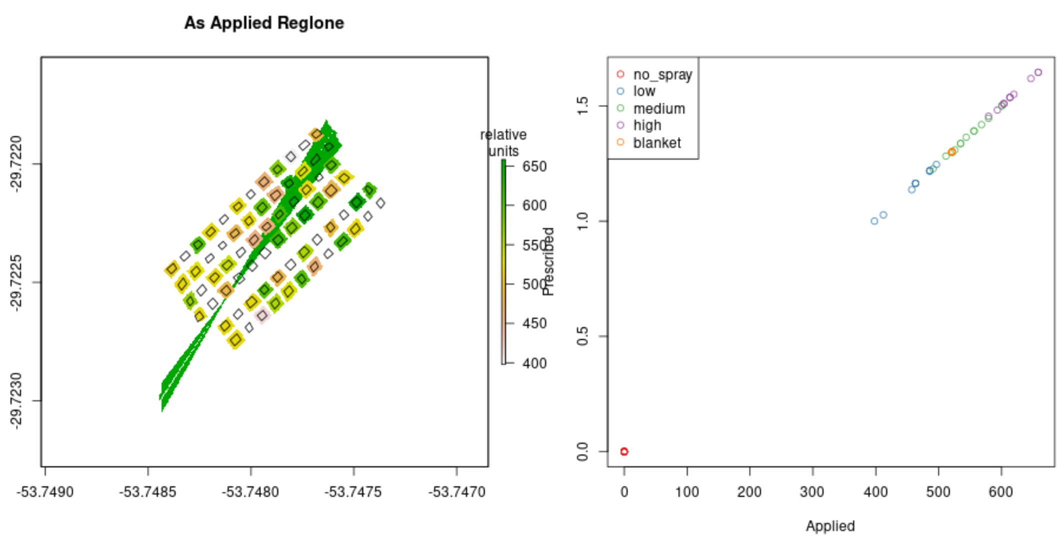

Figure 5: Left: As applied map of the spraying task map, the units are L/ha of diluted product. Right: correlaiton between prescribed volumes and applied volumes averaged by plot.

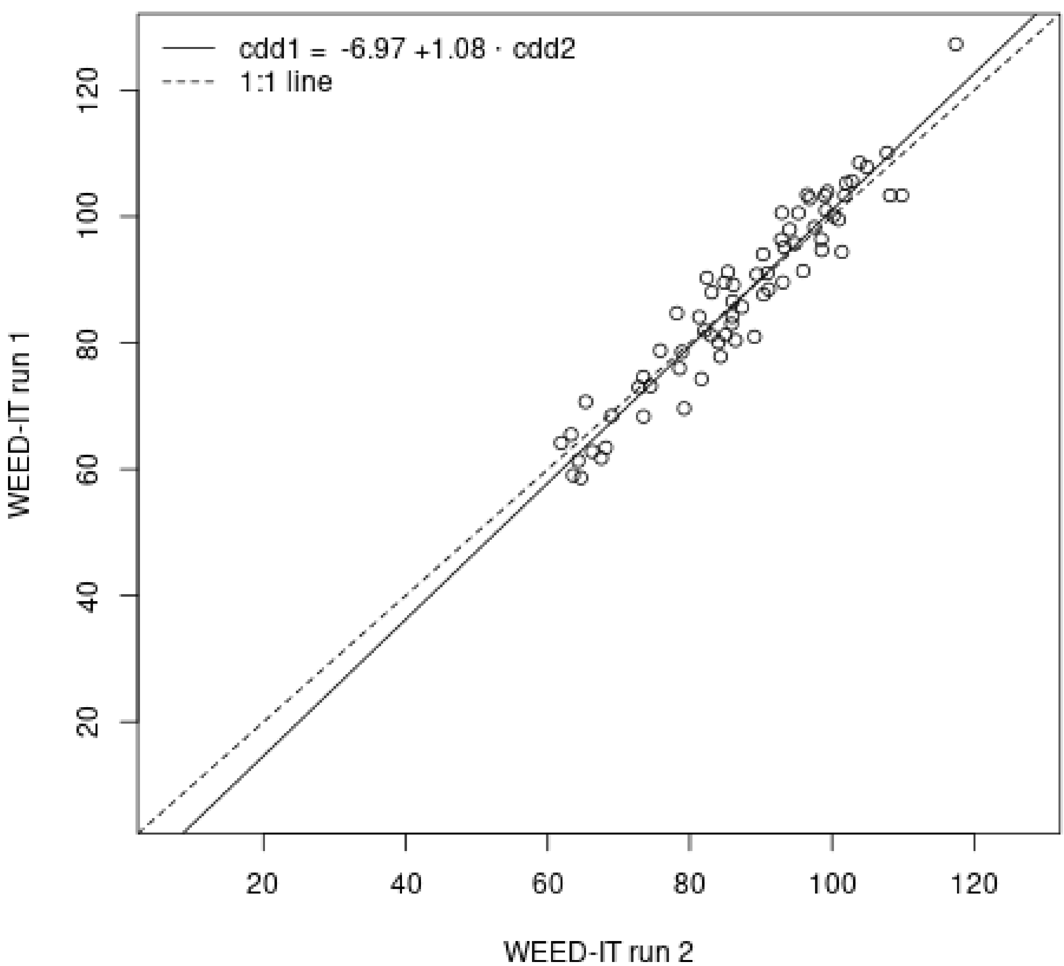

Figure 6: Comparison of WEED-IT run number 1 and WEED-IT run number 2 on April 18 2024, the plots have been redrawn to account for the problem in geoferencing, values are average by plot, units are arbitraty and range between 0 and 255

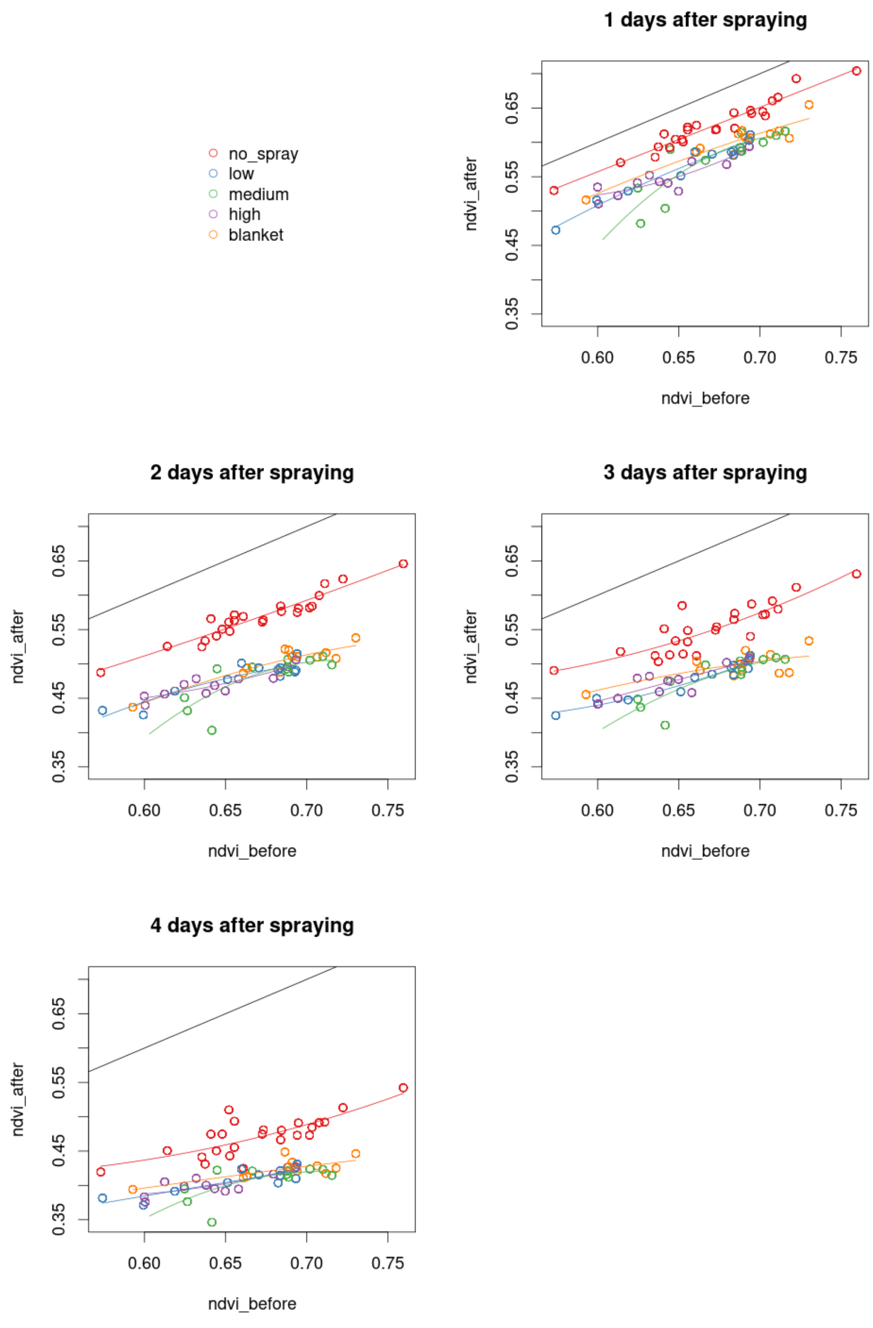

Figure 7: Drop in NDVI 1,2,3,and 4 days after spraying. The x axis refers to NDVI measure on the 18th of April 2024(spraying occurred on 19 April 2024). The black line represent the 1:1 and is the upper boundary, since the crop is senescing.

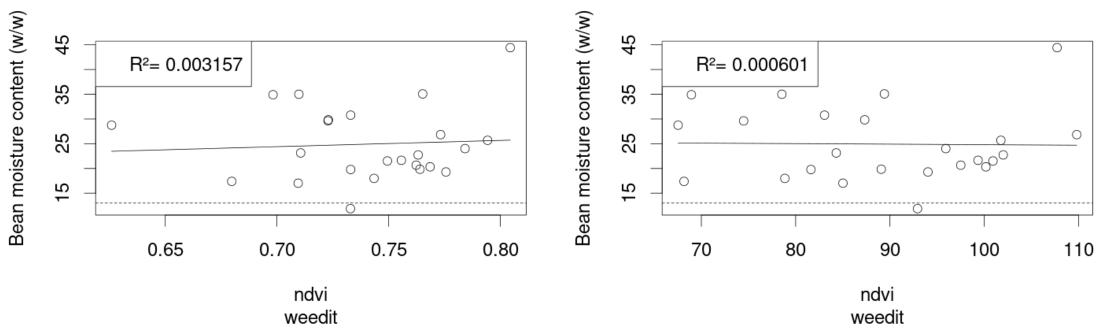

Figure 8: Left: Correlation between NDVI 2 days before spraying and bean moisture content 7 days after spraying, Right: Correlation between WEED-IT biomass index (measured in the morning 1 day before spraying) and bean moisture measured 7 days after spraying.
The line is the prediction of a linear model predicting bean moisture given biomass proxy (NDVI or WEED-IT) and treatment.

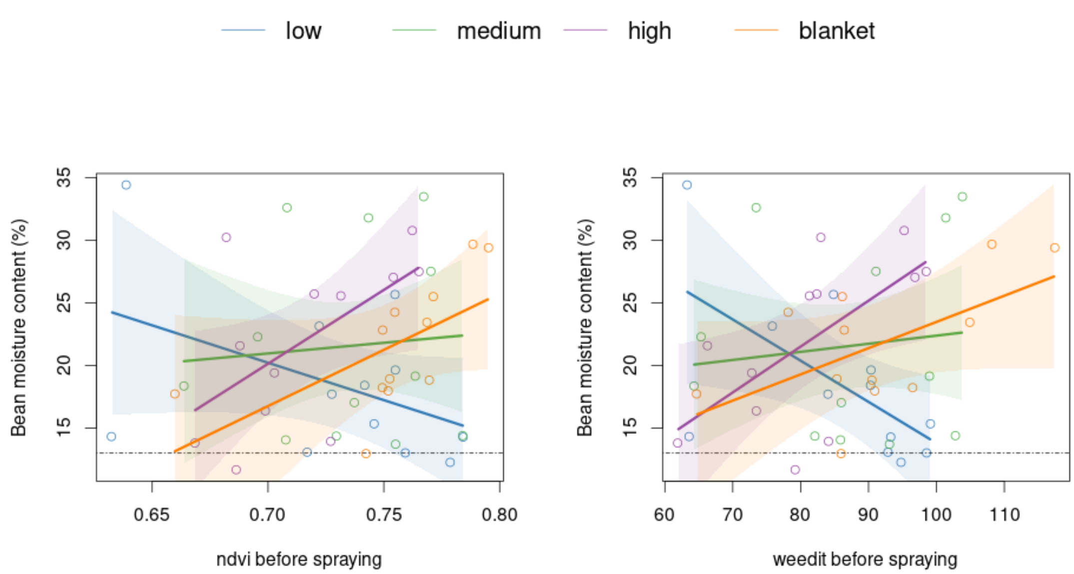

Figure 9: Relationship between NDVI or WEED-IT 1 day before spraying and bean moisture content 7 days after spraying.

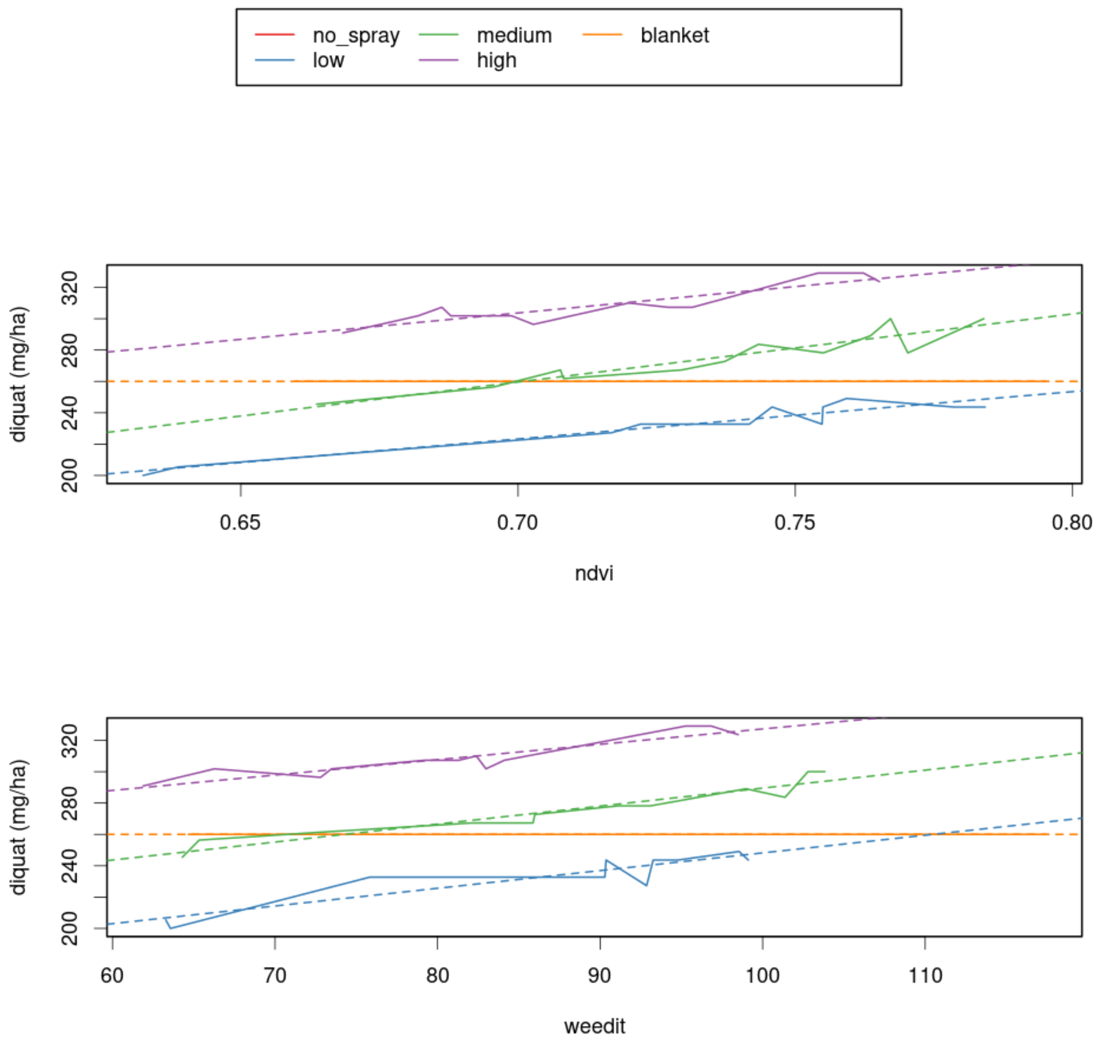

Figure 10: Relationship between diquat applied and WEED-IT and NDVI in the various treatments

Smart Soybean in Brazil WP4 - Soybean Desiccation Dosage 2023 Santa Maria experiment

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1 Introduction

Soybean desiccation is a common practice in Brazil to anticipate the harvest by a few days and the second crop of the season (typically corn) can be planted earlier. Weed-IT is a variable rate spraying system composed of chlorophyll fluorescence sensors and PMW solenoids. We believe that major savings in herbicide for end-of-season desiccation can be reached if Weed-IT is used to distribute the herbicide based on the amount of alive biomass present in the canopy. To reach this goal we need an algorithm that defines the amount of desiccant to be sprayed. For such purpose we identified the following algorithm that combines spot and VR spraying:

$$Diquat(mg/ha) = \begin{cases} if(\,biomass\_proxy < \mathbf{threshold})\{0\} \\ else\ \{\mathbf{a} + biomass\_proxy * \mathbf{b}\} \end{cases}$$

The biomass_proxy can be either vegetation indices from remote sensing (e.g. drone, satellite) or the biomass index produced by Weed-IT itself. To identify the parameters *threshold* (the threshold below which it is not necessary to apply the desicant), and a and b we setup an experiment where different rates (including no spraying) of diquat (a popular desiccant for soybean) were applied to 6x8 m plots in a soybean field. The purpose of the study was to identify the parameters *threshold*, a and b, assuming that harvest would take place 7 days after spraying.
The parameter *threshold* is identified as the value of NDVI below which we estimate that 7 days after NDVI observation soybean grains will have a moisture content lower than 13% even without spraying. To identify this parameter we related NDVI and Weed-IT before spraying and beans moisture 7 days after spraying. The results are presented in section 3.6
The parameters a and b are presented in section 3.7, and are the parameters of the treatment that minimized the dosage of diquat while still reaching an average desiccation of 13%.

2 Materials and methods

2.1 Field and destructive measurements

The experiment took place in a soybean field in the Rio Grande Do Sul, we set up 50 plots organized in 10 blocks. The plots had a size of 6 (approximately 13 rows) x 8 meters. A subplot from each of the 50 plots was harvested one day before spraying (28/3/2023), two days after spraying (31/3/2023), and one week after spraying (5/4/2023). The subplots had a size of 0.5 x 0.9 m and occupied the area of two rows, as row distance was 45cm. The plants were harvested, partitioned between leaves, stems, and bean and pods. A subsample corresponding on average to 17% of the pods was then opened depending on the weight of the beans and pods to partition pod and bean weight and estimate their moisture content. The samples and subsapmles (bean and pod) were separately dried at 70 degree C for 72 hours.The water content of soybean (without the pod) in the field was calculated as:

$$watercontent = \frac{(bean_{fresh} - bean_{dry})}{bean_{fresh}}$$

2.2 Treatments

We tested the following different variable rate treatments:

Treatment	Lowest dosage	Max dosage
No spray	0	0
Low	1	1.3
Medium	1.2	1.5
High	1.4	1.7

The treatments were applied using a linear interpolation based on the measured values of biomass index (cdd) calculated from the Weed-IT sensor measured in the morning of March 27 2023, so that the lowest spot would receive the minimum and the max spot would receive the max treatment, with a linear interpolation for the plots in between.

2.3 Equipment: Weed-IT and sprayer

A six meter boom sprayer was retrofitted with a Weed-IT (Figure 2) sensor system connected to pulse modulation width solenoids, in order to apply variable rate and measure green biomass index. The Weed-IT sensors were placed approximately 1 m over the crop, and an embedded logging system was used to record the Weed-IT signal, generate a map of the Weed-IT signal, execute the task map and

Table 1: Drone flights during the experiment

date	Res. x (cm)	Res. y (cm)	file
2023-03-24	3.14	3.14	raw_data//NDVI24marc2023/NDVI_24marc2023.tif
2023-03-27	3.11	3.11	raw_data//NDVI27março2023/NDVI_27março2023.tif
2023-03-31	3.15	3.15	raw_data//NDVI31marc2023/NDVI31março2023.tif
2023-04-02	3.00	3.00	raw_data//NDVI_02april2023/NDVI 02april2023.tif
2023-04-09	3.20	3.20	raw_data//NDVI09april2023/NDVI09april2023.tif

record an as_applied map. The Weed-IT biomass index was mapped two days before spraying in the morning and in the afternoon. The spraying of the desiccant occurred on March 29 2023 at 7.30 AM. The biomass maps captured by weedit two days prior spraying (27th of March) are reported in Figure 1. The plots were identified on the Weed-IT biomass maps and a negative buffer of -1 m was applied reduce border effect when calculating average Weed-IT signal per plot.

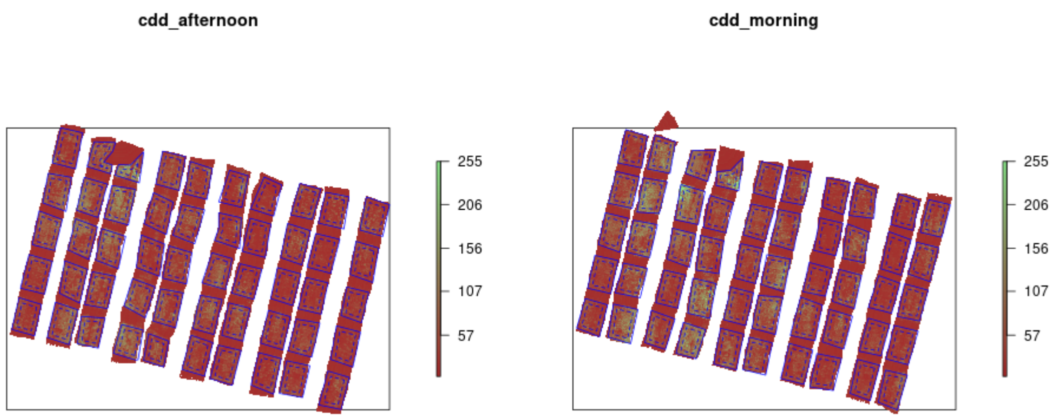

Figure 1: Weedit biomass measured using weedit sensor. The plots on the top-left part of the field experienced a problem and were thus partly not included in plot calculation. The problem was related to calculations of position and velocity of the boom while turning from one row to the next. The irregular contour of the plots are caused mainly by the movement of the tractors over the rough terrain, such irregularities would be minor if a longer is used.

2.4 Drone flights

Over the course of the experiment a drone was flown regularly to monitor the crop. The resolution of the stitched images was approximately 3 cm (see 1). The NDVI images of the drone flights are reported in Figure 3. The plots were identified on the NDVI maps and a negative buffer of -1 m was applied to reduce border effect when calculating average NDVI per plot. Subplots used for destructive samplings were not identifed in the NDVI images. NDRE images were also captured but since the correlation with bean moisture was worse with NDRE than with NDVI we present only NDVI.

3 Results

3.1 Grain and abovegroud biomass

The results on the biomass partitioned among beans, stem and leaves is reported in table 2.

Table 2: Results of destructive sampling aggregated by plant organ, diquat dosage (2023-03-29), and sampling date. Leaves, stem, pods and beans are reported as dry ton/ha, water content is reported as percent of fresh weight and refers to the water content of beans. Standard deviations of the sample are reported in brackets.

	high	low	medium	no_spray
	stem			
2023-03-28	1.32(0.31)	1.26(0.16)	1.47(0.27)	1.36(0.25)
2023-03-31	1.49(0.26)	1.43(0.24)	1.47(0.29)	1.46(0.29)
2023-04-05	1.18(0.1)	1.28(0.19)	1.4(0.22)	1.27(0.2)
	leaf			
2023-03-28	1.12(0.42)	0.99(0.3)	1.26(0.43)	1.07(0.28)
2023-03-31	0.81(0.18)	0.78(0.26)	0.72(0.21)	0.73(0.25)
2023-04-05	0.45(0.24)	0.44(0.13)	0.48(0.16)	0.43(0.19)
	bean			
2023-03-28	3.5(1.2)	3.68(0.88)	3.89(0.81)	3.88(0.98)
2023-03-31	3.2(0.59)	2.99(0.39)	3.1(0.55)	3.28(0.41)
2023-04-05	3.33(0.72)	3.78(0.93)	3.85(0.53)	3.53(0.71)
	pod			
2023-03-28	1.53(0.41)	1.35(0.24)	1.55(0.55)	1.48(0.29)
2023-03-31	1.73(0.43)	1.69(0.46)	1.79(0.51)	1.69(0.4)
2023-04-05	1.16(0.21)	1.24(0.29)	1.3(0.21)	1.16(0.22)
	watercontent			
2023-03-28	48.36(13)	52.35(12.75)	48.45(12.62)	53.46(10.27)
2023-03-31	31.25(18.59)	27.79(15.55)	33.79(14.91)	24.45(11.58)
2023-04-05	8.75(2.76)	10.13(3.27)	7.36(4.09)	12.31(7.8)

3.2 Comparing biomass proxies

We compared several biomass proxies among them and against the actually measured aboveground biomass (both including and excluding beans and pods, figure 4) at the moment of spraying. The correlation between destructive samples and remote sensing samples was poor. As observed already in the Dutch experiment, at the end of the season the determination of biomass is difficult because there is a great mix of dead and alive biomass. Nontheless Weed-IT and NDVI show a good agreement.

3.3 Execution of the task map

The task map was correctly executed and recorded by the Weed-IT system. The *as applied* map and the correlation between prescribed task map and executed is presented in figure 5. Please note that the as_applied map produced in this case by Weed-IT is only indicative of the the correct communication between task-map reader and the solenoids, it does not reflect actual flow measurements through the solenoids.

3.4 Reproducibility of CDD maps

We tested the reproducibility of biomass index maps generated using Weed-IT. We produced a Weed-IT biomass index in the morning and one in the afternoon of 27/3/2023. We then extracted the values by averaging the pixels by plot, and compared them in Figure 6.

Table 3: Parameters of a linear mixed model of type: $y = a + (b + c + RE) * x$ where y is the bean moisture 7 days after spraying the predictor x is either weedit (morning measurement) or NDVI, b is the slope of predictor if treatment is low, c is a slope modifier if treatment is either medium or high and RE is a random effect of the slope.

	Estimate	Std. Error
	ndvi	
a	-0.952	3.374
b	20.182	6.357
c	-3.688	1.747
	weedit	
a	4.704	1.533
b	0.089	0.03
c	-0.032	0.016

Table 4: Estimated parameter for equation efeq:1

value	parameter	predictor
0.5502(0.5211,0.5840)	threshold	ndvi
136.1071(115.0458,157.1684)	a	ndvi
157.7002(119.5953,195.8051)	b	ndvi
58.5504(48.3128,80.1383)	threshold	weedit
179.3555(174.5554,184.1555)	a	weedit
0.7264(0.6496,0.8031)	b	weedit

3.5 Effect of diquat Dosage on NDVI

We observed an effect of diquat on NDVI on all measured dates after spraying (2,4,11), however we did not observe differences between the low,medium and high treatments (see figure 7).

3.6 Identifying parameter *threshold* NDVI and bean moisture 7 days after spraying

There was a positive correlation between ndvi and Weed-IT measured flourescence before spraying and bean moisture measured 7 days after (figure 8). Because it may be helpful for farmers to think in terms of probability of having their crop dry in 7 days we also fitted a generalized linear model (family binomial) predicting the probability that the crop will be dry in 7 days.

3.7 Identifying parameter *a* and *b*

We did not observe an interaction between NDVI and amount of diquat applied, suggesting that lower rates of diquat are sufficient to ensure crop desiccation 7 days after application. However 7 days after spraying the plots treated with a low dosage diquat showed a higher bean moisture content,see figure 9 and table 3. We observed that using dosage low for cases where biomass index is above the threshold an average bean moisture of 13% was reached. Thus we suggest as parameters a and b, the parameters of treatment low in table 4.

4 Discussion

Based on the results of this experiment and the spraying algorithm 1 we identified the parameters for the algorithm as reported in table 4, and depicted in figure 11:

4.1 Backcalculation of savings in 2022 soybean field

We backcalculated the savings that would have been obtained if this equation was applied to the experimental UFSM field in 2022. If the equation 1 was applied to that field the average diquat application rate over the field would have been 155.76 which represent a saving of 40% compared to an average blanket application rate of 260 mg/ha. If the same equation was applied to the field of 2023 the savings would be 89.79 which represents a saving of 66% compared to 260 mg/ha blanket application. The maskmap generated by applying the Diquat equation is reported in figure 13.

If instead of a spot+VR approach as described in eq. 1 we were to use a spot-spraying approach where if the biomass proxy was lower than the threshold we do not spray and if higher we spray 200 mg/ha we would save 52 % in 2022 and 72 % in 2023. Such taskmap using NDVI as biomass proxy is reported in Figure 14.

4.2 Short-term increase in moisture with spraying

We found that two days after spraying the water content of the crop was higher in the desiccated treatments compared to the controls. It is possible that by interrupting photosynthesis chain the plant transpire less and leading to a more humid microclimate taht slows the bean desiccation.

Figure 2: Sprayer (6m boom) being tested with the Weed-IT mounted on it.

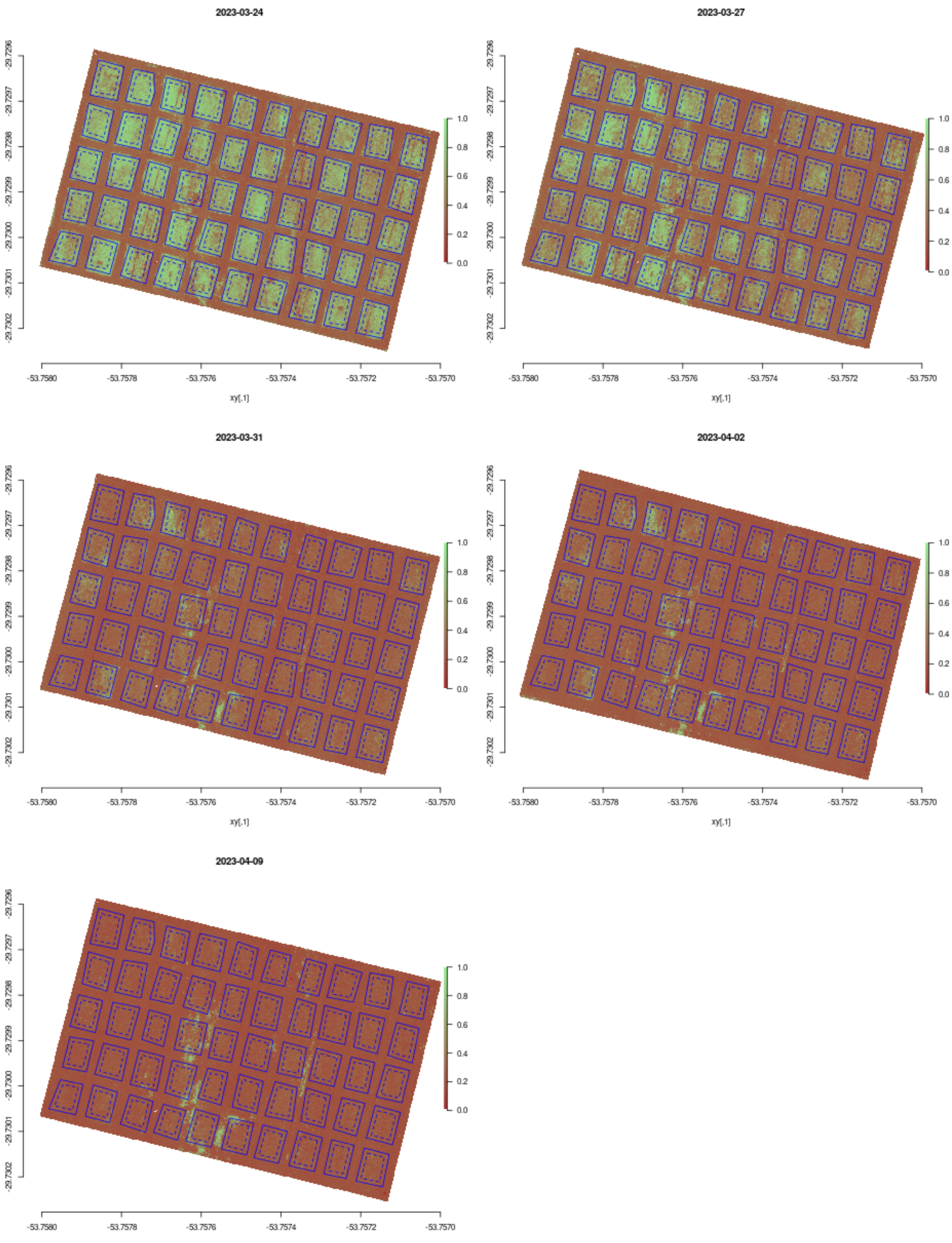

Figure 3: NDVI measured in drone flights

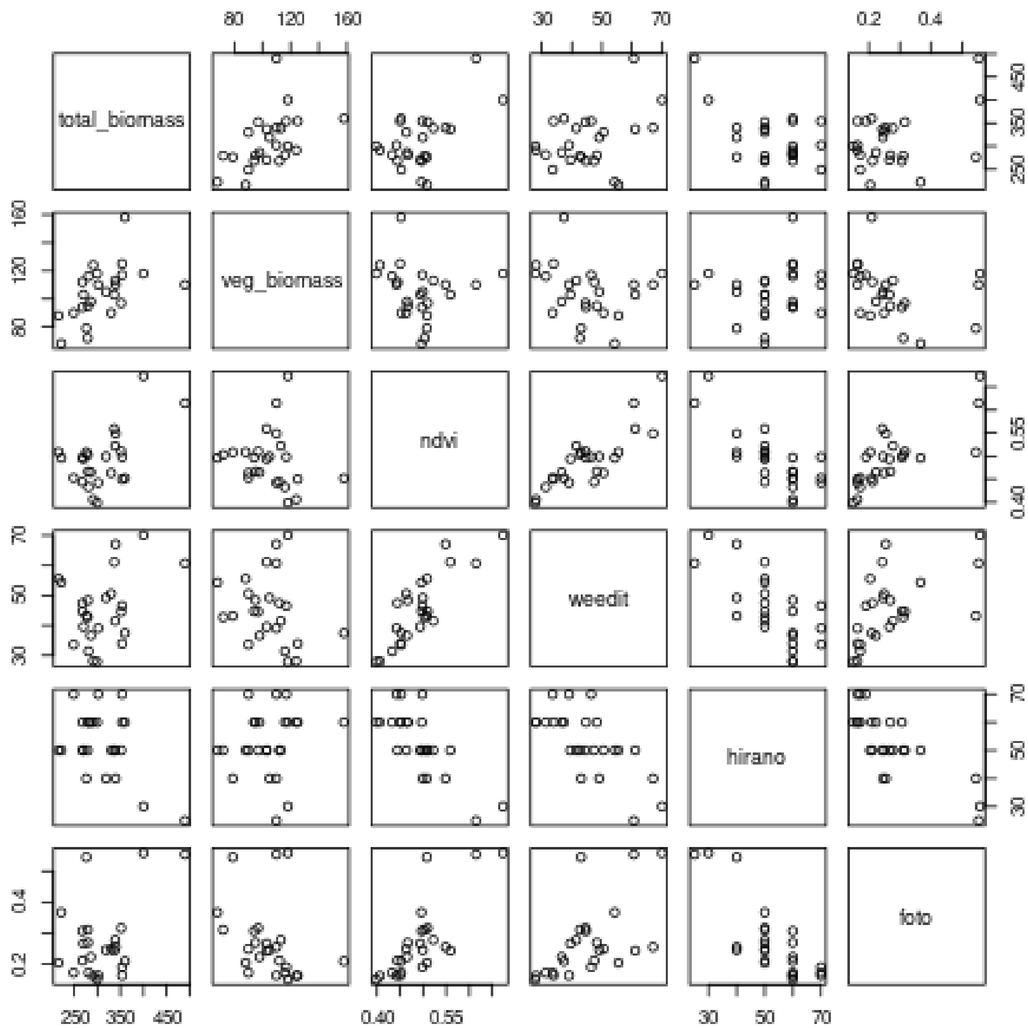

Figure 4: Comparison of biomass proxies used in this experiment, including actually measured biomass.

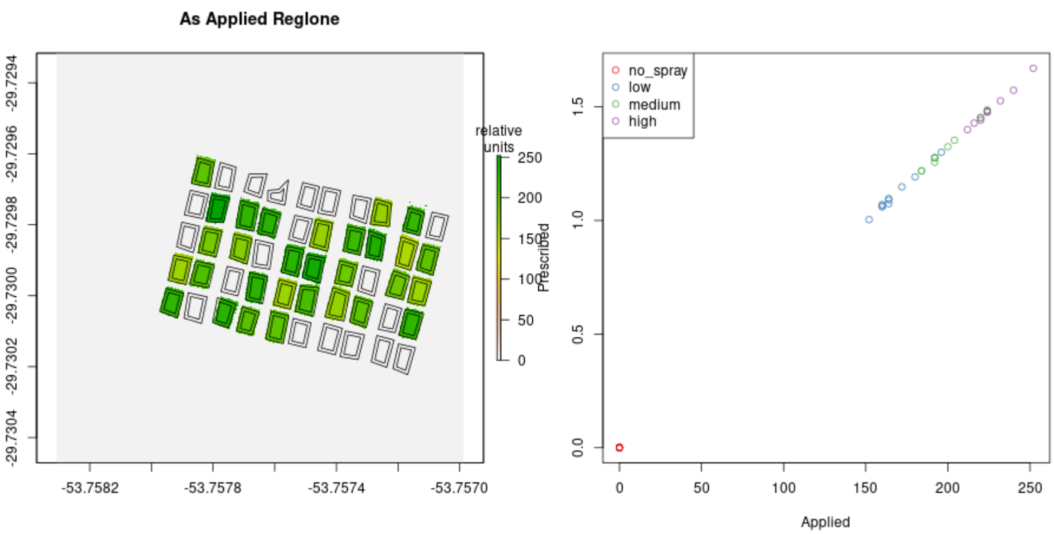

Figure 5: Left: As applied map of the spraying task map, the unit are arbitrary and range between 0 (min) and 255 (max). Right: correlaiton between prescribed volumes and applied volumes averaged by plot.

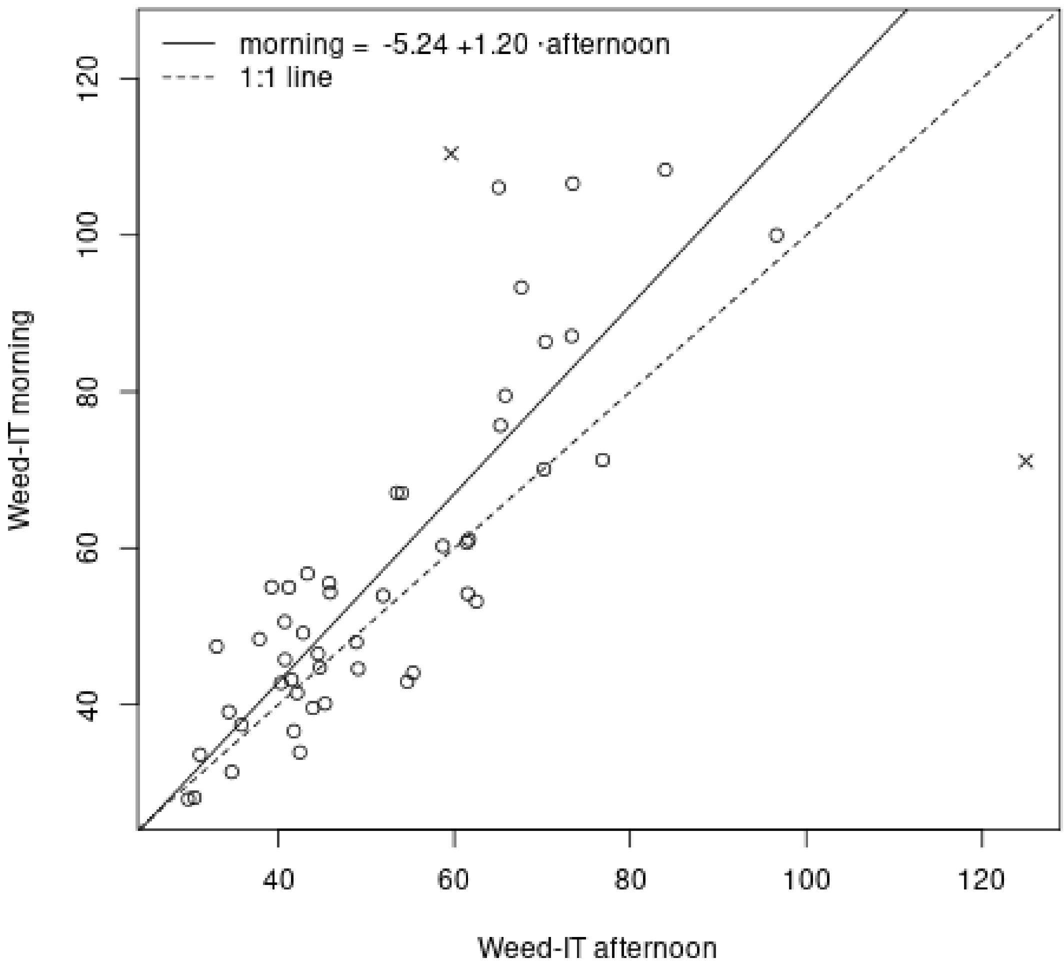

Figure 6: Comparison of Weed-IT measured in the morning and in the afternoon of 27/3/2023 (2 days before spraying),values are average by plot.

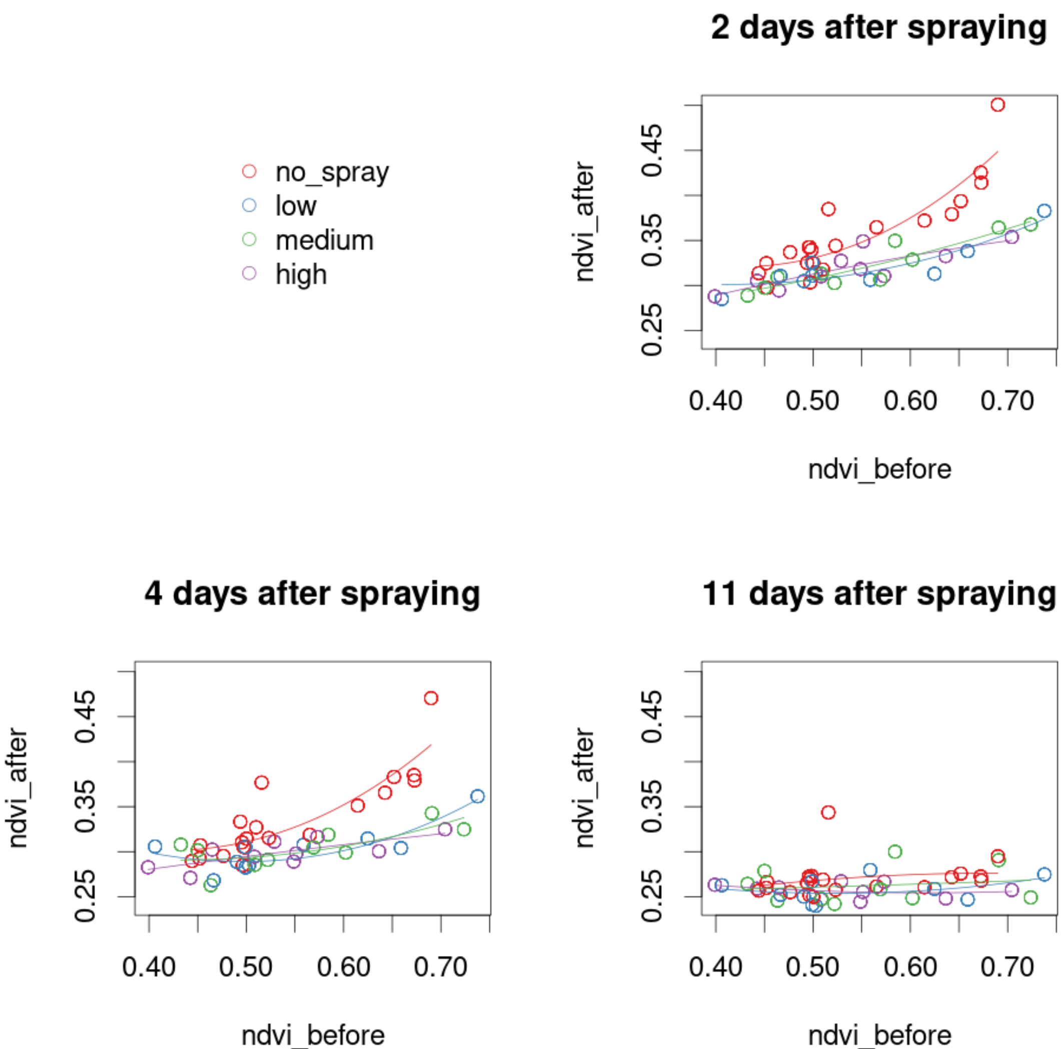

Figure 7: Drop in NDVI 2, 4 and 11 days after spraying. The x axis refers to NDVI measure on the 27th of March 2023(spraying occurred on 29 March 2023).

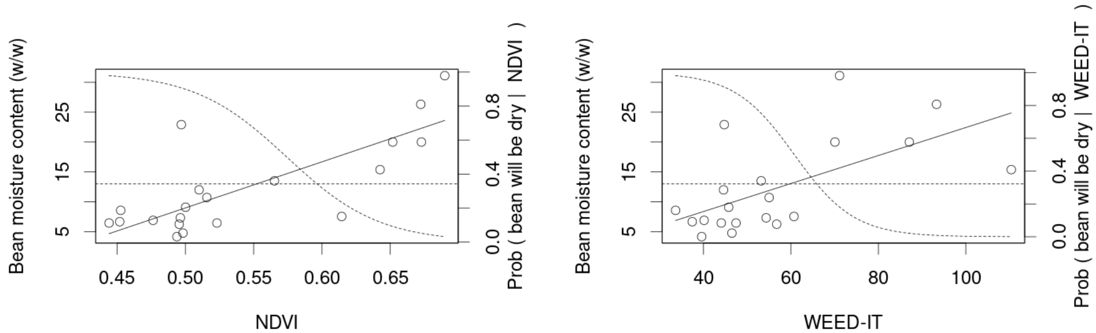

Figure 8: Left: Correlation between NDVI 2 days before spraying and bean moisture content 7 days after spraying, in control treatments Right: Correlation between WEED-IT biomass index (measured in the morning 1 day before spraying) and bean moisture measured 7 days after spraying for control treatments.
The continuos line is a linear model correlating moisture and biomass proxy (NDVI or WEED-IT), whereas the dashed line reprent a model of the probability that the bean will be dry in 7 days given biomass proxy.

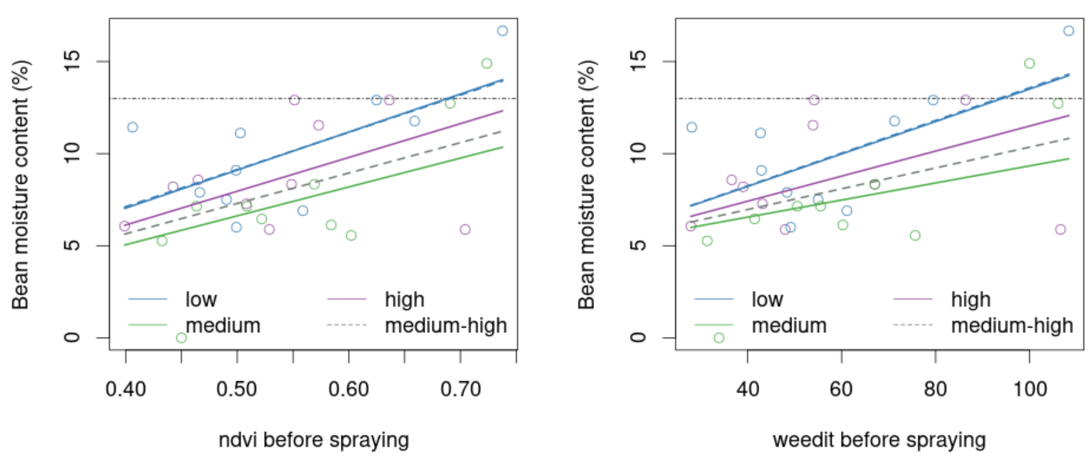

Figure 9: Relationship between NDVI 2 days before spraying and bean moisture content 7 days after spraying. The continuous line represent the model with three levels (low, middle, high), whereas the dashed line represent the model where the medium and high treatment were collapsed into a single medium-high level.

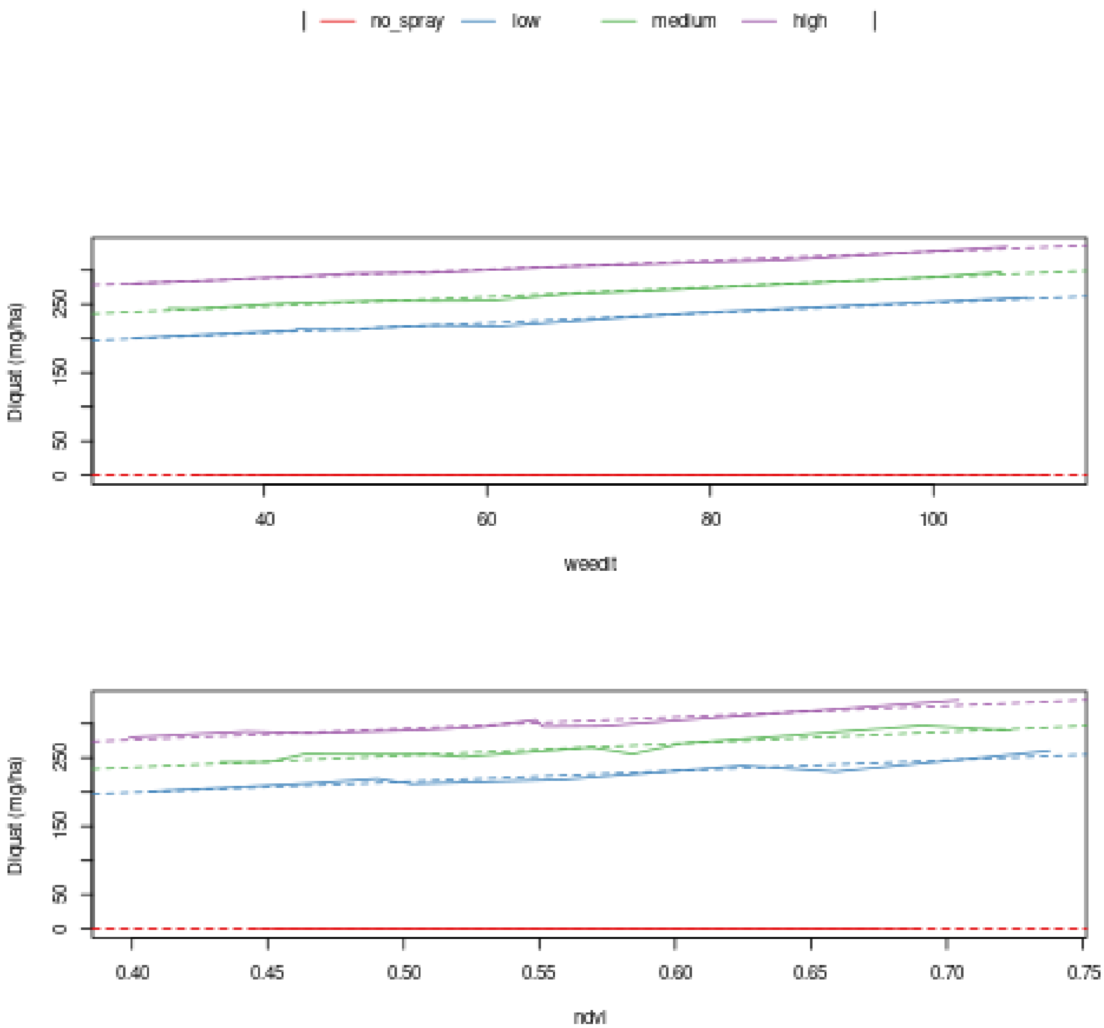

Figure 10: Relationship between diquat applied and Weed-IT and NDVI in the various treatments

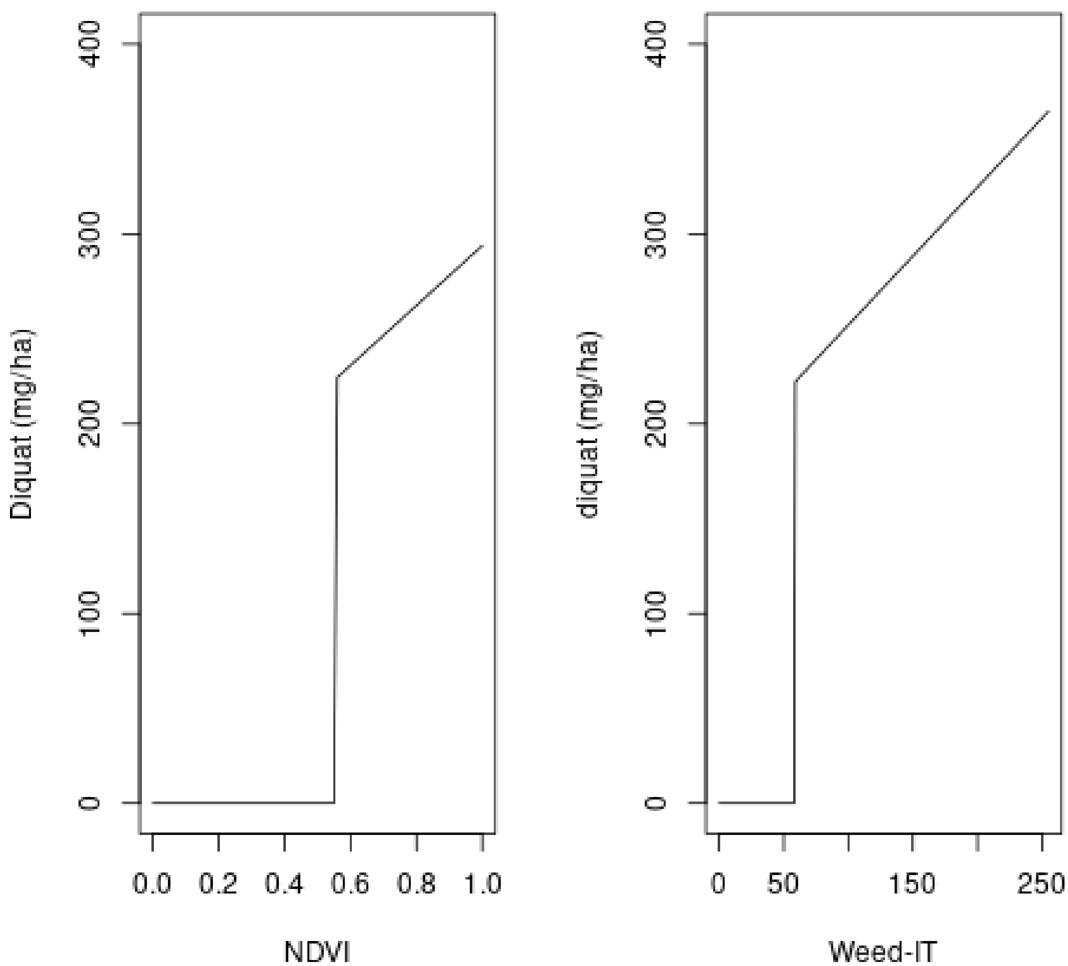

Figure 11: Equation for relating the amount of diquat to be sprayed based on NDVI (left) and Weed-IT (right), using equation 1 and parameters from table 4 4

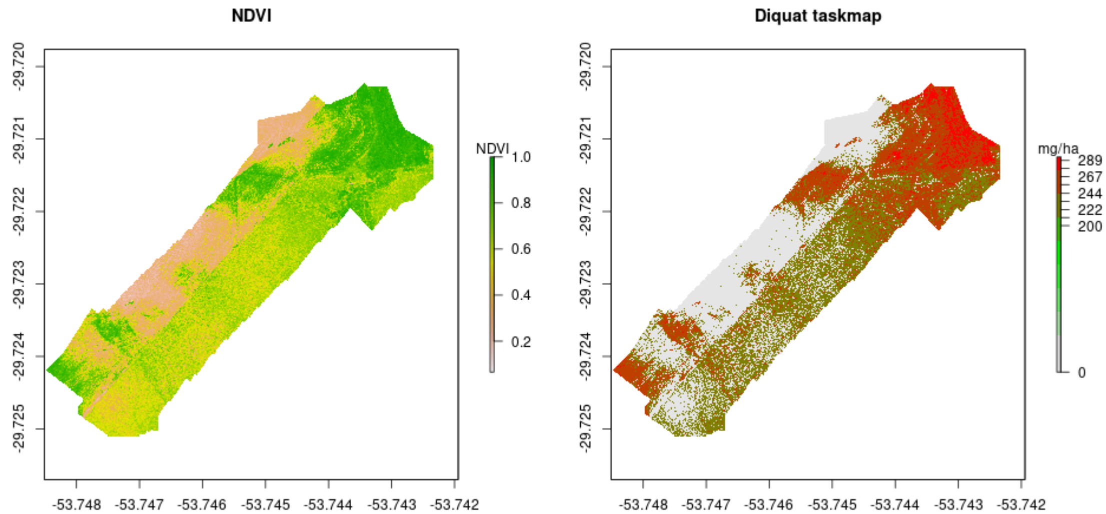

Figure 12: Taskmap generated by applying eq. 1 to the field of 2022 experiment (measured on March 5, 2022).

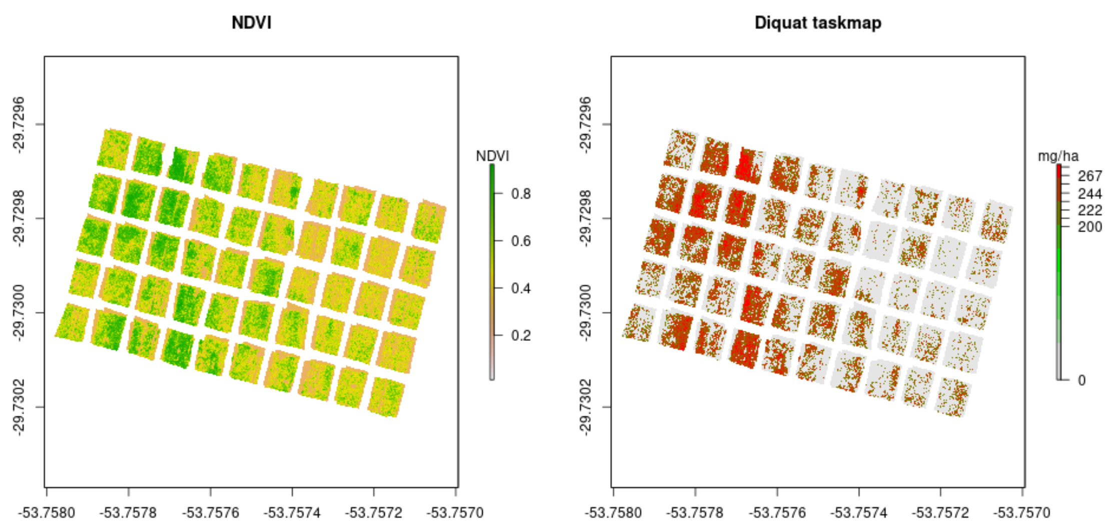

Figure 13: Taskmap generated by applying eq. 1 to the field of 2023 experiment.

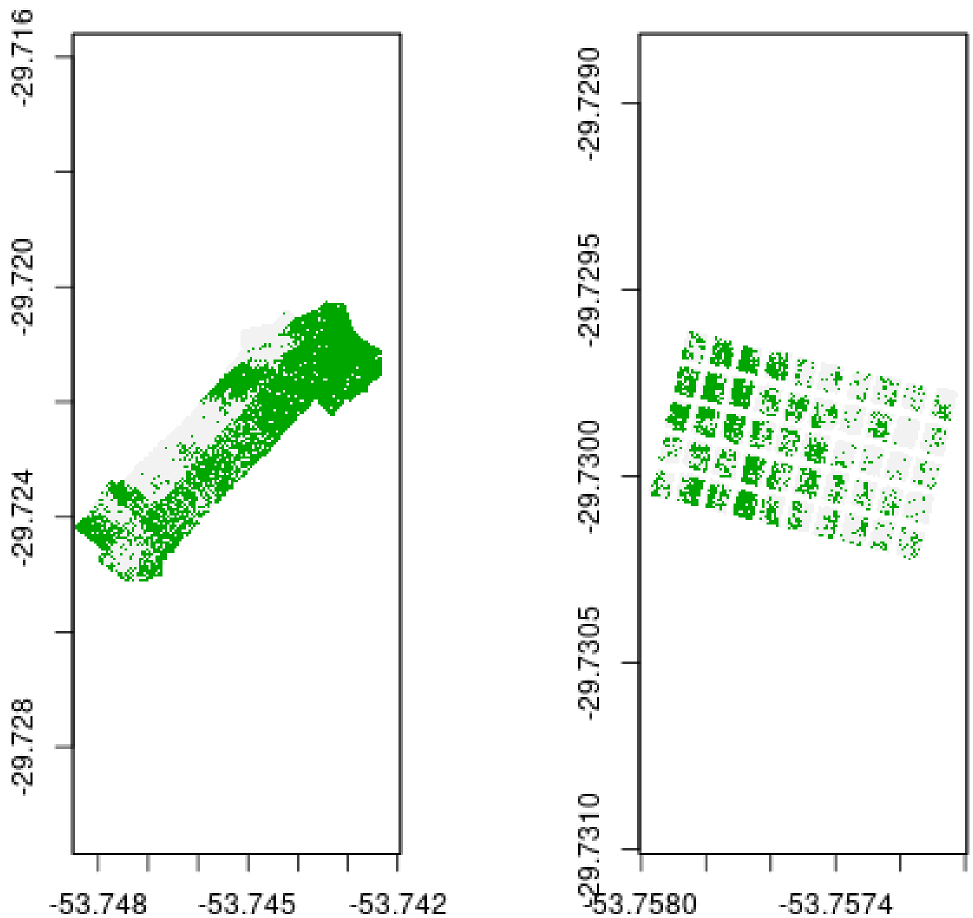

Figure 14: Taskmap generated by using a spot only approach (no variable rate). The green pixels are the only pixels to be sprayed using the spot spraying approach.

Smart Soybean BR-NL project: Results from the experiment on NDVI-fluorescence correlation in 2022 in Brazil

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2022/03/07

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Overarching objective

The overarching objective of the experiment was to relate biomass and fluorescence measured by WEED-IT. The equation relating fluorescence to NDVI that we want to derive in this study can then be used to vary the amount of diquat applied for end-of-season desiccation (see dosage equation developed by Julia, Corne and Fred, *Adapting diquat dosage as a function of NDVI from potato to soybean*).

In this experiment we observed a good non-linear correlation (r^2=0.89) between NDVI and chlorophyll fluorescence measured by WEED-IT.

Materials and methods

The experiment took place in a field owned by the Colégio Politécnico – UFSM, on the 5th of March 2022. The field team was led by Prof. Vinicius Marini and Prof. Telmo Amado, with the help of Mateus Eitelwein (Smart Sensing) for the management of the WEED-IT sensor, Frederico Doeler (Locus Precision Ag) for agronomic evaluations and Prof. Luciano Pes for the aerial image collection. The WEED-IT sensor was mounted on a quad as shown in Figure 1.

Figure 1: image of the quad with the measuring device in the field.

The field aerial image is reported in Figure 5. The experimental setup consisted of 39 plots (median size 7.7 m, interquartile range 1.1 m) located near a service road bordering the field. The plots have been marked on the ground by removing the grass from the beginning and the end of each plot. In this way it was possible identify the plots from the aerial images. The plots comprised a variety of different canopy situations, ranging from low NDVI (0.2) to high NDVI (0.9). The data used to establish the correlation between NDVI and WEED-IT (Figure 4) were derived as follows:

- **NDVI, NDRE data:** A drone was flown over the plots, with a camera collecting images in the RGB, RedEdge and NDVI bands, NDVI was calculated as (NIR-RED)/(NIR+RED) and NDRE as (NIR-Red_edge)/(NIR+Red_edge).
  The median of the NDVI and NDRE inside the plots was calculated for the two indices. A buffer of 0.3 m was removed from the borders of the plot. The pixel resolution was 7.2 cm.
- **WEED-IT fluorescence data:** The single plots data were originated by starting the recording at the beginning of each plot and saving the data in a separate file. From each plot we removed the first 20k recordings to ensure that we did not have any border effect, and calculate the median of the 4 senors. The WEED-IT settings used for the recording were light intensity of 120% and Gain of 24 dB. The WEED-IT was kept 1.1 m above the canopy, we averaged the value of the 4 sensors. The WEED-IT was equipped with 4 sensors, with a footprint of 25 cm each, totally an area of 1 m (approximately 2 rows of soybean).

The similarity between the NDVI interquartile range measured in the plots and in the rest of the field indicate that the chosen plots were a representative sample of the rest of field (Figure 7). It is important to note that weeds may have contributed to the NDVI and fluorescence signal observed, however since the purpose of end-of-season desiccation is to kill both weeds for next crop and dry the beans for the current crops it not so relevant if the source of greenness (measured through NDVI or WEED-IT) is soybean or weed, as in both it requires desiccation.

Figure 2: A portion of the field with a canopy already mostly dry.

Figure 3: Image of the field with a lot green biomass

Results

Correlation NDVI WEED-IT fluorescence

The correlation between NDVI and fluorescence is reported in Figure 4. The results indicate that the correlation between NDVI and fluorescence is non-linear and it saturates near an NDVI of 0.8, whereas NDRE does not indicate a saturation. We fit a logarithmic equation to the observations. The equation relating WEED-IT fluorescence (measured under the conditions described in materials and methods) is reported in the figure. The r squared between fluorescence and NDVI was 0.84 and between fluorescence and NDRE was 0.75.

The relatively high variability in canopy NDVI measured along our transects (interquartile NDVI range 0.27, Figure 7-right) and in the rest of the field (interquartile NDVI range 0.25, Figure 7-left) suggests that within field canopy variability toward the end of the season can be high and thus varying the amount of desiccant applied can result in desiccant saving.

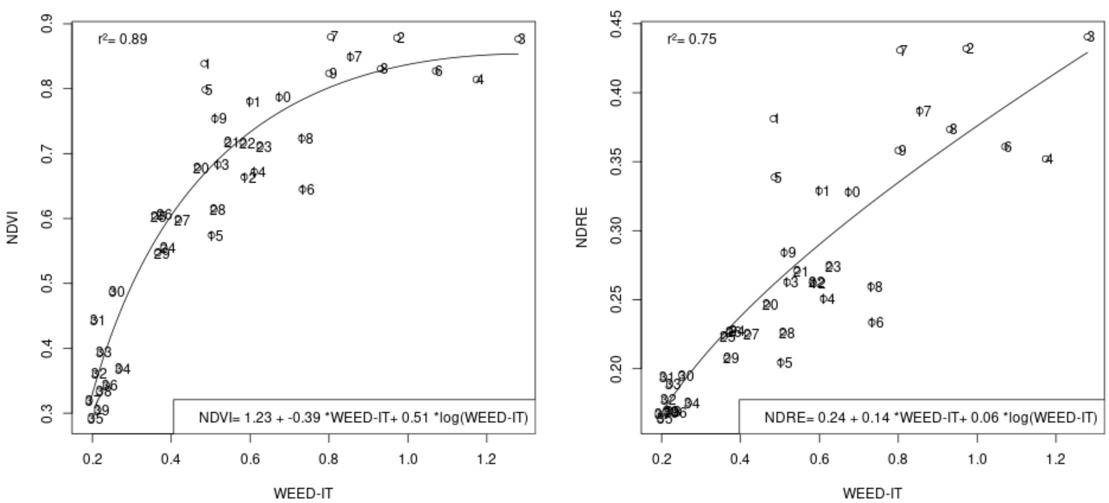

Figure 4: Correlation between NDVI and WEED-IT fluorescence counts and NDRE - WEED-IT fluorescence counts.

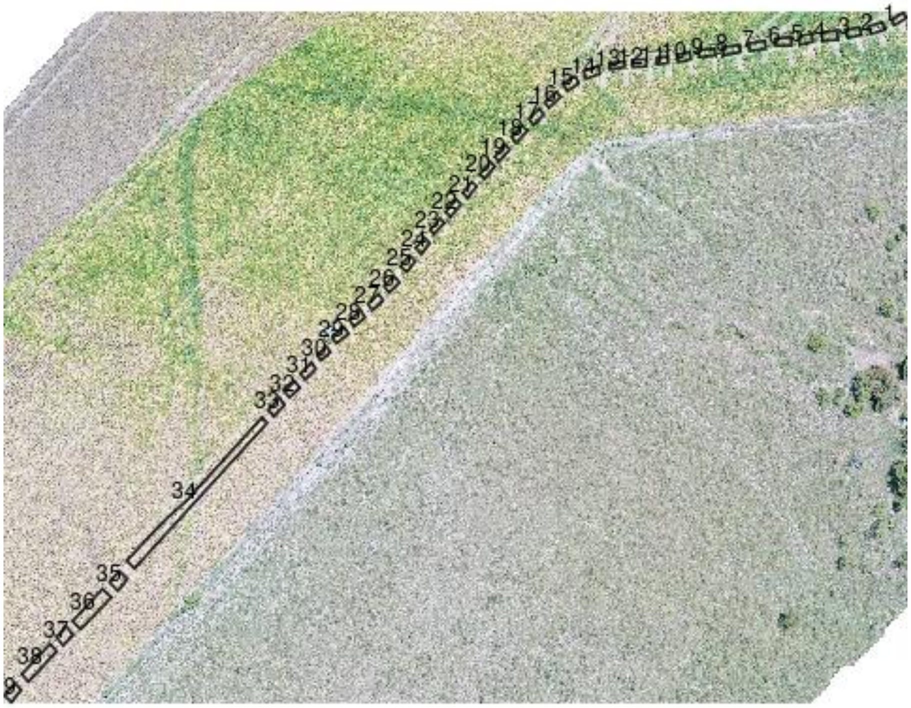

Figure 5: RGB Image of the field, indicating the plots. The plots indicate the plot number.

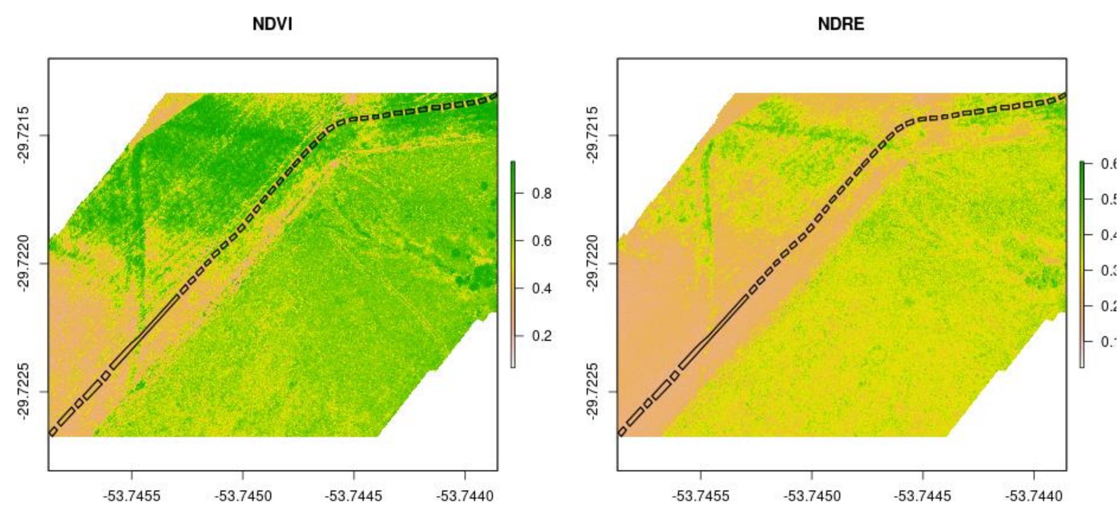

Figure 6: NDVI and NDRE image of the field.

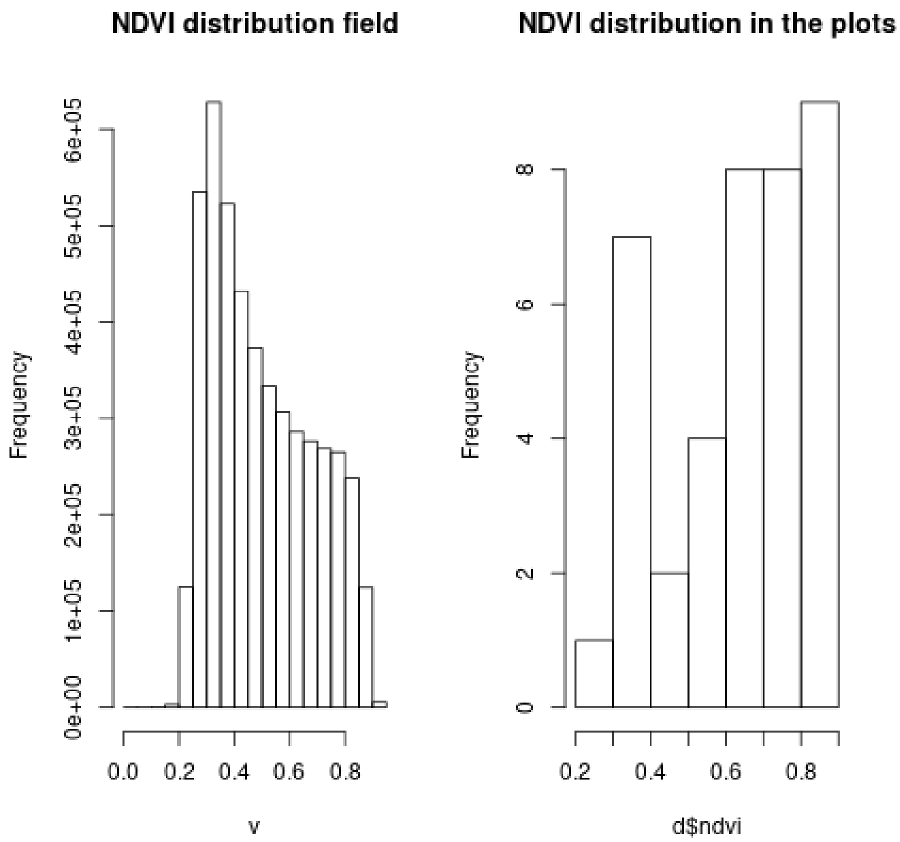

Figure 7: Histogram of NDVI in the section of the field considered for the task map of variable desiccation rate exercise (red polygon Figure 8), and in the plots.

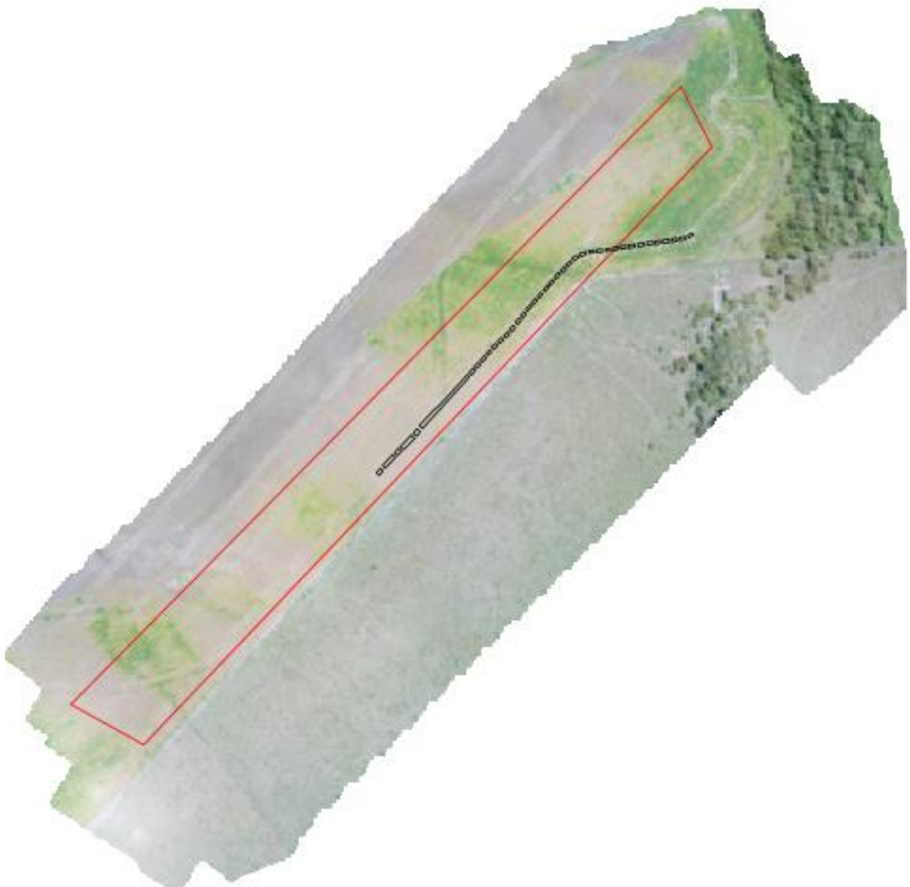

Figure 8: Section of the field considered for simulating saving in desiccant application. The black polygons indicate the plots used for measurements.

Smart Soybean in Brazil – WP4 Soybean Desiccation Dosage 2022 Dutch experiment

Report

Wageningen Plant Research

DATE
29 September 2022

AUTHOR
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1 Introduction

We carried out an experiment at Wageningen University and Research to study the effect of different dosages of on soybean canopy desiccation and to investigate the relationship between NDVI and fluorescence as measured by the WEED-IT sensor. The research questions that we are trying to answer with this experiment are:

1) What is the relationship between NDVI and WEED-IT? How does it compare to the measurements carried out in Brazil in March 2022 ? -> Answer in section 3.1
2) How effective are different dosages of diquat in decreasing canopy biomass? -> Answer in section 3.2.1
3) Does the dosage of diquat applied influence bean moisture? -> Answer in section 3.2.2

2 Materials and methods

A soybean experimental field has been setup on Unifarm land. The field was sown on the 16 May 2022. The experimental setup was the following:

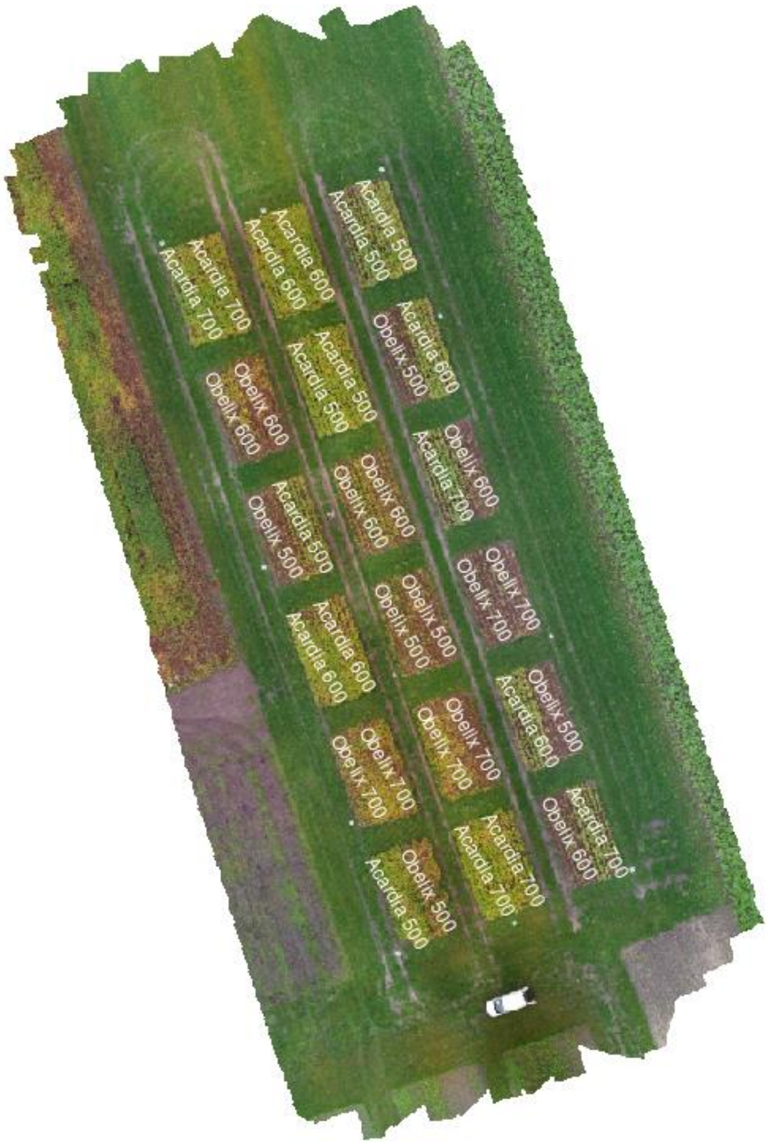

Figure 1: Experimental design, the labels indicate cultivar and sowing densities (kg seed/ha). Image was taken on the 20/9/2022 two days prior spraying.

The cultivars used were Arkadia (from SaatenUnion) and Obelix (from Agrico). The sowing rates were: 500,600 and 700 (k plants /ha). The first part of the season was used for the desiccation experiment, whereas the second part of the season was used for the green-on-green weed detection experiment of WP1. However in this second part of the season the treatments had been disregarded and we only looked at relationships between NDVI and WEED-IT and NDVI and diquat dosages.

The crop was sprayed on the 2022/09/22. The rows were planted at a distance of 0.5 m to mimic the growing conditions in Brazil. Staging of soybean phenology was scouted on the following dates: 14, 22,26,29 of September, and pictures of the plots were taken on the same dates.

2.1 Harvest

On the 29th of September, one week after spraying a destructive sample of the crop was collected. The sampled area was 1x1 m (two rows for 1 one meter). The samples was processed in the lab to measure the following variables: stem biomass, leaves biomass, pod biomass, bean biomass. Dry and fresh biomass were determined, a subset of pods was opened to extract the beans and measure the moisture at 105 °C content of the beans.

2.2 Spraying operation

A single spray event was applied to the crop. The active ingredient of the desiccant used in the experiment was diquat, a permit from CTGB was obtained to conduct the experiment, as diquat is banned in the Netherlands. The sprayer was adjusted to 50 cm above the canopy to ensure an homogenous spraying. The applied rates are reported in

Table 2. The NDVI values refer to values measured on the 20th of September and diquat was sprayed on the 22nd of September. The spraying scheme was the following: the plots were divided in 3 groups based on their NDVI level (low, medium, high) so that each group would contain 12 plots. Each NDVI group was then randomly divided into 4 spraying group (control, low, medium, high). The low, medium and high group corresponded to three different dosage curves, reported in Figure 2, for each NDVI group we calculated the amount to be sprayed based on the average of the group, we then calculated the combination of nozzle, pressure, tractor speed and concentration to be used to apply the determined dosage to the plot. To minimize the influence of droplets size and pressure we kept constant the nozzle and pressure and only varied the tractor speed and diquat concentration. The applied rates and the corresponding nozzle, pressure, concentration and speed are reported in Table 1. To check the amount of sprayed volumes a fluorescence dye was added to the diquat mix. We observed an agreement of 93% between planned spraying volumes and dye recovery.

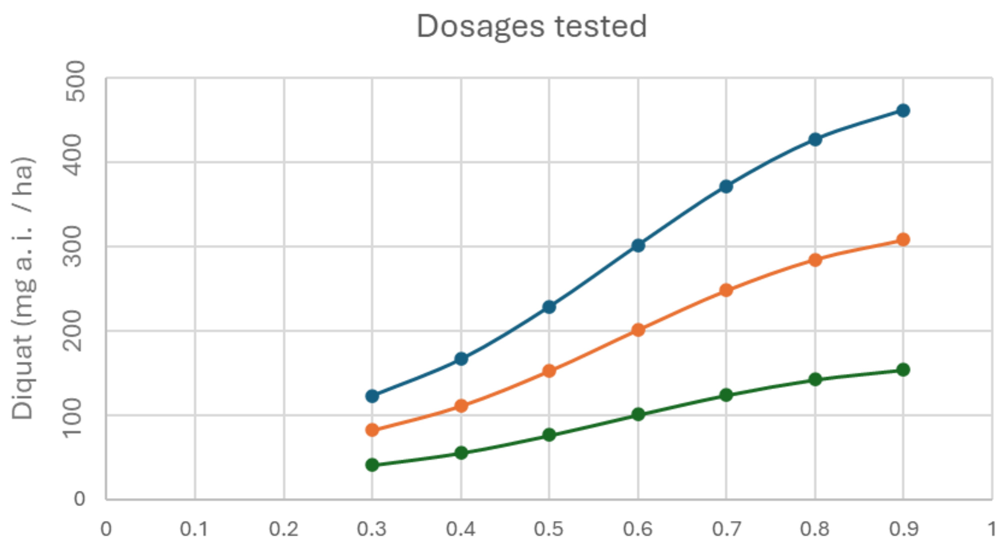

Figure 2: Dosages curves tested. The blue curve is the high dosage (derived from Figure 18 of Anna's report), the orange is the medium dosage curve and corresponds to 2/3 of the high dosage, the grey curve is the low dosage and corresponds to 1/3 of the high dosage.

Table 1: Sprayer parameters (pressure, speed, nozzle, concentration) to apply the amounts of desiccant (each litre of desiccant agent contains 200 mg diquat) to the plots.

		300			04 nozzel @ 3 bar						
Reglone Dosage [L/ha]	L Reglone in 300 L water	concentration [L R/L water]	L/ha needed		**speed [km/h]**	L/ha sprayed		plot 1	plot 2	plot 3	spray order
0.39	**0.4**	0.0013	**293**		**7**	270		105	213	313	1
0.59	**0.6**	0.0020	**295**		**7**	270		103	112	302	2
0.68	**0.6**	0.0020	**340**		**6**	320		106	205	316	3
0.79	**0.6**	0.0020	**395**		**5**	380		212	214	314	4
1.17	**1.2**	0.0040	**293**		**7**	270		111	113	211	5
								115	303	305	5
1.37	**1.2**	0.0040	**343**		**6**	320		201	206	306	6
1.76	**1.8**	0.0060	**293**		**7**	270		114	203	204	7
2.05	**1.8**	0.0060	**342**		**6**	320		116	215	304	8

Table 2: Amounts of diquat applied to each plot.

plot	ndvi	ndvi class	ndvi class mean	rate class	Rate (mg / ha)
104	0.44	low	0.52	control	0
301	0.53	low	0.52	control	0
312	0.52	low	0.52	control	0
105	0.53	low	0.52	low	78
213	0.52	low	0.52	low	78
313	0.54	low	0.52	low	78
212	0.46	low	0.52	medium	158
214	0.56	low	0.52	medium	158
314	0.56	low	0.52	medium	158
115	0.49	low	0.52	high	236
303	0.51	low	0.52	high	236
305	0.52	low	0.52	high	236
102	0.62	medium	0.68	control	0
202	0.65	medium	0.68	control	0
311	0.72	medium	0.68	control	0
103	0.74	medium	0.68	low	118
112	0.64	medium	0.68	low	118
302	0.72	medium	0.68	low	118
111	0.65	medium	0.68	medium	234
113	0.71	medium	0.68	medium	234
211	0.73	medium	0.68	medium	234
114	0.71	medium	0.68	high	352
203	0.61	medium	0.68	high	352
204	0.65	medium	0.68	high	352
101	0.77	high	0.78	control	0
216	0.81	high	0.78	control	0
315	0.77	high	0.78	control	0
106	0.75	high	0.78	low	136
205	0.81	high	0.78	low	136
316	0.77	high	0.78	low	136
201	0.79	high	0.78	medium	274
206	0.82	high	0.78	medium	274
306	0.74	high	0.78	medium	274
116	0.79	high	0.78	high	410
215	0.77	high	0.78	high	410
304	0.76	high	0.78	high	410

2.3 Calibration WEED-IT vs NDVI

2.3.1 Drone images

NDVI was measured from drone reflectance images (*Micasense Altum*) on the dates reported in Table 3 along with pixel resolution after images processing. The bands used for NDVI were NIR (center wavelength 842, bandwith 57) and RED (668, 14), the flying altitude was on average 15 m and ground control points were placed and measured with an RTK-gps.

Table 3: Drone image resolutions (in cm) after merging the different images.

Date	x	y	Weed-IT
2022-07-08	0.5	0.81	No
2022-08-09	0.51	0.82	Yes
2022-08-16	0.53	0.86	No
2022-08-23	0.49	0.8	Yes
2022-08-29	0.52	0.83	No
2022-09-09	0.66	0.66	No
2022-09-14	0.66	0.66	Yes
2022-09-20	0.66	0.66	No
2022-09-29	0.67	0.67	Yes
2022-10-06	0.68	0.68	No

2.3.2 WEED-IT measurements

Weed-IT canopy fluorescence measurements were performed on the dates reported in Table 3. The sensor was place at about 90 cm from the canopy, the highest allowed by the sprayer. In the Brazil experiment the sensor was place at 110 cm over the canopy. Two settings of the weed-it were used, form here-after named the *settings 1* and the *setting 2*.

3 Results

3.1 WEED-IT as an NDVI predictor

3.1.1 Absolute values correlation

We compared NDVI measured from drone and fluorescence with WEED-IT. We observed a relationship between NDVI and the logarithm of fluorescence measured by WEED-IT. The relationship is shown in Figure 3.

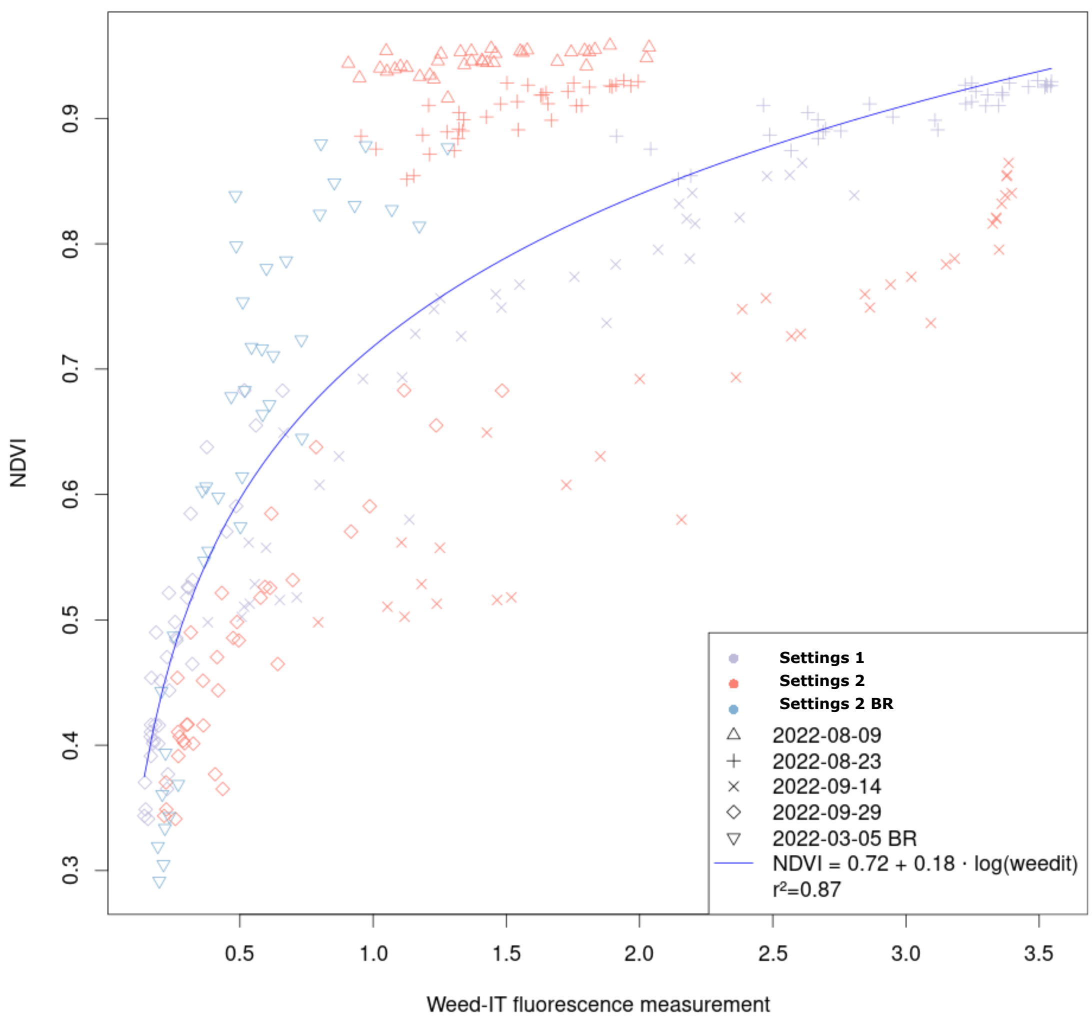

Figure 3: Comparison between fluorescence and NVDI across dates, sites (Brazil and Netherlands), and WEED-IT settings. The blue line is fit on the data collected using Settings 1 settings both in brazil and in the Netherlands.

3.1.2 Relative values correlation

We also evaluated the correlation between NDVI and weedit once they are scaled for each date and settings. To do each for date:settings set of measurements we rescaled the values of NDVI and WEED-IT fluorescence between 0 and 1 (minmax function) and calculated various regression models with different levels of complexities (from no-intercept linear regression to logarithmic regression).

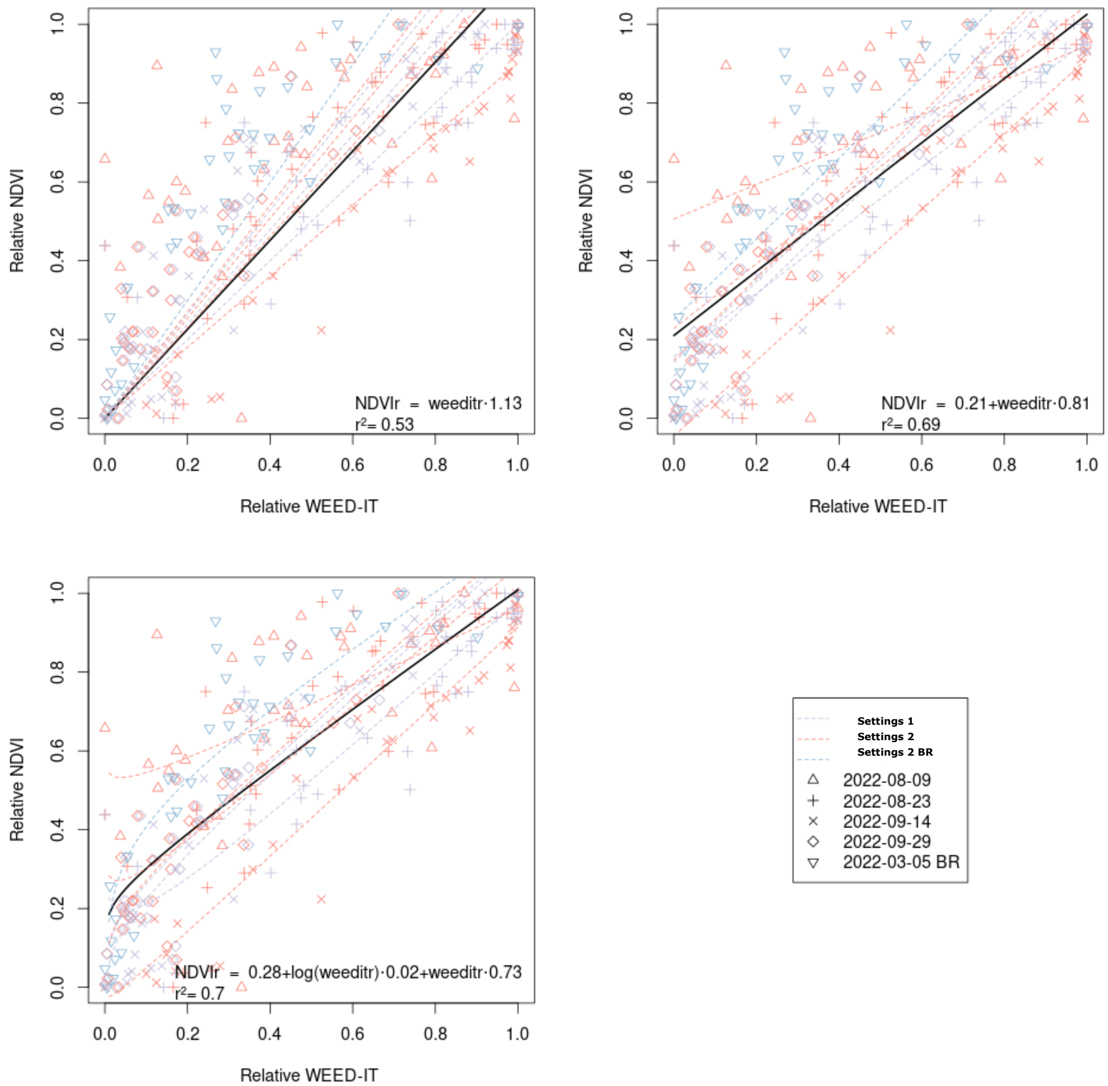

Figure 4: Relative NDVI-WEEDIT relationship. Both variables are rescaled between 0 and 1 for each date and settings combination. The three grapsh display the same data where models of increasing complexity have been fitted.

3.2 Diquat dosage

3.2.1 Effect on canopy

The impact of different dosages of diquat is reported in Figure 5. The addition of low dosages caused a stronger decrease in NDVI compared to control treatment (no spraying), and the addition of middle and high dosages induced a stronger effect than low dosages. However no significant difference between middle or high and low was observed.

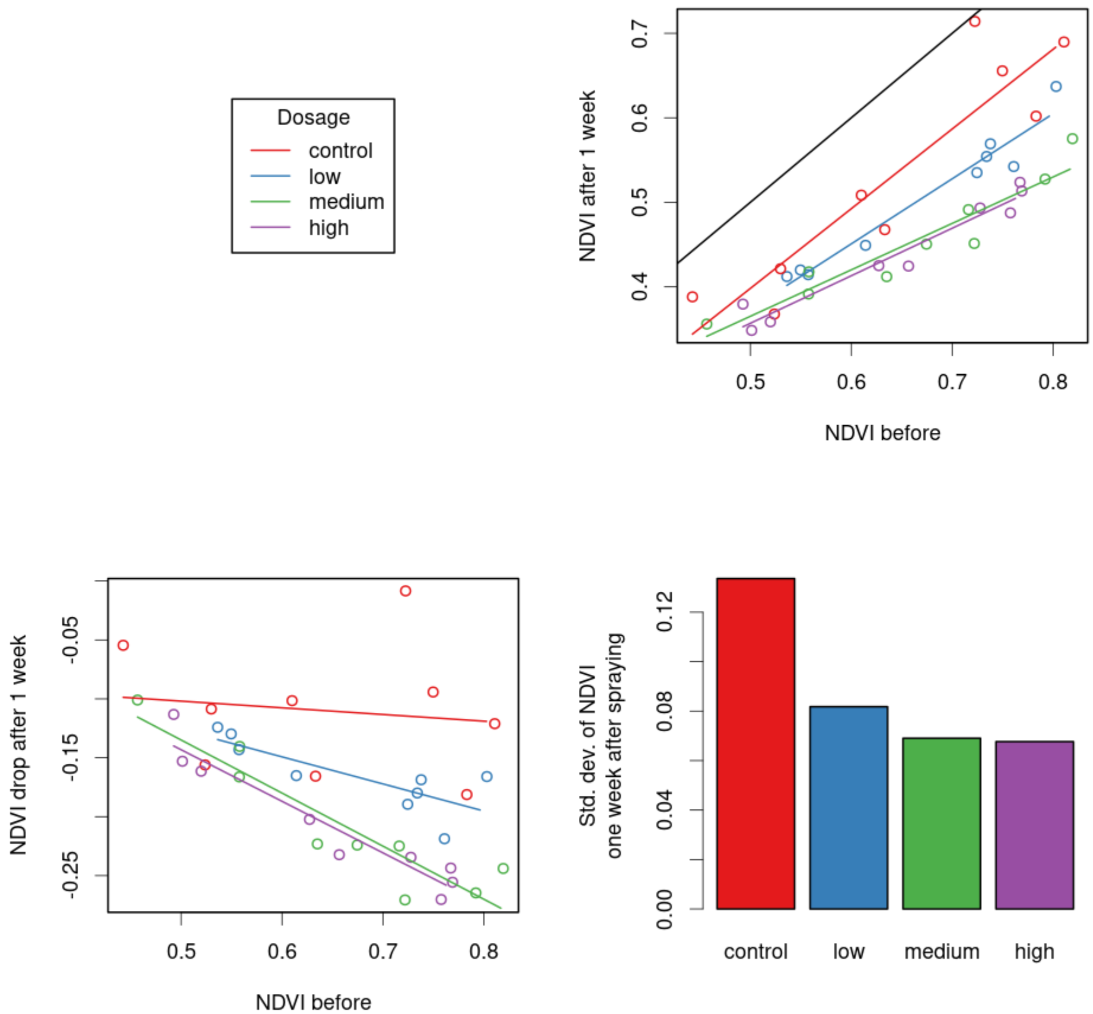

Figure 5: Top-right, effect of different dosages on NDVI after one week. Bottom-left: NDVI drop after one week depending on NDVI before application and dosages, black line is the 1:1 line. Bottom-right: Standard deviation of NDVI after one week depending on dosage.

The leaves biomass was measured one week after spraying. We found that spraying decreased the average amount of leaves remaining on the plant (Table 4), however there was no consistent trend between post-spraying biomass and dosage. The application of diquat also reduced the spread of the distribution of leaf biomass (Figure 6, Table 4).

Table 4: Mean, standard deviation, quartiles of leafy biomass one week after spraying.

	mean	sd	0%	25%	50%	75%	100%
control	42.91	46.06	5.08	12	27.9	70.1	142.8
low	28.09	27.45	5.74	8.86	16.9	37.7	84.9
medium	22.92	21.16	6.62	11.4	16.1	21.6	75.2
high	34.68	22.49	8.42	24.2	29.7	39.7	86.7

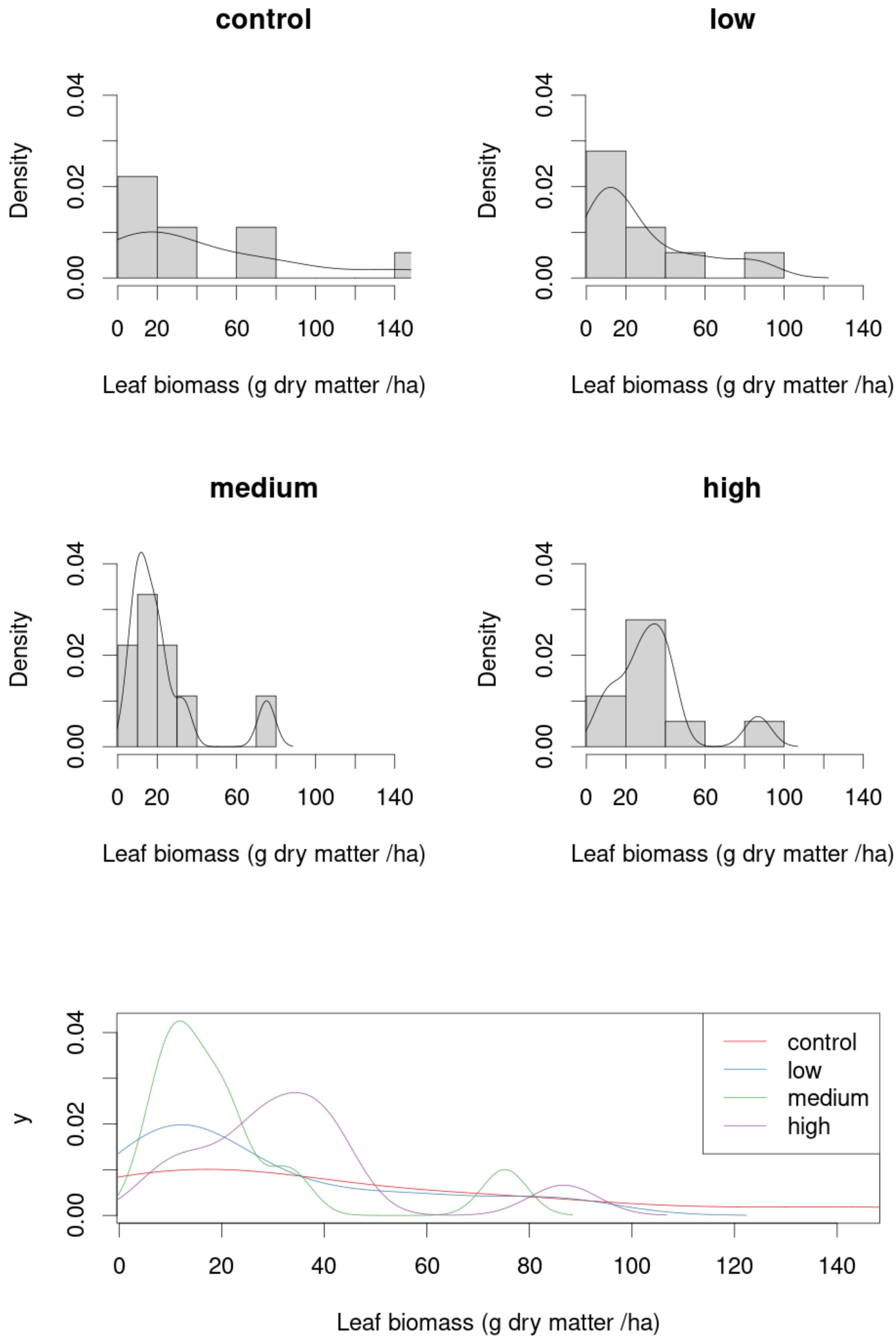

Figure 6: Leaf biomass distribution one week after spraying by dosage treatment.

3.2.2 Effect on beans moisture

The application of different dosages of diquat — including control — had no clear effect on bean moisture distribution one week after spraying.

Table 5: Mean, standard deviation and quartiles of pod moisture (w/w) one week after spraying.

	mean	sd	0%	25%	50%	75%	100%
control	0.44	0.09	0.27	0.38	0.43	0.51	0.55
low	0.45	0.08	0.33	0.35	0.49	0.52	0.53
medium	0.51	0.15	0.3	0.44	0.51	0.55	0.82
high	0.45	0.07	0.34	0.42	0.44	0.48	0.56

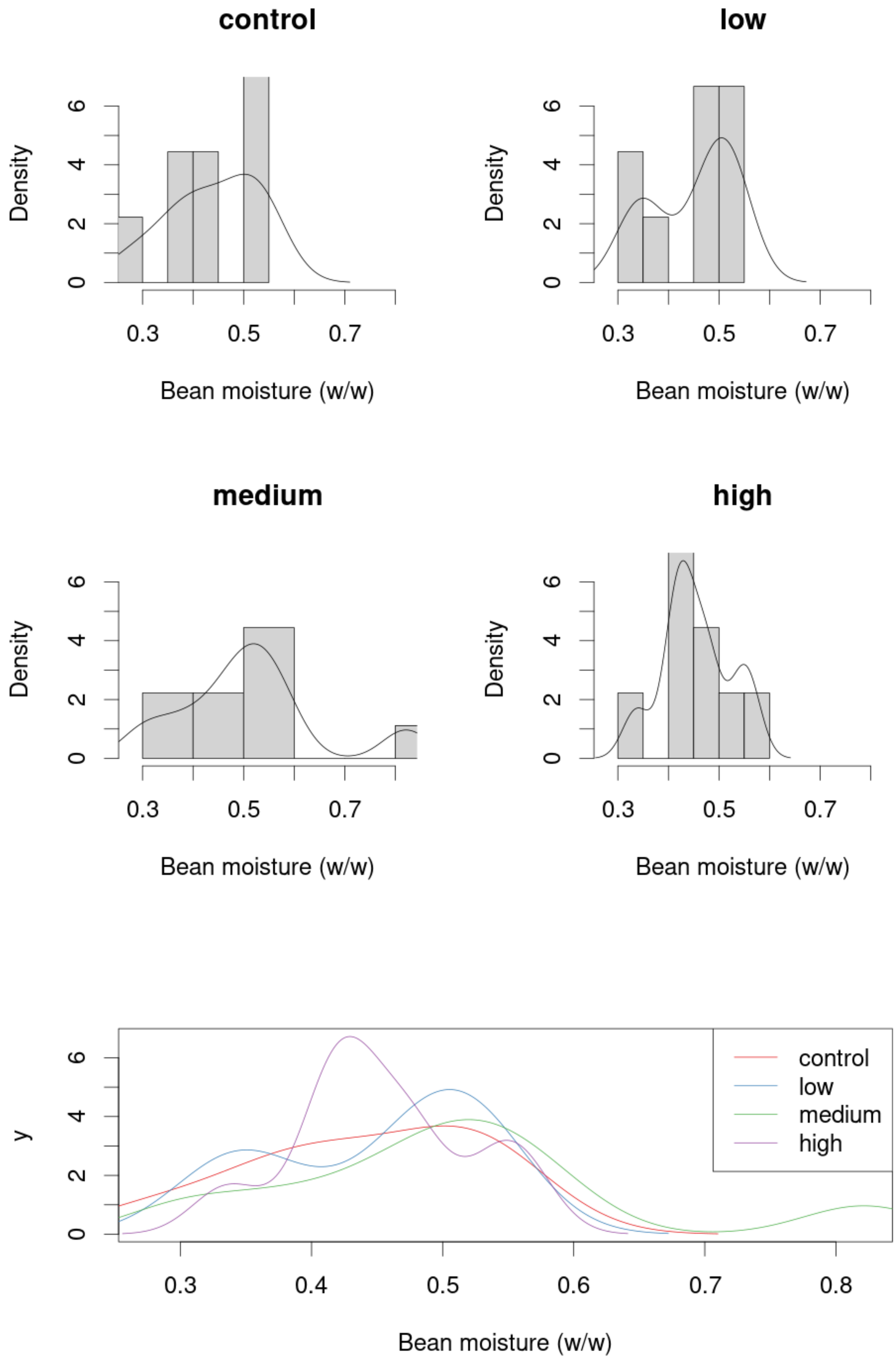

Figure 7: Bean moisture distribution one week after spraying by dosage treatment.

4 Discussion

4.1.1 Correlation between NDVI and WEED-IT

For the *Settings 1* settings there was good agreement between the measurements taken on 3 different sampling in the 2022 Dutch experiment (blue points, Figure 3). The relationship between NDVI and WEED-IT differed for the measurements taken using Settings 1 settings in Brazil and in the Netherlands, particularly after a WEEDIT value >1 (approximately NDVI>0.7). This maybe due to differences between the crop or differences in the WEED-IT settings between the two experiments. The Settings 2s settings show a marked difference between dates, possibly explained by different settings used in the machine.

4.1.2 Dosages of diquat and its effect on canopy and pod moisture

The application of increasing dosages of diquat had a clear effect on NDVI (a proxy for canopy biomass). We did not find a difference in the effect of high and medium dosages suggesting that a dosage curve based on NDVI could be bounded between the lower and the medium dosages that we tested. We did not find a correlation between post-spraying leafy biomass and dosage of the leafy biomass after spraying, this could be partly explained by the fact the leafy biomass included also dying leaves that were still attached to the plant, in fact at this stage of the season it was not possible to clearly distinguish between green and yellow leaves.

The application of diquat to anticipate canopy desiccation at the end of the season did not result in lower seed moisture. However Albrecht et al. (2022, doi:10.4067/S0718-58392022000300448) observed that the application of diquat in a Parana study reduced soybean seed moisture from 15% to 12% after 7 days of application. The difference between our findings (no effect) and their finding is likely explainable by the environmental conditions between September in the Netherlands (daily temperatures between 8 and 18 degree C) and March in Paraná (daily temperatures between 20 and 30 degrees). Therefore the results from our Dutch study with regard to the effect of dosages on bean moisture are not conclusive.

5 Acknowledgements and contributions

The experiment was carried out by WUR in collaboration with Rometron. Bernardo Maestrini lead the work package, Fred Kool and Eva de Jonge contributed to experimental design, data analysis, and field work, Jean Marie Michielsen contributed to calculate spraying dosages, recovery and field work, Annelies Beniers and Frank Hagedorn contributed to field work, Snoussi Mostafa analysed the fluorescence dye to estimate recovery of sprayed volumes. Vincent Wieringa, Bart Lammers, Youri Schoutsen, and Hendrick Braam (Rometron) performed the measurements using WEED-IT. Berry Onderstal performed drone flights and image processing. We are grateful to Ruud Timmer for sharing his experience on soybean cultivation in the Netherlands.

Estimating canopy biomass using WEED-IT fluorescence sensor

Smart Soybean WP4 – WUR Rometron

Bernardo Maestrini[1], Youri Schoutsen[2], Alwin Meenderink[2]

[1] Wageningen Research – PSG

[2] Rometron

Prepared by Bernardo Maestrini – 2021/10/08

Introduction and experimental setup

The objective of the study was to correlate fluorescence measurement from the Rometron sensor with biomass ground measurement in potato fields. Such correlation will be useful to apply variable rate haulm killing herbicide.

The experiment took place in three fields from WUR-Unifarm. The fields are managed from WUR-Unifarm following a traditional agronomic approach for potato cultivation in the region. Potatoes were sown on the first of April and field monitoring started in May.

Figure 1: Map showing the location of the three fields analysed in this study.

To establish a relationship between fluorescence and biomass on each sampling date we established a number of plots. In the period May-June the measurements were taken on 3 plots each counting 16 plants, the plot was composed of two rows, with 8 plants on each row. The design was changed in the second part of the season (August-September) because at this stage it was not possible anymore to go with the tractor over the plants as they were taller than the tractor ground clearance, thus they would get damaged before being measured for fluorescence. In August-September the plots were made 3.2 m long (row distance in 0.75m in potatoes). We had a total of 8 sampling dates, as reported in Figure 2.

We conducted an experiment to evaluate if the fluorescence signal of WEED-IT sensor is a good proxy of above ground biomass. The overarching objective of the experiment is to evaluate the use of the WEED-IT sensor for variable rate desiccant application.

The potato biomass was measured destructively by harvesting the plants and the dry matter content was measured by drying them at 70 degrees for 24 hours. The fluorescence measurement were carried out using a Rometron blue fluorescence sensor. The sensors were kept at two different heights from the ground. During the first part of the season the height was 70 cm and in the late season it was raised to 1.30 cm to avoid plant damage. The measurement took place using two sensor, each sensor was composed of 4 channels, which had a footprint image of approximately 25 cm for each channel. The sensors were placed so that using three sensors a whole potato row could be monitored (potato row distance 75cm = 3x25cm). Fluorescence was calculated as the sum of the signal of the three sensors over the plot length. The logger had a frequency of 70KHZ, this was resampled down to 7KHZ to speed up computations. In May-June we considered measurements carried out with gain 1, in July-August we considered measurements carried out using gain attenuated and Light 50 setup.

There was a total 7 sampling dates (plus another where the sd card failed so we could not use the data), these were: 2021-05-11,2021-05-18,2021-05-26, 2021-06-08,2021-08-26,2021-09-09,2021-09-16.

Results and discussion

The main result is reported in Figure 2. This shows that the fitness of a simple linear regression model correlating fluorescence and biomass, the r^2 in the early season is 0.89 (standard deviation of the residuals 47g dm/m2) and 0.71 (standard deviation of residuals 17 g dm / m2) in the late season. As expected the regression lines differed between the two parts of the season as the result of the difference in the setup of the fluorescence measurements.

We also fitted models to field: date subsets (e.g. field Avamond1 on the 9th of September) to test the suitability to predict within-field variability. The fitness of the two models was good and agreed with the overall trends in the moments of the seasons when the level of aboveground biomass was low, at the beginning of the season and at the end of the season. At the end of August the canopy cover was still so high that the signal was probably saturated.

We found that the correlation between the fluorescence signal and the amount of biomass measured on the ground was good (r2 of 0.89 in the late season and 0.71 in the early season). The correlation between samples of the same date:field also showed a good agreement which suggest the possibility of using the sensor to apply variable rate desiccant.

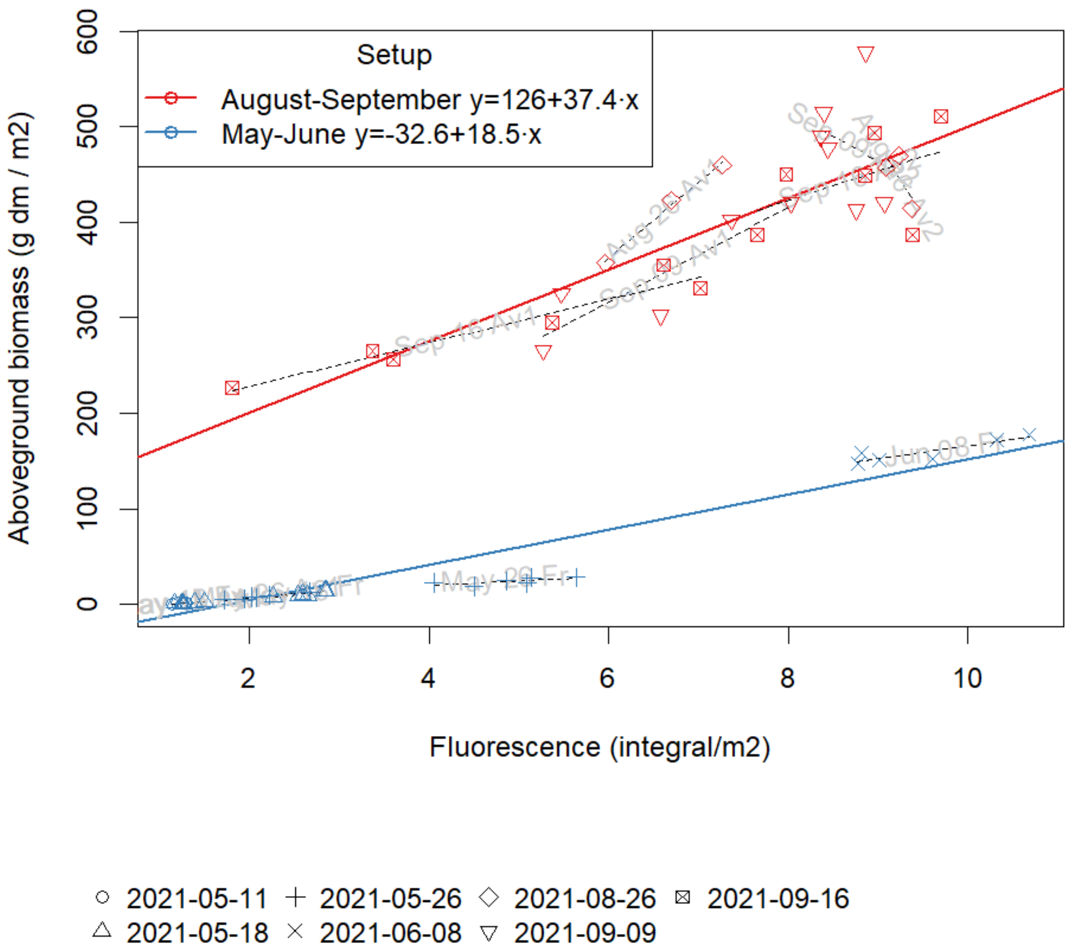

Figure 2: Results of the regression of biomass on fluorescence. The dashed line represent the correlation between samples from the same field and date (e.g. 9 September field Avamond1). The solid lines indicate the correlation to be used to correlation fluorescence integral and biomass, the dashed line are indicators for the suitability of the method to detect within-field variability and apply desiccant accordingly.

WEED-IT fluorescence sensor and NDVI for end-of-season variable rate soybean desiccation
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