

The normalized difference vegetation index (NDVI) GreenSeeker™ handheld sensor:

Toward the integrated evaluation of crop management

Part B: User guide¹

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¹ For more detailed technical information on operating the GreenSeeker™, please refer to Ntech Industries' Operation Manual (www.ntechindustries.com)

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A. Transport and maintenance

To transport the GreenSeeker™ over long distances, put it in its box and fasten the straps.

The GreenSeeker™ is charged by plugging in the battery charger. The light on the charger is yellow when the battery is charging and green when the battery is fully charged. Make sure the battery is fully charged before going to the field.

- **Tip** You can extend the life of the battery by keeping the GreenSeeker™ plugged in when not using it.
- **Tip** It is important to make sure the personal data assistant (PDA) always stays charged. When its battery is dead, the collected data and the installed software (NTechCapture) needed for the operation of the sensor will be erased.

B. Field measurements

1. Switch on the PDA:

Go to *Start/NTechCapture* (to enter to the program)

Go to *Sensor/Start GreenSeeker™* (to enable the sensor to record measurements)

Go to *Logging plots* (to measure rows)

- **Tip** With newer versions of the software you only need to go to *Start/NTechCapture*.
2. Switch on the GreenSeeker™
3. Push the green button during every measurement (keep the sensor horizontal and at a distance of 70-90 cm over the canopy)
4. To save data go to *File/Save as...*
5. Name the file and save.
- **Tip** When taking measurements in an experiment with crops that differ in height, it is convenient to make separate files for each crop so that the GreenSeeker™ can be adjusted to ensure adequate measurement of each crop (angle of the sensor, length of the telescoping tube).
 - **Tip** If different operators take measurements in the same experiment, make sure they all walk at the same speed to facilitate data processing. A suitable walking speed is 1 m s⁻¹.
 - **Tip** Indicate the sample number and the walking direction of each sample on a map of the experimental field.

C. Data reading

The GreenSeeker™ generates three Notepad files, which are as follows:

1. A general file with the normalized difference vegetation index (NDVI) and Red/NIR for each measuring point.
2. A file with the mean of the NDVI and Red/NIR for every measured sample (indicated with the suffix Avg).
3. A file with diagnostic information about the sensor used for the measurement (indicated with the suffix Diag).

For example, if you were to save a file on the sensor as "maize-15-12-2009" the software would then save the following three files:

1. maize-15-12-2009.txt
2. maize-15-12-2009Avg.txt
3. maize-15-12-2009Diag.txt

To save the PDA files on another computer, connect the PDA to the USB-port and copy the files from My Computer/Mobile device to the other computer (You need to have ActiveSync installed on your computer).

- **Tip** The PDA needs to remain in the English language to avoid changing the number formats. English uses a period "." for a decimal indicator as opposed to the European convention of using a comma ",". Changing the PDA's language means other settings are altered which can lead to confusion between the meaning of periods and commas and can create data conflicts and alternation.

D. Data processing

Use the general file to process the data.

Clean the file, checking the measurement points at the start and end of every measured sample and delete the points that do not belong to the measured plot (e.g. sensing a soil bund at the start of the plot will give low NDVI value) or that are not representative of the plot (by comparison with points further from the border). Delete any mistakes (e.g. measurements from when the green button was pressed unintentionally).

Example: Maize in the vegetative stage in the central highlands of Mexico.

GreenSeeker™ Time(ms)	Sample	Count	NDVI	Red/NIR
[...]				
2289530,	1,	147,	0.8065,	0.1071
2289640,	1,	148,	0.7949,	0.1143
2289750,	1,	149,	0.8502,	0.0810
2289860,	1,	150,	0.8408,	0.0865
2289970,	1,	151,	0.8022,	0.1098
2290080,	1,	152,	0.8155,	0.1016
2290190,	1,	153,	0.8384,	0.0879
2290300,	1,	154,	0.7984,	0.1121
2290410,	1,	155,	0.6769,	0.1927

End of measuring row

⇒ The NDVI for count 155 is low in comparison to the other counts, so count 155 was deleted.

GreenSeeker™ Time(ms)	Sample	Count	NDVI	Red/NIR
[...]				
2310950,	2,	143,	0.8040,	0.1086
2311060,	2,	144,	0.7321,	0.1547
2311170,	2,	145,	0.6375,	0.2214
2311280,	2,	146,	0.6311,	0.2262
2311390,	2,	147,	0.7487,	0.1437
2311500,	2,	148,	0.8171,	0.1006
2311610,	2,	149,	0.7563,	0.1388
2311720,	2,	150,	0.5870,	0.2602
2311830,	2,	151,	0.2035,	0.6618

End of measuring row

⇒ The NDVI for counts 150 and 151 are low in comparison to the other counts, so counts 150 and 151 were deleted.

Example: Maize in the reproductive stage in the central highlands of Mexico.

GreenSeeker™ Time(ms)	Sample	Count	NDVI	Red/NIR
[...]				
52950,	2,	145,	0.627,	0.246
53050,	2,	146,	0.611,	0.237
53150,	2,	147,	0.654,	0.184
53260,	2,	148,	0.697,	0.174
53360,	2,	149,	0.623,	0.296
53460,	2,	150,	0.423,	0.535
53560,	2,	151,	-0.298,	-0.900
53670,	2,	152,	-0.899,	-0.900
53770,	2,	153,	-0.899,	-0.900
53870,	2,	154,	0.628,	0.245
53970,	2,	155,	0.612,	0.236

End of measuring row

⇒ Counts 150-153 were deleted. The negative NDVI values are measured when the sensor is lowered while still recording and touches the canopy.

GreenSeeker™ Time(ms)	Sample	Count	NDVI	Red/NIR
[...]				
584890,	14,	154,	0.583,	0.228
585000,	14,	155,	0.611,	0.255
585110,	14,	156,	0.536,	0.353
585210,	14,	157,	0.534,	0.258
585310,	14,	158,	0.629,	0.199
585410,	14,	159,	0.670,	0.195
585510,	14,	160,	0.638,	0.247
585610,	14,	161,	0.489,	0.456
585710,	14,	162,	0.384,	0.435

End of measuring row

⇒ The NDVI for counts 161 and 162 are low in comparison to the other counts, so counts 161 and 162 were deleted.

a) For an analysis of crop growth and development (see Part A)

1. Open the macro file.
2. Push the button in the first sheet to start and then open the cleaned file you want to process. The macro does two things, it opens the cleaned file in Excel, and generates a file with the mean, standard deviation, and coefficient of variation (CV) of the NDVI of each measured row. This is the file you need to save.
3. Close the macro without saving the changes made.

→ **Tip** Do not change the name of the macro-file.

→ **Tip** When the cleaned file contains a lot of data, the macro will not be able to process all the data at once. When this happens the macro will give NA as output from a certain sampling number (this number will vary depending on the amount of counts in each sample). Delete the samples that are already processed from the file (check with the count number that the whole sample was taken into account) and run the macro again with the remaining part of the file.

Example:

The measurements in this example were taken in the maize plots of the 2006 growing season of a long-term sustainability trial. The trial took place in the semi-arid, subtropical highlands of central Mexico at the International Maize and Wheat Improvement Center (CIMMYT). The trial compares rainfed cropping systems varying in: (1) rotation (monocropping vs. a maize/wheat rotation); (2) tillage (conventional [CT], vs. zero-tillage [ZT]); (3) residue management (removal [R], vs. full retention [K]). Individual plots were 7.5 m x 22 m. Maize was planted at 60,000 plants per ha in 75 cm rows. The experimental design consisted of a randomized complete block with two replications. Two sample sequences, each time the same two central rows, were measured per plot 3x/week. For a more detailed description of the experiment, refer to Part A of this manual.

Travel velocities were at a slow walking speed (approximately 1 ms⁻¹), resulting in NDVI readings averaged over approximately 0.10 m.

The data files for each sampling date were cleaned as previously described. The macro-file was used to calculate the average NDVI and CV for each sampling sequence (Table 1). There were 8 treatments in total with 2 field repetitions and 2 sampling sequences per plot, so a total of 32 samples were recorded. Plot and treatment numbers were added to each sample by using the experiment map, which showed the location of each sampling number. The data files for each sampling date were processed in the same way and put together in one file (part of the data is shown in Table 2). The table was sorted according to treatment and accommodated for statistical analysis with the PROC MIXED (SAS institute, 1994) using the REPEATED statement for the analysis of repeated measurements. The 'repeated measures' analysis of data considers a covariance structure for the observed data in the sense that two measurements taken at adjacent times are more highly correlated than two measurements taken at times further apart; it should be pointed out that the traditional statistical analysis assumes that these measurements are equally correlated. The variance-covariance structure was modeled after the compound symmetry model for the correlation between observations. The residual maximum likelihood (REML) method of estimation was used for the estimation of the variances.

For graphical representation, the treatment average was calculated for each sampling date and graphs of NDVI and CV versus days after sowing were made (Figures 1a and 1b).

Table 1. Output of the macro for the data file of the measurement on 18/08/2006 (73 days after planting) in the maize plots of CIMMYT's long-term sustainability trial in El Batán, Mexico.

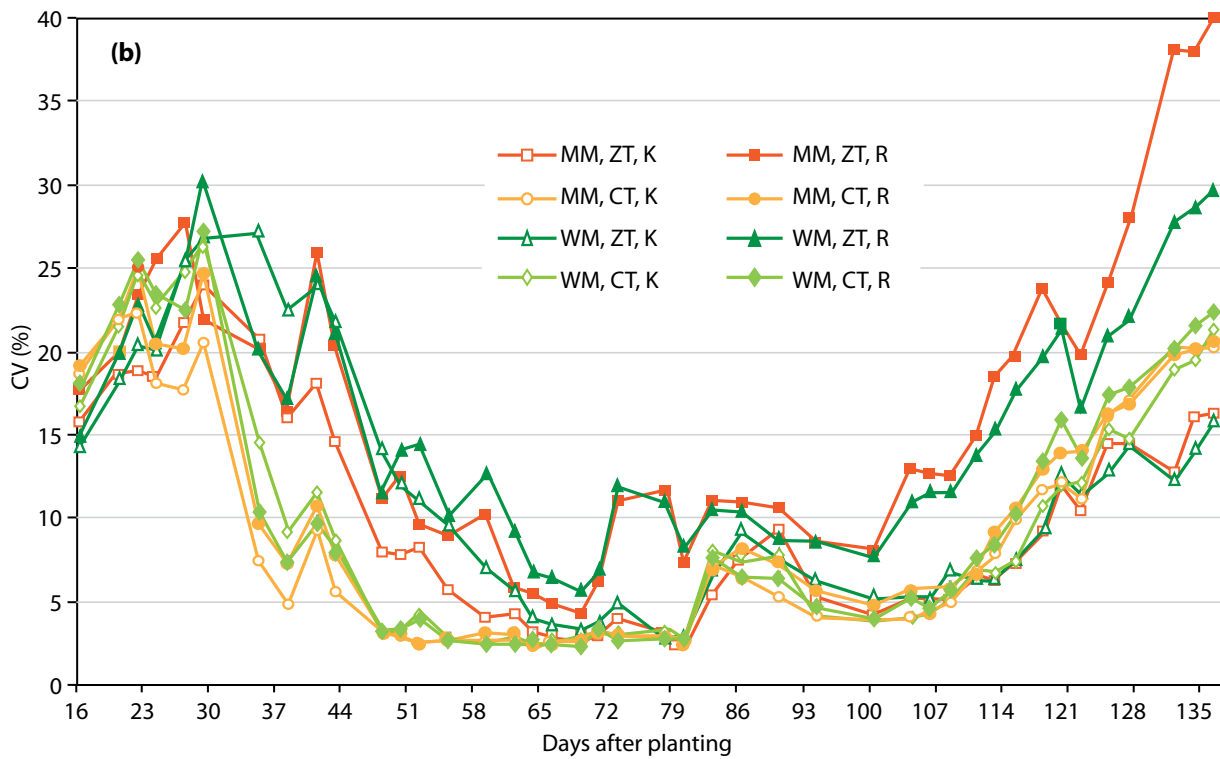
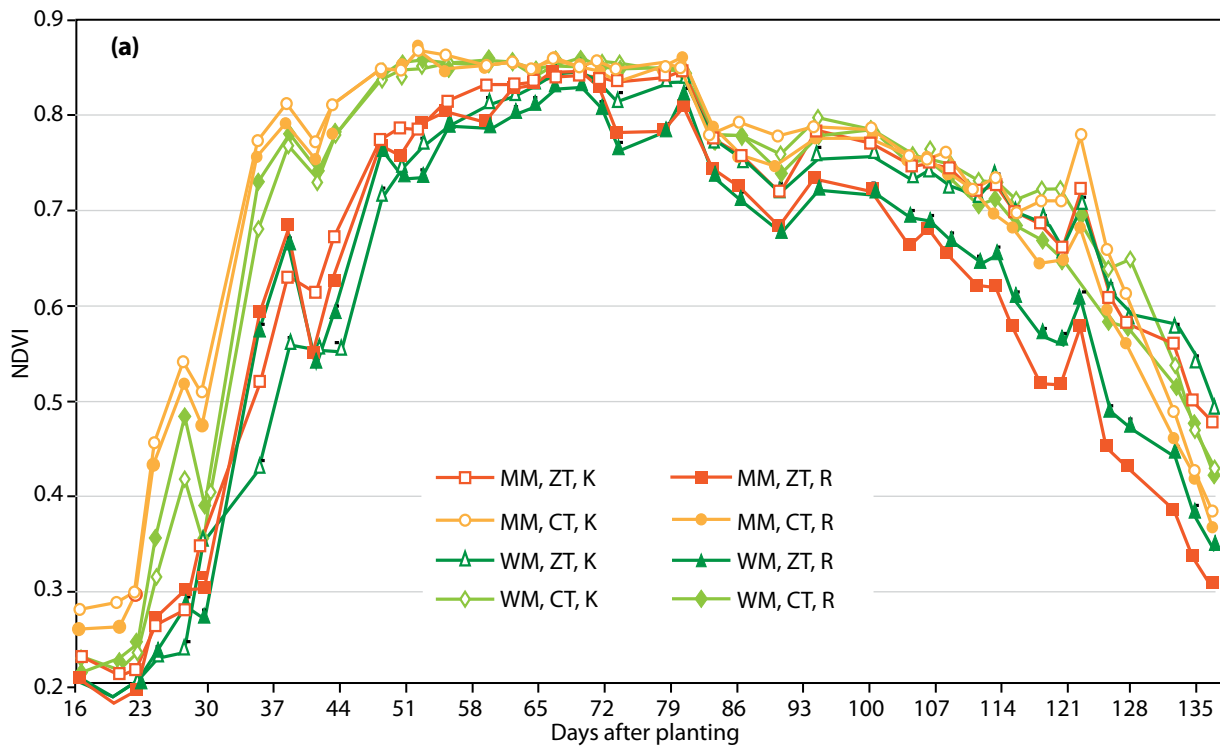
Sample No	Count	Avg NDVI	Stdev	CV
1	155	0.783677	0.09141	11.66429
2	163	0.787914	0.092379	11.72451
3	234	0.867607	0.029067	3.350253
4	271	0.865277	0.024264	2.804136
5	211	0.836588	0.03251	3.885973
6	220	0.838682	0.027936	3.330997
7	221	0.841629	0.022865	2.716705
8	222	0.831306	0.042422	5.103077
9	256	0.846719	0.029509	3.485058
10	256	0.840781	0.03833	4.558859
11	225	0.851111	0.027355	3.214071
12	241	0.846722	0.022759	2.687864
13	199	0.850302	0.025818	3.036349
14	207	0.859903	0.022939	2.667642
15	188	0.835691	0.028921	3.460713
16	191	0.846806	0.025829	3.050115
17	218	0.85844	0.020418	2.378546
18	223	0.862646	0.020614	2.389663
19	186	0.818118	0.03672	4.488304
20	213	0.825164	0.03357	4.06834
21	165	0.77297	0.093758	12.12955
22	157	0.75828	0.102508	13.5185
23	216	0.842407	0.026549	3.15162
24	223	0.843722	0.025399	3.010315
25	187	0.820267	0.030097	3.669195
26	215	0.835581	0.030456	3.644913
27	223	0.843946	0.026991	3.198162
28	211	0.843744	0.030933	3.666192
29	201	0.821045	0.038489	4.687807
30	179	0.816648	0.037774	4.625539
31	176	0.80375	0.043116	5.36437
32	189	0.810582	0.045978	5.672281

Sample No= sample number, Count = total number of measurements in a sample, Avg= average, NDVI= normalized difference vegetation index, Stdev= standard deviation, CV= coefficient of variation.

Table 2. Summarizing file for the 2006 growing season of measurements in the maize plots of CIMMYT's long-term sustainability trial at El Batán, Mexico (only the first three measurement dates are shown).

Date				26/07/2006		28/07/2006		31/07/2006	
Days after planting				50	50	52	52	55	55
PLOT	TRT	REP	MREP	Avg NDVI	CV	Avg NDVI	CV	Avg NDVI	CV
3	4	1	1	0.740	12.752	0.806	6.626	0.802	8.385
3	4	1	2	0.752	11.693	0.805	6.839	0.818	6.504
4	5	1	1	0.837	2.943	0.858	3.165	0.861	2.444
4	5	1	2	0.844	2.336	0.871	3.280	0.864	2.490
29	12	1	1	0.842	3.118	0.859	2.205	0.857	2.481
29	12	1	2	0.849	2.268	0.877	2.532	0.854	2.320
25	11	1	1	0.854	2.620	0.859	2.541	0.859	2.883
25	11	1	2	0.838	2.760	0.856	2.164	0.859	3.092
23	3	1	1	0.796	6.686	0.834	4.603	0.828	4.725
23	3	1	2	0.796	6.740	0.832	4.305	0.831	4.132
22	6	1	1	0.849	3.111	0.873	2.598	0.852	2.397
22	6	1	2	0.862	3.092	0.880	3.196	0.860	2.572
18	7	1	1	0.749	12.015	0.772	11.613	0.794	9.676
18	7	1	2	0.741	13.298	0.769	10.408	0.782	10.186
17	8	1	1	0.748	14.566	0.802	8.789	0.800	9.648
17	8	1	2	0.732	16.408	0.742	15.102	0.777	11.853
33	11	2	1	0.839	2.765	0.862	2.299	0.853	2.352
33	11	2	2	0.848	2.783	0.869	2.453	0.855	2.642
41	5	2	1	0.831	4.480	0.859	3.503	0.851	2.717
41	5	2	2	0.854	3.425	0.829	7.633	0.856	3.327
42	3	2	1	0.759	9.797	0.763	9.655	0.803	6.358
42	3	2	2	0.784	7.701	0.706	14.175	0.785	7.302
64	4	2	1	0.743	16.240	0.764	13.317	0.775	11.870
64	4	2	2	0.786	9.054	0.777	11.417	0.803	8.803
60	8	2	1	0.765	11.907	0.765	10.184	0.804	8.196
60	8	2	2	0.732	13.152	0.637	23.131	0.781	10.520
59	7	2	1	0.767	10.705	0.637	20.400	0.793	8.759
59	7	2	2	0.740	12.523	0.651	21.650	0.785	9.295
58	6	2	1	0.858	4.125	0.839	5.929	0.846	2.650
58	6	2	2	0.869	2.948	0.845	4.393	0.846	3.281
51	12	2	1	0.850	2.990	0.848	2.366	0.837	2.795
51	12	2	2	0.863	3.818	0.888	2.583	0.837	2.915

PLOT= number of experimental plot, TRT= treatment number, REP= field repetition, MREP= measurement repetition (2/plot), Avg NDVI= average NDVI for sample, CV= coefficient of variation (%) of NDVI for sample



Crop sequence: MM monoculture of maize, WM yearly rotation of maize and wheat. Tillage system: CT conventional tillage, ZT zero tillage. Residue management: R all residues removed from the field, K all residues kept on the field.

Figure 1. (a) NDVI-based crop growth and development curves (adapted from Verhulst et al., 2010) and (b) Coefficient of variation (CV) corresponding with the NDVI curves (adapted from Govaerts et al., 2007c) for maize in the 2006 crop cycle in the long-term sustainability trial at El Batán, Mexico.

b) For a spatial analysis

Convert the cleaned general file to an Excel file. Add the X and Y coordinates for every point and make maps (e.g. with Surfer or ArcMap) or semivariograms (e.g. with Variowin).

Example:

The data for this example were also taken from the long-term trial at CIMMYT El Batán during the 2006 growing season. NDVI was measured in all rows of the maize plots, except for border rows, giving a total of 8 rows (see Figure 3). As for the non-spatial measurements, between 180 and up to 230 individual NDVI readings were recorded per row (approximately 1 sampling point each 10 cm).

Data were imported in Excel and per plot descriptive statistics were calculated (mean, standard deviation, CV, minimum and maximum value). The descriptive statistics were then averaged per treatment.

X and Y coordinates were added by georeferencing each point with respect to the south-west corner of the plots (putting the X- and Y-axis as in Figure 3):

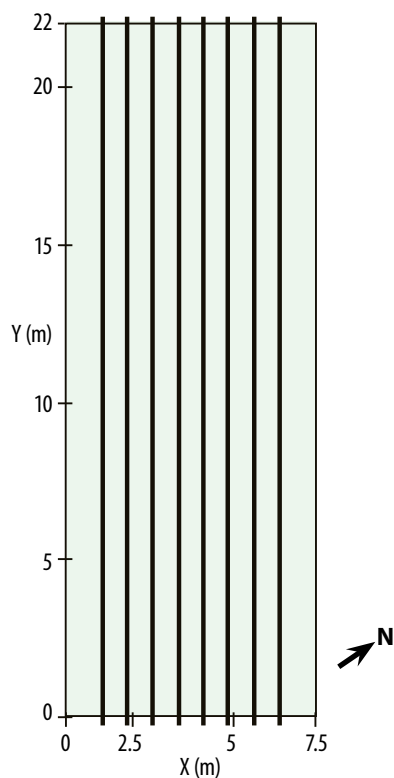


Figure 3. Location of NDVI sampling sequences within each plot.

X coordinates for the measured rows were as follows: 1.125; 1.875; 2.625; 3.375; 4.225; 4.875; 5.625; and 6.375 m. Y coordinates were calculated by putting the first measurement on 0 m and the last measurement on 22 m, to cover the full length of the plot (or the other way around, depending on the walking direction during the measurement).

When walking from 0 to 22 m, the Y-coordinate was:

$$Y = \frac{L}{(N-1)}(n-1)$$

where: L is the length of the plot (22 m);

N is the total number of counts for that row;

n is the count number.

Table 3. X and Y coordinates for the third row (second measured row) in one of the maize plots where NDVI was measured spatially.

SAMPLE	COUNT	NDVI	X	Y
50	1	0.835	1.875	0
50	2	0.84	1.875	0.125714
50	3	0.845	1.875	0.251429
50	4	0.845	1.875	0.377143
50	5	0.84	1.875	0.502857
50	6	0.795	1.875	0.628571
50	7	0.75	1.875	0.754286
50	8	0.65	1.875	0.88
50	9	0.695	1.875	1.005714
50	10	0.825	1.875	1.131429
50	11	0.8	1.875	1.257143
50	12	0.75	1.875	1.382857
[...]				
50	164	0.875	1.875	20.49143
50	165	0.855	1.875	20.61714
50	166	0.85	1.875	20.74286
50	167	0.875	1.875	20.86857
50	168	0.885	1.875	20.99429
50	169	0.865	1.875	21.12
50	170	0.855	1.875	21.24571
50	171	0.865	1.875	21.37143
50	172	0.87	1.875	21.49714
50	173	0.86	1.875	21.62286
50	174	0.835	1.875	21.74857
50	175	0.805	1.875	21.87429
50	176	0.725	1.875	22

This data is from the 2006 growing season of CIMMYT's long-term sustainability trial at El Batán, Mexico (only part of the row is shown). Walking direction was from the southeast to the northwest side.

When walking from 22 to 0 m, the Y-coordinate was:

$$Y = L - \frac{L}{(N-1)} (n - 1)$$

As an example the X and Y coordinates of the second measured row (the third row in the field) in one of the maize plots are given in Table 3.

The files with georeferenced NDVI-values per plot were used as input for ArcMap (version 9.2) and maps of NDVI were made (Figure 4). To allow for comparison between plots and treatments, a scale containing the whole range of values in all the measured plots was developed and all maps were adjusted to this scale. Then a map of the whole experimental field was compiled from the maps of the individual plots (Figure 5).

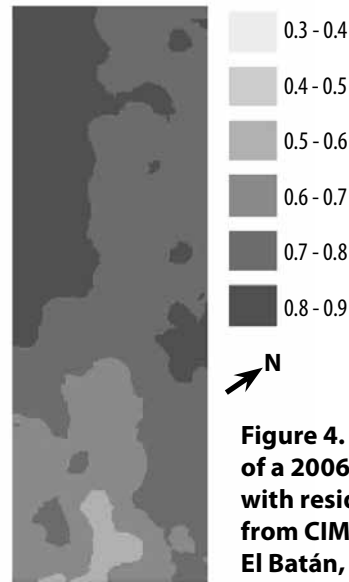
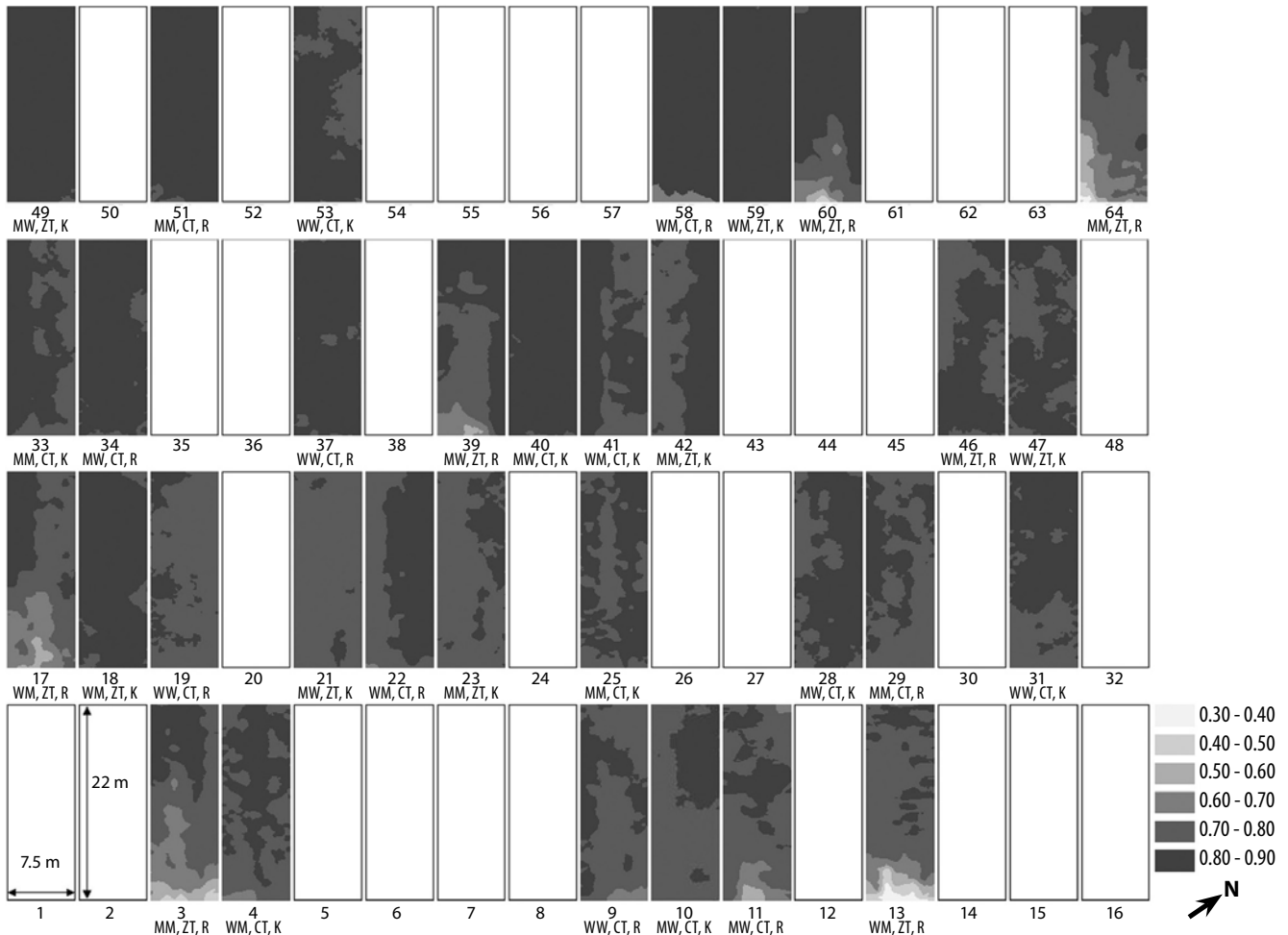


Figure 4. Example of an NDVI-map of a 2006 zero-tillage maize plot with residue removal treatment from CIMMYT's long-term trial in El Batán, Mexico.



W=wheat, M=maize. Crop sequence: WW=monoculture of wheat, MM=monoculture of maize, WM or MW=yearly rotation of maize and wheat. Tillage system: ZT=zero-tillage, CT=conventional tillage. Residue management: R=all residues removed from the field, K= all residues kept on the field.

Figure 5. Maps of plant performance (NDVI values) for CIMMYT's long-term sustainability trial at El Batán, Mexico, 2006. (Plots marked in white were not measured).

E. Problems and solutions

The GreenSeeker™ does not log data

First check if the cable between the control box (with the battery) and the PDA is properly connected and not broken. Sometimes during flowering you need to remove pollen from the connection points. If the cable is fine, try resetting the PDA.

PDA errors

To deal with error messages (e.g. 'gate not available'), try resetting the PDA by pushing a pencil into the small hole at the bottom of it. You can also try this when the PDA 'hangs,' or the GreenSeeker™ is not logging data (even though the cables are properly connected).

Not all counts are recorded

When you see in the general file that the GreenSeeker™ is not recording all counts there is probably a problem with the cable.

for example:

GreenSeeker™ Time(ms),	Sample,	Count,	NDVI,	Red/NIR
[...]				
1524560,	2,	74,	0.5821,	0.2642
1524670,	2,	75,	0.5913,	0.2568H01524780
1524890,	2,	77,	0.6162,	0.2375
1525000,	2,	78,	0.5365,	0.3016

or a more extreme example:

1564320,	4,	13,	0.2847,	0.5568
1566300,	4,	31,	0.6309,	0.2263
1567290,	4,	40,	0.5799,	0.
1567840,	4,	45,	0.5533,	0.2876
1568940,	4,	55,	0.6717,	0.1964

The battery does not charge

When the battery charger light does not come on, the GreenSeeker™ battery is not charging. This can be because one of the fuses is broken. Open the control box and replace the fuse. The newer GreenSeekers™ contain two spare fuses, indicated as 'spare' on the green board. Pull out the broken fuse and replace it with one of the spares.

**For more advanced problems,
contact Ntech Industries:**

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NTech Industries, Inc.
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