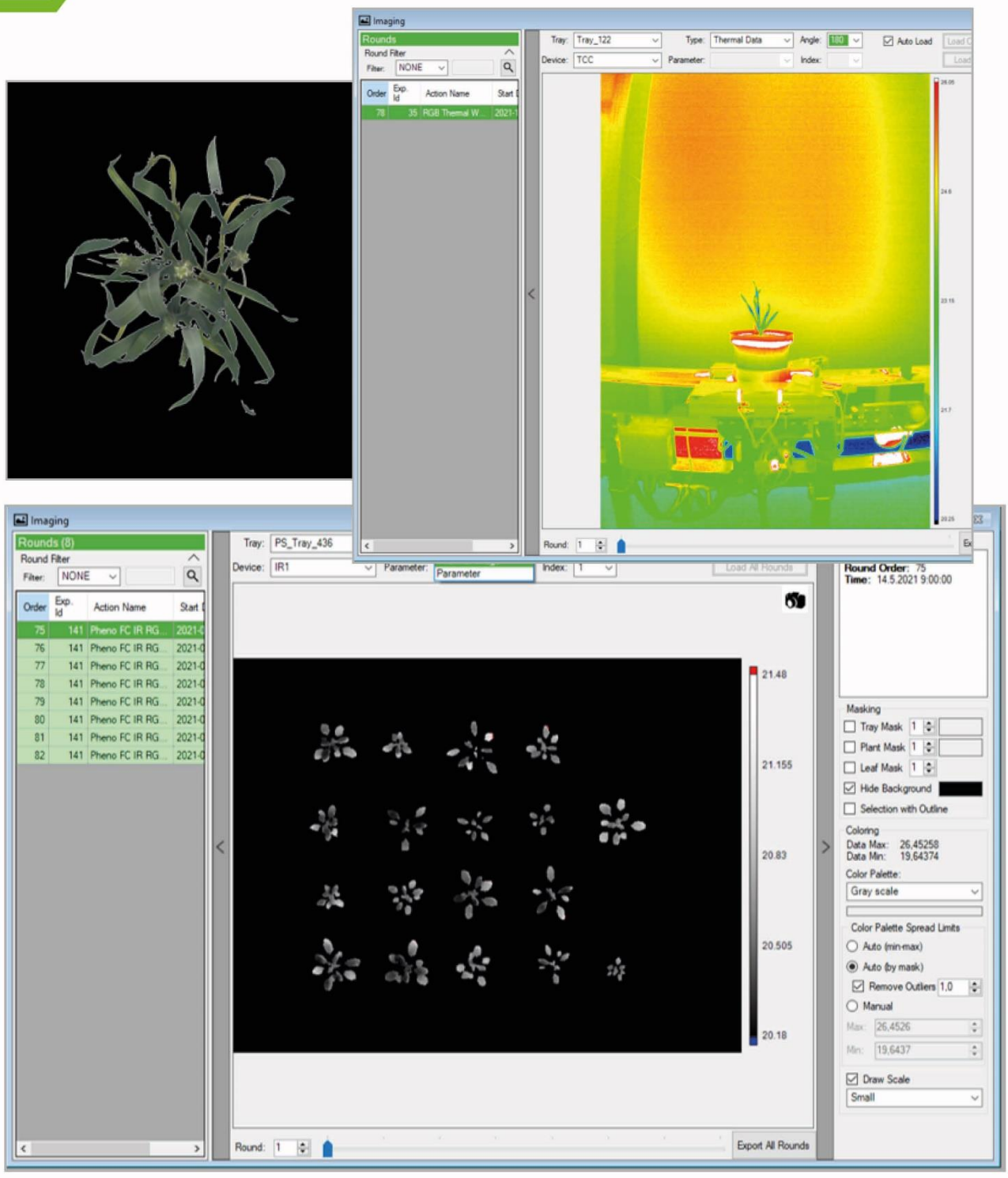
Instruction Guide

PHOTON SYSTEMS INSTRUMENTS

PlantScreen™ Data Analyzer

Please read the Guide before operating this product



Manual Version: 2024/03

www.psi.cz

TABLE OF CONTENTS

1 SAFETY

	Read this manual carefully before operating the device. If you are not sure about anything in the manual, contact the manufacturer for clarification. By accepting the device, the customer agrees to follow the instructions in this guide. Always follow corresponding manuals while working with the PlantScreen system or doing the maintenance. It is forbidden to interfere with the hardware or software of the PlantScreen system in any way without previous agreement with the manufacturer. It is forbidden to perform any installation or re-installation of the software without PSI permission.

	Copying or other interference in the device software without PSI permission is forbidden. These activities can also lead to loss of warranty on the device and its accessories and/or may also cause damage to health and property.

The following table presents basic highlight symbols used in this manual:

Symbol	Normal Style - Description
	Normal Style - Important information, read carefully.
	Normal Style - Complementary and additional information.

Tab. 1 Used symbols

2 PLANTSCREEN DATA ANALYZER

This section of the manual contains description of the PlantScreen Data Analyzer application. This manual describes PlantScreen Data Analyzer version 3.2.0.25.

2.1 INTRODUCTION

PlantScreen Data Analyzer application enables visualization of image and analyzed datameasured by the PlantScreen system. It supports FluorCam, RGB, IR and hyperspectral sensors and also weight and height measurement stations and ambient sensors.
Sensor raw data are displayed as images and various mask overlay can be selected. Analyzeddata are plotted into the time series in charts and basic statistical functions are available. Raw data, analyzed data and all the visualized images and charts can be exported. Application supports export to text files or directly to the Excel spreadsheets.

2.2 PERMISSIONS

PlantScreen Data Analyzer application uses PlantScreen system accounts. Accounts can be created, modified or deleted from the PlantScreen Scheduler software, please refer to its manual for further details.

2.3 LOG IN

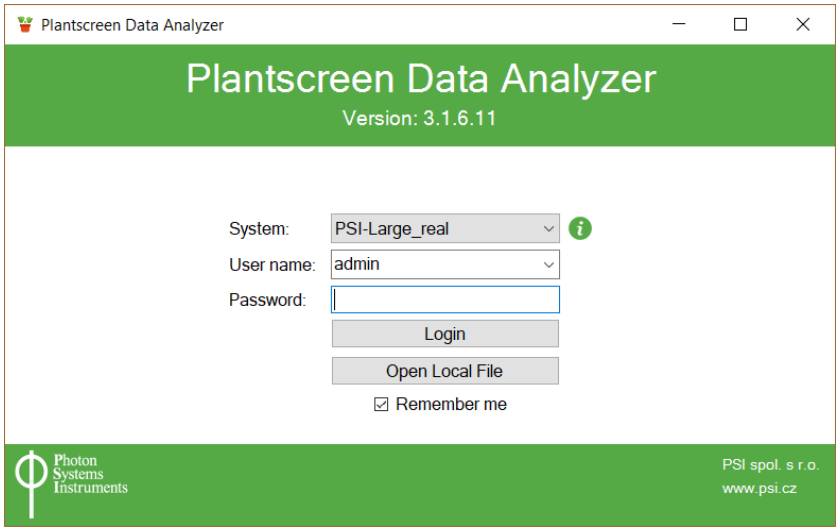


Fig. 1 Log In Screen

Log In screen is displayed in Fig. 1 contains controls for database selection and user authentication. Data from the measurement systems are stored in a database, typically one database per measurement device. *System* combo box allows choosing database, which is used as data source. If only one database is available, it is automatically preselected. System combo box may also contain connections to databases from different systems (Fig. 2). Green icon next to the combo box shows connection information.

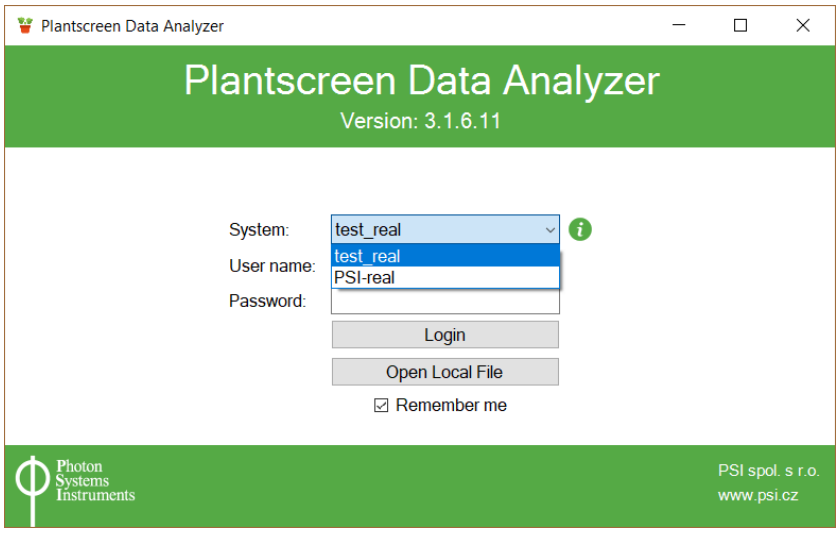


Fig. 2 More System Connections

User and *Password* field are used for user credentials. Credentials can be saved by *Remember me* checkbox, in that case, they are automatically prefilled during the next application startup.
Open Local File button is used for opening archive zip files created in local analysis, more in chapter 2.11 Local Analysis or zip files created in 2.9 Selection Place.

	When setting up the passwords, we recommend following the general rules: The ideal length is at least six characters. It is recommended that the password contains both uppercase and lowercase letters, numbers, punctuation and symbols (e.g. #, %,!). It is also recommended to keep the password in a safe place and do not share it with anyone.

2.4 Main Menu

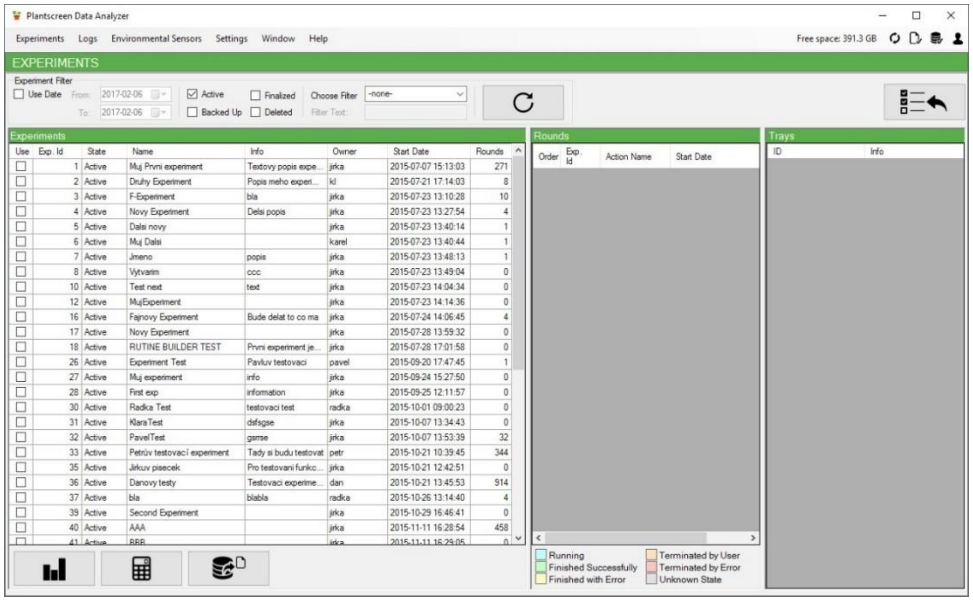


Fig. 3 Main Screen

After successful login, main screen is displayed (Fig. 3). Top part of the window containsmenu bar. Menu items for the application control are on the left side of the menu bar, statusicons are on the right.

Application control menu contains following items:

1. *Experiments* – opens experiment selection window, more in chapter 2.7 Experiments
2. *Settings* – opens application settings window, more in chapter 2.13 Settings
3. *Window* – displays currently opened windows
4. *Logs* – opens window with application log, more in chapter 2.14 Logs
5. *Environmental Sensors* – opens window with ambient sensors data, more in chapter 2.15 Environmental Sensors
6. *Help* – opens window with application information, more in chapter 2.16 HelpStatus icons on the right side of the menu bar are displayed in the Fig. 4

Fig. 4 Status Icons

File storage connection icon (Fig. 4-1) and database connection icon (Fig. 4-2) show status of the connection to the file storage service/database. If the background is white, connection isok, if it is red, service is not available.
Clicking on the user info icon (Fig. 4-3) shows simple menu with *About* and *Logout* items. *About* item shows info about the currently logged in user, *Logout* item logs the user out and shows *Log In* screen (Fig. 1).
Warning icon (Fig. 4-4) shows system warnings, details about the warning are displayed on mouse over. It is hidden when there are no warnings.
Label (Fig. 4-5) show file storage free space.

2.5 UPDATE

If new version of the PlantScreen Data Analyzer is available, *Update Available* button (Fig. 5) is displayed next to the status icons on the menu bar.

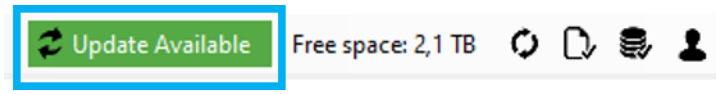


Fig. 5 Update button

After the button is clicked, Update window (Fig. 6) is shown. It displays information about new version of the application, new functionality is highlighted in green, bug fixes in blue. *Update* button starts the update process, *Cancel* button closes the window and if update is in progress, it is stopped.

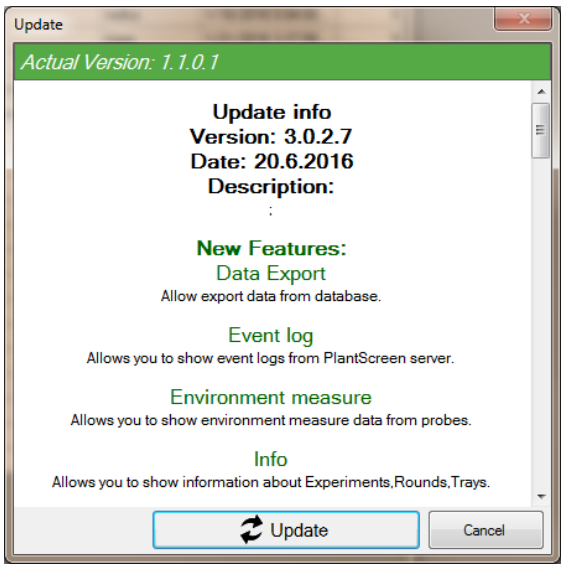


Fig. 6 Update Window

	Update function downloads content from the PSI website, it is available only if the PC is connected to the internet and webpage www.psi.cz is reachable.

2.6 Common Table Controls

Basic selection control elements are used on multiple places across the application. If the table contains selectable items, right click displays context menu (Fig. 7), which among other options contains items to select/deselect all items and to show brief information about the current item
Select all/deselect all functions are also available as key shortcuts, under CTRL+A/CTRL+D combinations. Mouse cursor needs to be placed over the corresponding table in order to recognize the shortcuts.

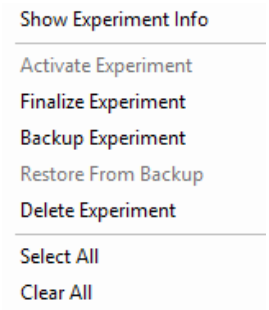


Fig. 7 Table Context Menu

2.7 Experiments

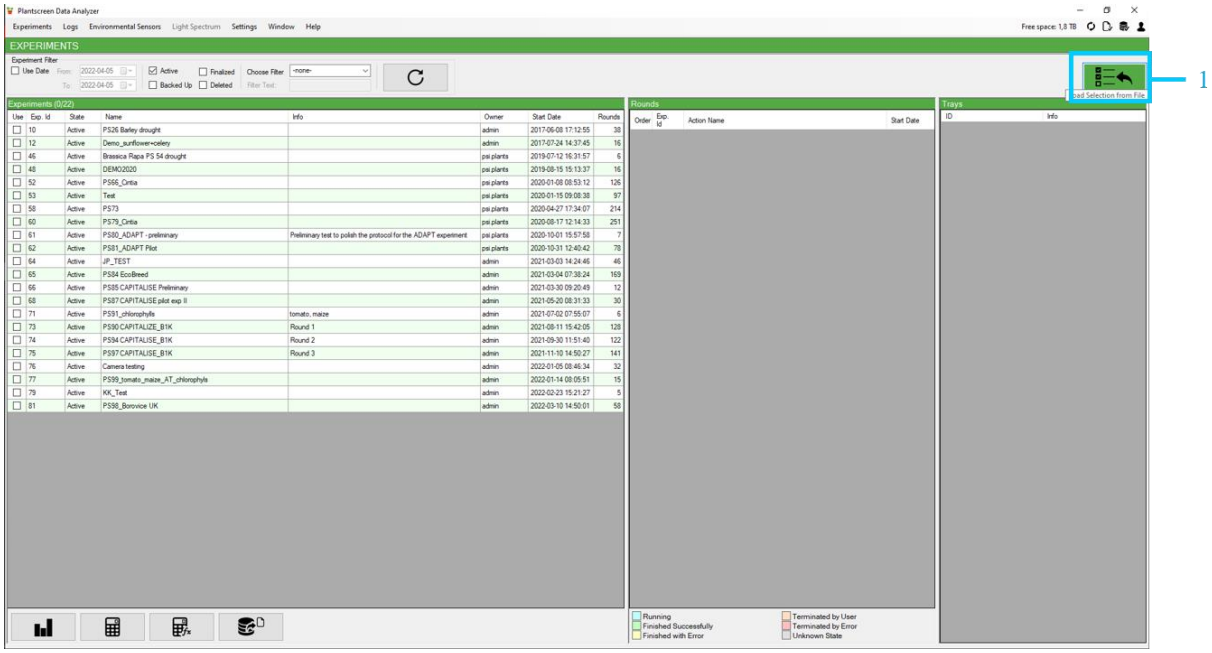


Fig. 8 Experiments Window

In the experiment window (Fig. 8), data selection for further processing is made. Top part of the window contains filter bar with controls for data filtering (Fig. 9) and buttons for further data processing, described in the chapter 2.7.5 Selection processing buttons. Experiment (Fig. 10), round (Fig. 13, chapter 2.7.3 Round Table) and tray (Fig. 18, chapter 2.7.4 TrayTable) tables are in the bottom part of the window.

2.7.1 EXPERIMENT FILTER BAR

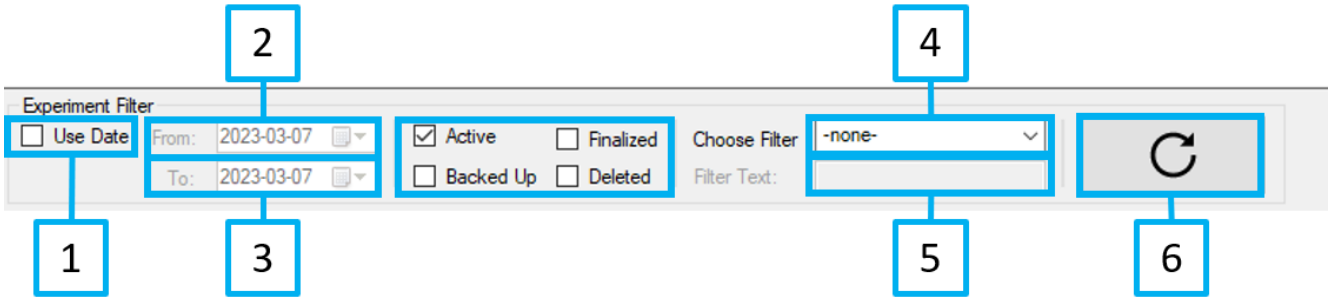


Fig. 9 Experiment Filter Bar

Experiment filter bar (Fig. 9) allows experiment filtering based on date and/or text value in one of the experiment fields. After the filter selection and setup is made, *Load experiments from DB* button connects to the database and displays matching experiments in the experiment table (Fig. 10).

Use Date checkbox (Fig. 9-1) enables date based filtering. When checked, *From* (Fig. 9-2) and *To* (Fig. 9-3) date selects are enabled. Experiment passes this filter if both *From* and *To* conditions are valid.

From field defines the earliest start of the experiment round. Condition is valid if any roundof an experiment started after or at this date.

To field defines the latest start of the experiment round. Condition is valid if any round of an experiment started before or at this date.

Experiment state filtering is in section (Fig. 9-4). By default, only *Active* experiments pass thefilter.

Choose Filter selection (Fig. 9-5) enables text based filtering. Drop down list contains columnsnames in the experiments table (Fig. 10). If value *NONE* is selected, filter is disabled.

Value of the *Filtered text* field is matched against the values in the selected column and ifvalue contains the searched text, experiment passes the filter.

	If some filters are used (Use Date checkbox is checked, column name is selected or state filter is checked), experiment needs to pass all filters to be displayed.

2.7.2 EXPERIMENT TABLE

Experiments

Use	Exp. Id	State	Name	Info	Owner	Start Date	Rounds
☐	1	Active	Muj Prvni experiment	Textovy popis expe...	jirka	2015-07-07 15:13:03	271
☐	2	Active	Druhy Experiment	Popis meho experi...	kl	2015-07-21 17:14:03	8
☐	3	Active	F-Experiment	bla	jirka	2015-07-23 13:10:28	10
☐	4	Active	Novy Experiment	Delsi popis	jirka	2015-07-23 13:27:54	4
☐	5	Active	Dalsi novy		jirka	2015-07-23 13:40:14	1
☐	6	Active	Muj Dalsi		karel	2015-07-23 13:40:44	1
☐	7	Active	Jmeno	popis	jirka	2015-07-23 13:48:13	1
☐	8	Active	Vytvarim	ccc	jirka	2015-07-23 13:49:04	0
☐	10	Active	Test next	text	jirka	2015-07-23 14:04:34	0
☐	12	Active	MujExperiment		jirka	2015-07-23 14:14:36	0
☐	16	Active	Fajnovy Experiment	Bude delat to co ma	jirka	2015-07-24 14:06:45	4
☐	17	Active	Novy Experiment		jirka	2015-07-28 13:59:32	0
☐	18	Active	RUTINE BUILDER TEST	Prvni experiment je...	jirka	2015-07-28 17:01:58	0
☐	26	Active	Experiment Test	Pavluv testovaci	pavel	2015-09-20 17:47:45	1
☐	27	Active	Muj experiment	info	jirka	2015-09-24 15:27:50	0
☐	28	Active	First exp	information	jirka	2015-09-25 12:11:57	0
☐	30	Active	Radka Test	testovaci test	radka	2015-10-01 09:00:23	0
☐	31	Active	KlaraTest	dsfsgse	jirka	2015-10-07 13:34:43	0
☐	32	Active	PavelTest	gsrse	jirka	2015-10-07 13:53:39	32
☐	33	Active	Petrův testovací experiment	Tady si budu testovat	petr	2015-10-21 10:39:45	344
☐	35	Active	Jirkuv pisecek	Pro testovani funkc...	jirka	2015-10-21 12:42:51	0
☐	36	Active	Danovy testy	Testovaci experime...	dan	2015-10-21 13:45:53	914
☐	37	Active	bla	blabla	radka	2015-10-26 13:14:40	4
☐	39	Active	Second Experiment		jirka	2015-10-29 16:46:41	0
☐	40	Active	AAA		jirka	2015-11-11 16:28:54	458
☐	41	Active	BBB		jirka	2015-11-11 16:29:05	0

Fig. 10 Experiment Table

Experiment table displays all experiments selected by the filtering. Experiment is selected/deselected by left mouse button click. Right click displays common context menu described in the chapter 2.6 Common Table Controls**.**

Permission

Experiments

Use	Exp. Id	State	Name	Info	Owner	Start Date	Rounds
☐	1	Active	Muj Prvni experiment	Textovy popis expe...	jirka	2015-07-07 15:13:03	271
☐	2	Active	Druhy Experiment	Popis meho experi...	kl	2015-07-21 17:14:03	8
☐	3	Active	F-Experiment	bla	jirka	2015-07-23 13:10:28	10
☐	4	Active	Novy Experiment	Delsi popis	jirka	2015-07-23 13:27:54	4
☐	5	Active	Dalsi novy		jirka	2015-07-23 13:40:14	1
☐	6	Active	Muj Dalsi		karel	2015-07-23 13:40:44	1
☐	7	Active	Jmeno	popis	jirka	2015-07-23 13:48:13	1
☐	8	Active	Vytvarim	ccc	jirka	2015-07-23 13:49:04	0
☐	10	Active	Test next	text	jirka	2015-07-23 14:04:34	0
☐	12	Active	MujExperiment		jirka	2015-07-23 14:14:36	0
☐	16	Active	Fajnovy Experiment	Bude delat to co ma	jirka	2015-07-24 14:06:45	4
☐	17	Active	Novy Experiment		jirka	2015-07-28 13:59:32	0
☐	18	Active	RUTINE BUILDER TEST	Prvni experiment je...	jirka	2015-07-28 17:01:58	0
☐	26	Active	Experiment Test	Pavluv testovaci	pavel	2015-09-20 17:47:45	1
☐	27	Active	Muj experiment	info	jirka	2015-09-24 15:27:50	0
☐	28	Active	First exp	information	jirka	2015-09-25 12:11:57	0
☐	30	Active	Radka Test	testovaci test	radka	2015-10-01 09:00:23	0
☐	31	Active	KlaraTest	dsfsgse	jirka	2015-10-07 13:34:43	0
☐	32	Active	PavelTest	gsrrse	jirka	2015-10-07 13:53:39	32
☐	33	Active	Petrův testovací experiment	Tady si budu testovat	petr	2015-10-21 10:39:45	344
☐	35	Active	Jirkuv pisecek	Pro testovani funkc...	jirka	2015-10-21 12:42:51	0
☐	36	Active	Danovy testy	Testovaci experime...	dan	2015-10-21 13:45:53	914
☐	37	Active	bla	blabla	radka	2015-10-26 13:14:40	4
☐	39	Active	Second Experiment		jirka	2015-10-29 16:46:41	0
☐	40	Active	AAA		jirka	2015-11-11 16:28:54	458
☐	41	Active	BBB		jirka	2015-11-11 16:29:05	0

Fig. 11 Owner Column

Experiment is accessible only to the owner of the experiment and to the users who havegranted *Access Other Users Experiments* right.

	User rights management is accessible in the PlantScreen Scheduler application for the accounts with the Administrator permissions.

2.7.2.1 Experiment Information

Show Experiment Info item from the experiment table context menu opens new window with the details about the selected experiment (Fig. 12). It contains basic experiment information (Fig. 12-1), round table (Fig. 12-2), experiments notes (Fig. 12)-3) and log (Fig. 12)- 4). Round table is further described in the chapter 2.7.3 Round Table, log in the chapter 2.13 Logs. Log section shows only log entries related to the selected experiments and only basic filtering options.

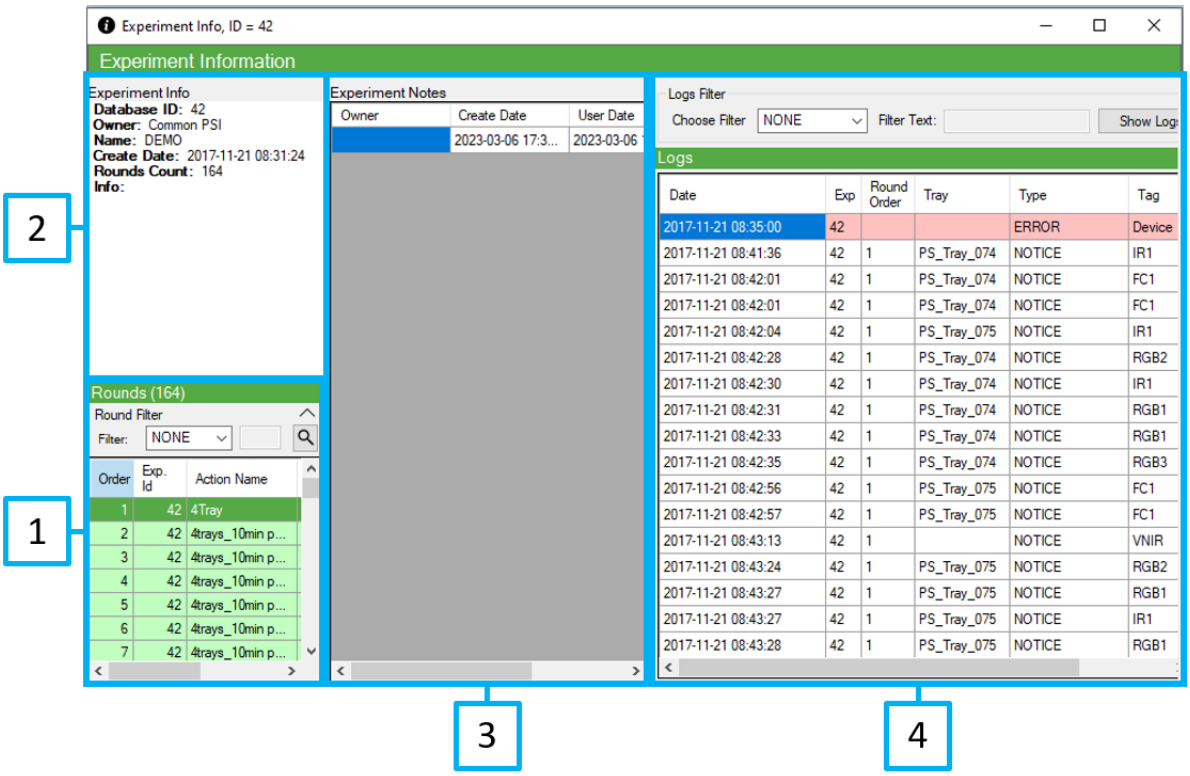


Fig. 12 Experiment Information

2.7.3 ROUND TABLE

Round table displays information about rounds for selected experiment. Column *Order*contains round order in the experiment, *Exp. Id* identification of the experiment and *Start Date* start time of the first action of the round.
Table can be display-only, or selectable. Display only version just shows the round information, selectable version enables round selection via row checkboxes or context menu.

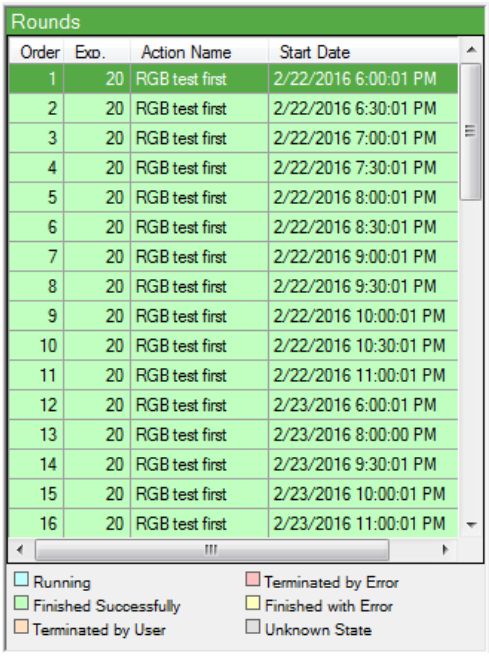


Fig. 13 Round Table

Background color of the table row (or color in the status column, if table is selectable) indicates the round status. If the legend is enabled, it is displayed in the bottom part of the window. Color can be one of the following:

1. Running – round is in progress
2. Finished Successfully – round was finished without any errors
3. Terminated by User – round was terminated by user
4. Terminated by Error – round was terminated by error
5. Finished with Error – round was finished, but one or more errors occurred
6. Unknown State – round state was unknown

Right mouse button displays context menu described in the chapter 2.6 Common Table Controls**.** *Show Info* item opens window with details about the selected round 2.7.3.1 Round Information.

	Legend can be hidden/shown from the application settings or from context menu displayed by the right mouse button click. Settings menu is described in the chapter 2.13 Settings.

2.7.3.1 Round Information

Round information window shows details about selected round. It contains round information (Fig. 14-1), list of trays used in the round (Fig. 14-2) and log (Fig. 14-3). Tray tableis described further in the chapter 2.7.4 Tray Table, log in the chapter 2.14 Logs. Log section shows only log entries related to the selected round and only basic filtering options.
Log section may be switched by corresponding tab (Fig. 14-4) to protocol section, which contains tabs (Fig. 15-1, Fig. 17-1) with Visual (Fig. 15) and Text (Fig. 17) representation of the round protocol.

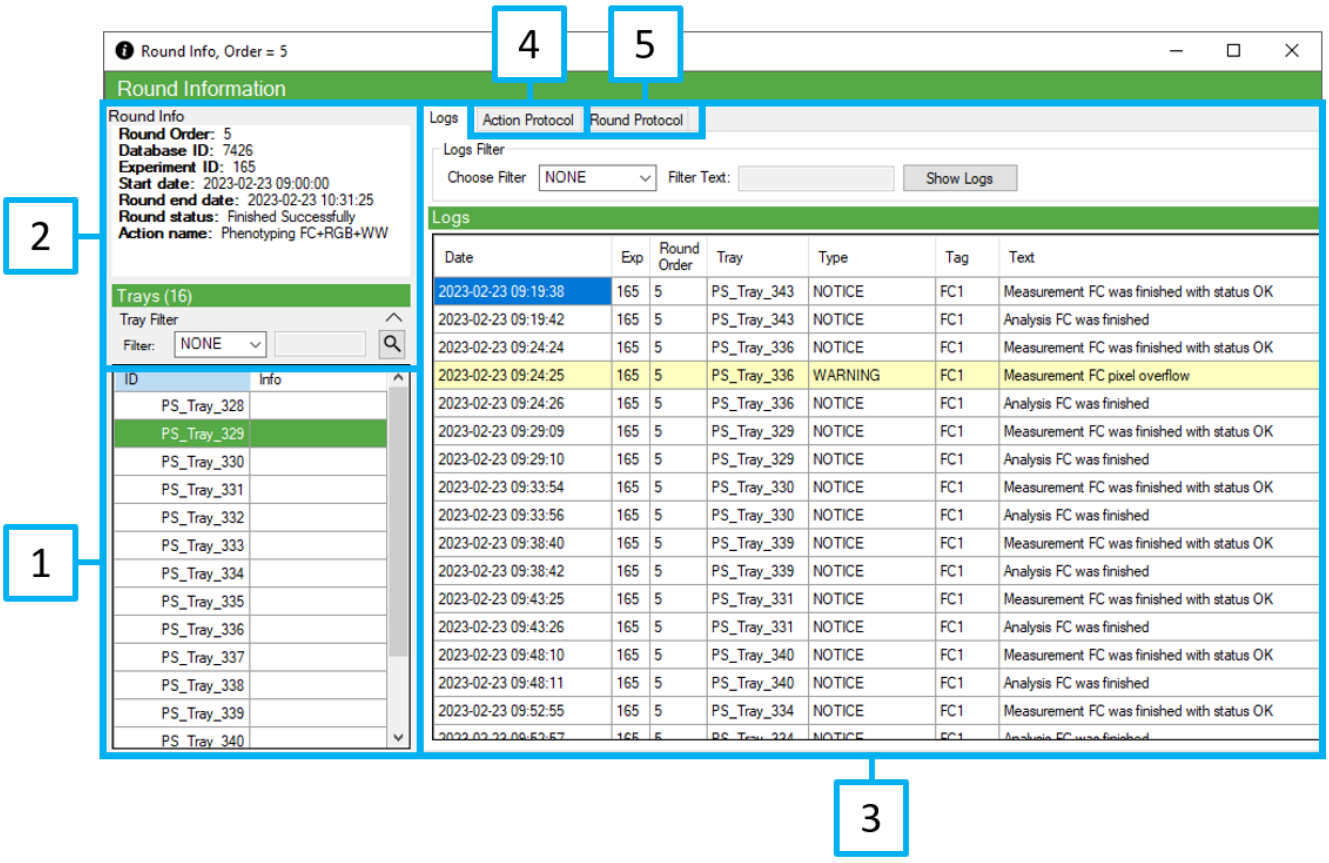


Fig. 14 Round Information

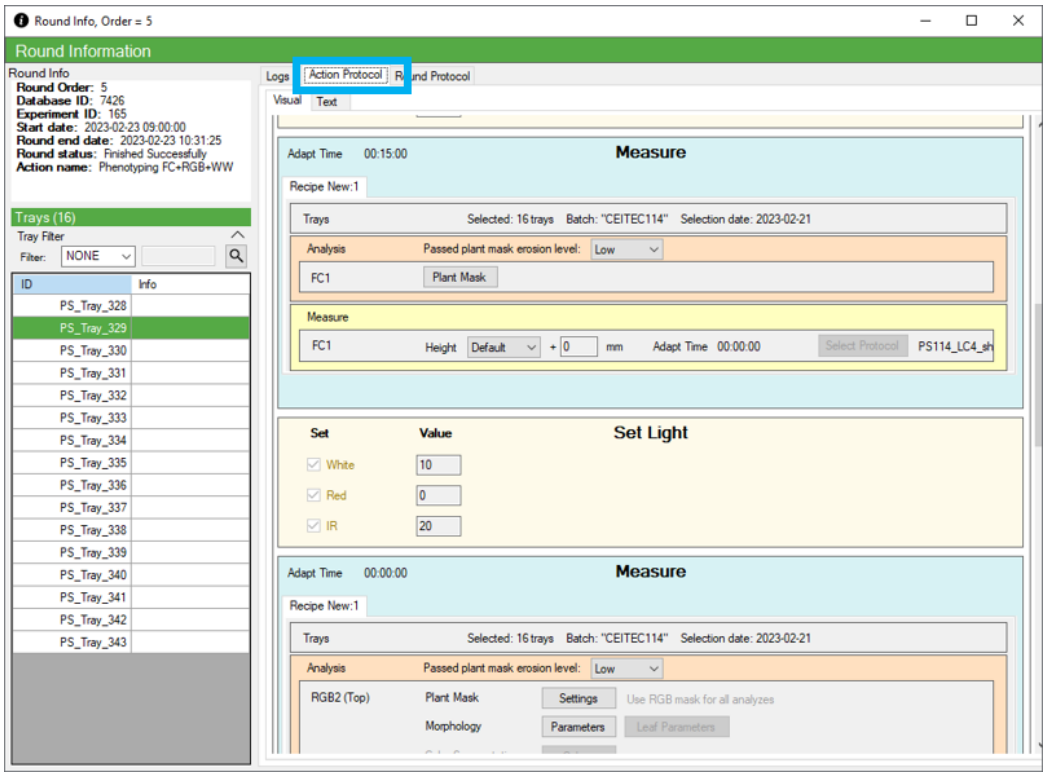


Fig. 15 Action Protocol - Visual View

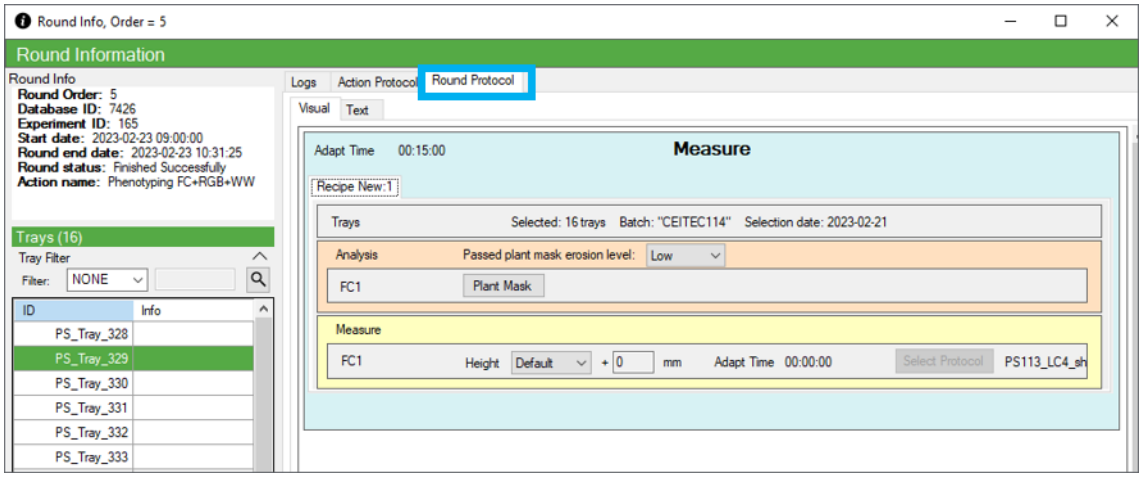


Fig. 16 Round Protocol – Visual view

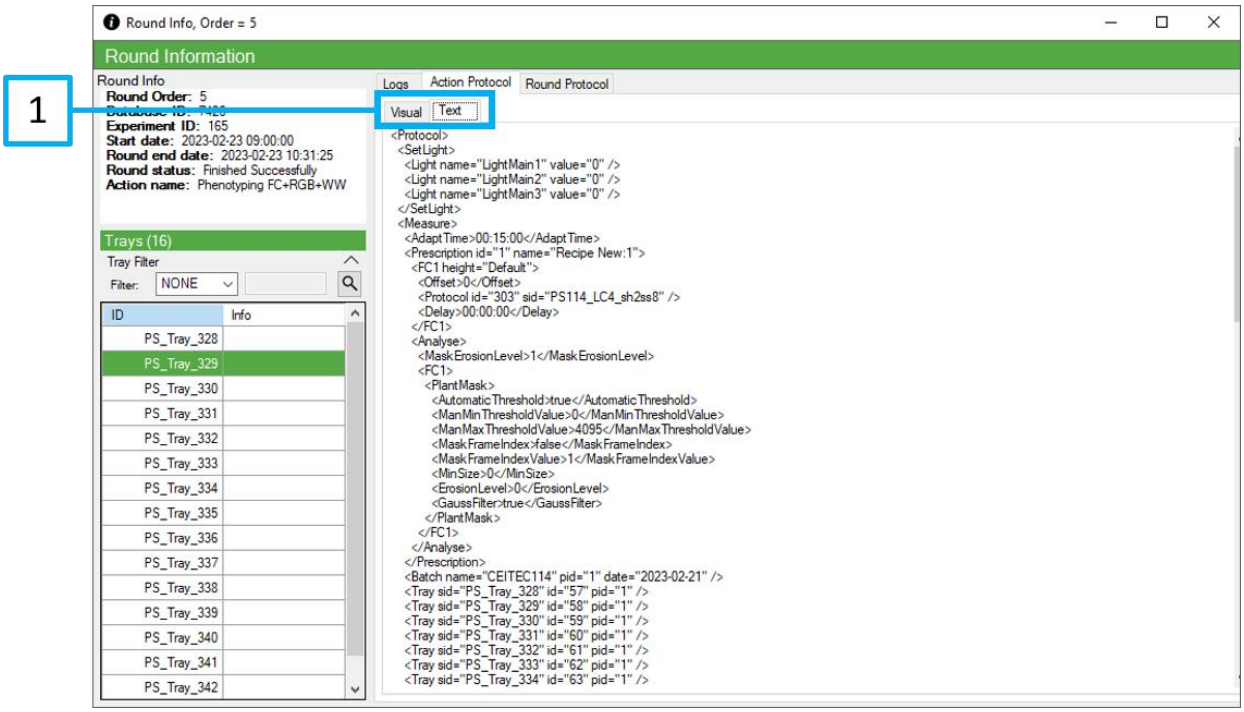


Fig. 17 Action Protocol - Text View

2.7.4 TRAY TABLE

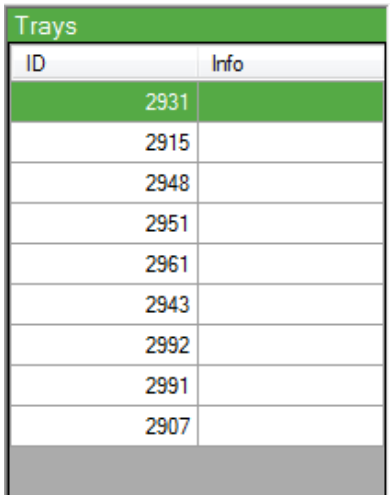


Fig. 18 Tray Table

Tray table shows trays used in the selected rounds. It can be display-only, or selectable. Display only version just shows the tray information, selectable version enables tray selection via row checkboxes or context menu.
Right mouse button displays context menu described in the chapter 2.6 Common Table Controls**.** *Show Info* item opens window with details about the selected round 2.7.4.1 Tray Information**.**

2.7.4.1 TRAY INFORMATION

Tray information window (Fig. 19) shows details about the selected tray.
History only for selected rounds (Fig. 19-1) filters plant to tray assignment. If checked, only assignments valid in the selected rounds are shown. Otherwise, all assignment history for selected tray is displayed. Plant to tray assignment topic is covered in the PlantScreen Scheduler manual.
Each row of the plant assignment table (Fig. 19-2) displays one assignment of the plant totray positions and the date when it was created. When any plant cell is selected, tray top/side view mask from the selected assignment is displayed in the *Mask Top View* window (Fig. 19-3) *Mask Side View* window (Fig. 19-4), information about the plant assigned to the selected position is shown

in the *Plant Info* text area (Fig. 19-5) and mapping of the tray position to the scales position is shown in the *Scales Mapping* text area (Fig. 19-6).

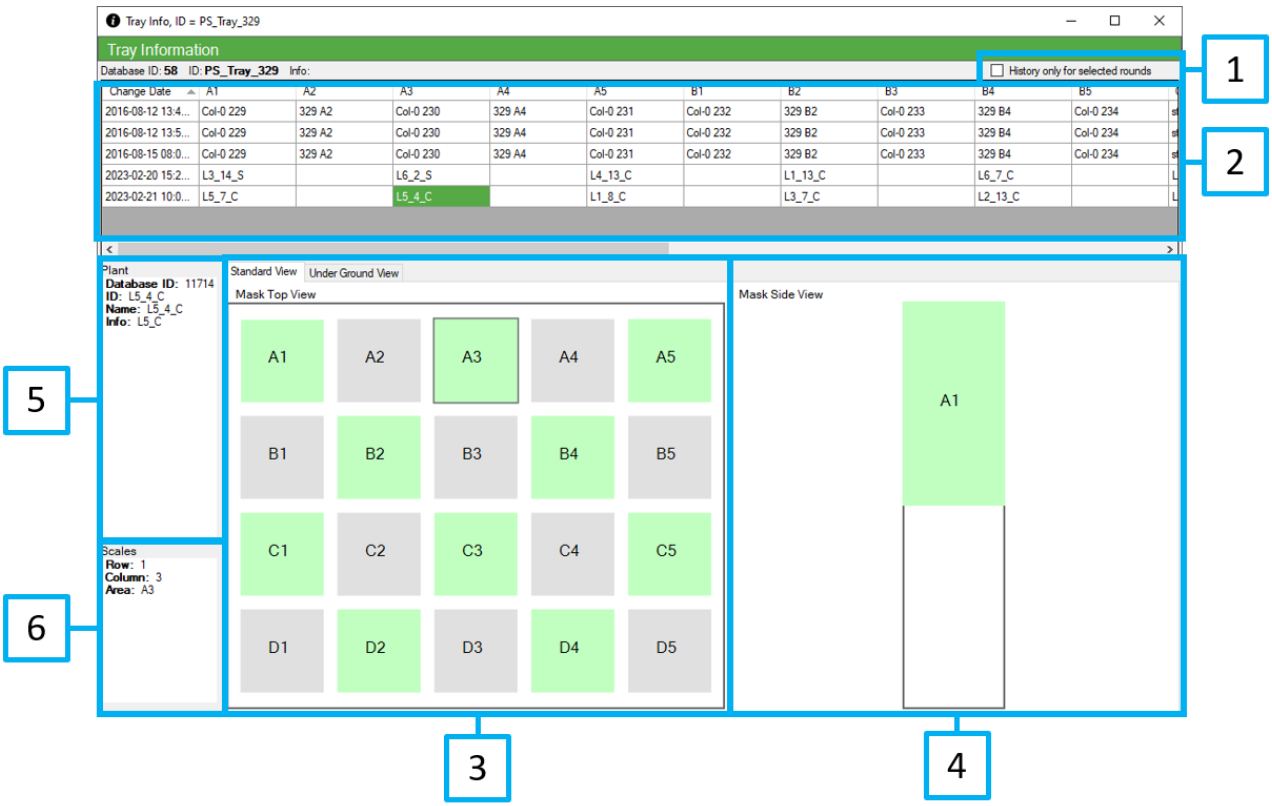


Fig. 19 Tray Information

2.7.5 SELECTION PROCESSING BUTTONS

Fig. 20 Continue with selection

Fig. 21 Load Selection,

Continue with Selection and *Load selection* buttons open *Selection place* window. *Continue with selection* passes currently selected experiments as source data, *Load selection* opens file dialog, where the previously saved selection file can be chosen. *Selection place window* isdescribed in the chapter 2.9 Selection Place.

Fig. 22 Local Analysis

Local Analysis button opens local analysis window, described in the chapter 2.11 LocalAnalysis. Source data for the local analysis are currently selected experiments.

Fig. 23 Export

Export button opens export window, described in the chapter 2.8 Export**.** Source data for the export are currently selected experiments.

2.7.6 Experiment State

Every experiment stored in database is in one of the following states: *Active*, *Finalized*, *Backed up* and *Deleted*. Experiment state can be changed by context menu (Fig. 24). Only owner of experiment or user with permissions to modify others experiments can change experiment state.

- Active – default state of new experiment. Only experiment in this state can be used for measurement. If an active experiment has no scheduled actions, it can be finalized, backed up or deleted.
- Finalized - Experiment in finalized state is closed for further measurement addition, but all stored data are available. Finalized experiment can be set back to active state, backed up or deleted.
- Backed up - Data of the experiment were transferred out of database so they are not available at the moment. Experiment can be restored using backed up data or it can be permanently deleted.
- Deleted - Data of the experiment were permanently deleted with no option to restore it. Only metadata like name, owner, dates of measurements etc. remain in database.

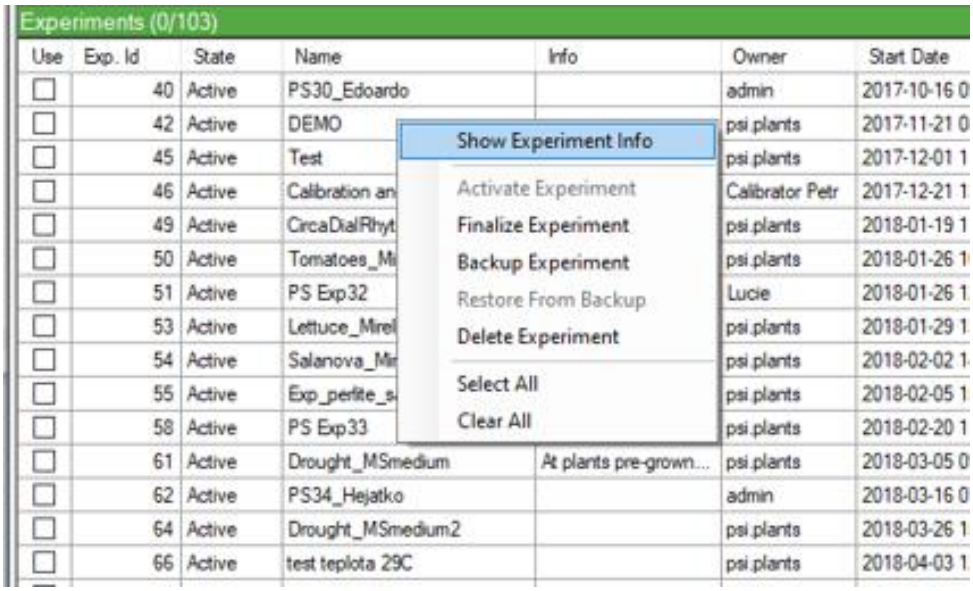


Fig. 24 Experiment context menu

2.7.6.1 Experiment Backup / Delete

Stable operation of the system database requires enough disk space for new data (free space is shown in right upper corner of application Fig. 4-5). If the disk space is low, one of the options is to delete or backup older experiments. Both options are available in the context menu of the selected experiment.

	Experiments can be removed via option *Delete Experiment*. This action is irreversible, data of the experiment are deleted permanently. Progress of this action is shown in dialog window (Fig. 25).

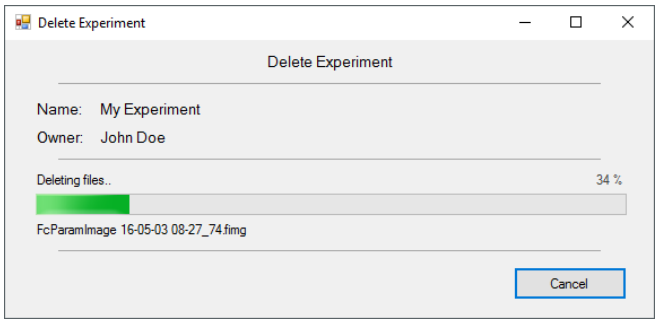


Fig. 25 Delete experiment

Option Backup experiment moves data of the selected experiment to local disk or another available storage. It releases space like deleting of an experiment, but allows restoring data back to the database in the future.

Option Copy experiment allows to save data of the selected experiment to local disk or another available storage. The data is not deleted from the database as in the case of backup option.

	We recommend that the user perform this step before backing up to avoid unwanted data loss in case an error occurs during the backup process. Created backup file can then be used in the future to restore an experimental data.

Window is shown after selection of the *Backup / Copy Experiment* option. Backup directory isselected by the *Save to* (Fig. 26-1).

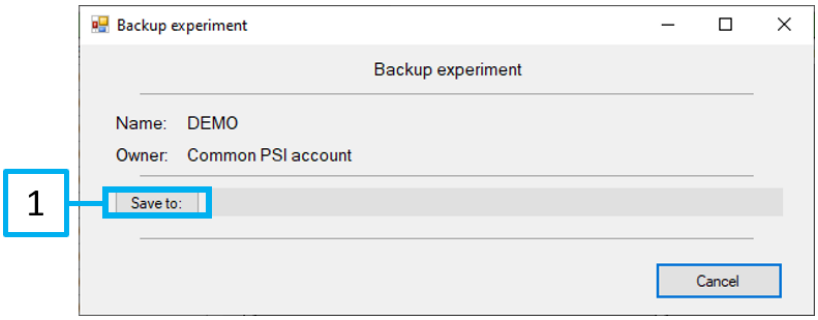


Fig. 26 Backup experiment

Backup process automatically starts after the target directory is selected (Fig. 27).Successfully created backup is confirmed by a message.

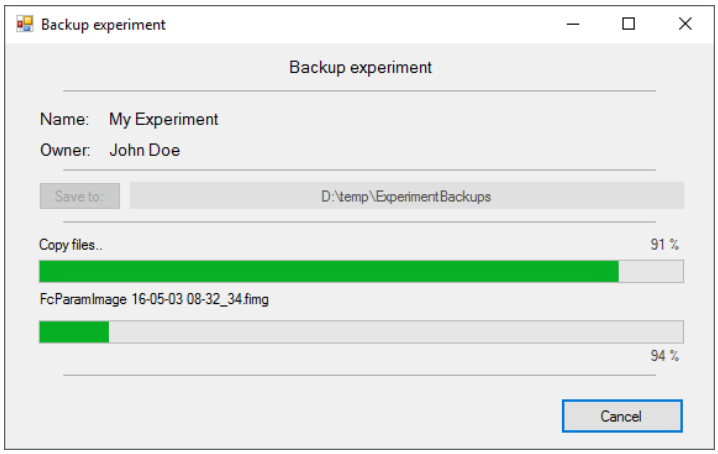


Fig. 27 Backup experiment in progress

2.7.6.2 Experiment Restore

Restoring of backed up experiment is available by the *Restore from Backup* option. Window (Fig. 28) is shown after selecting this option. Directory with backup/copied data is selected by the *Select backup* button (Fig. 28-1). Data validity check is processed before the *Restore* button comes available (Fig. 28-2). Clicking on it starts the restore action.

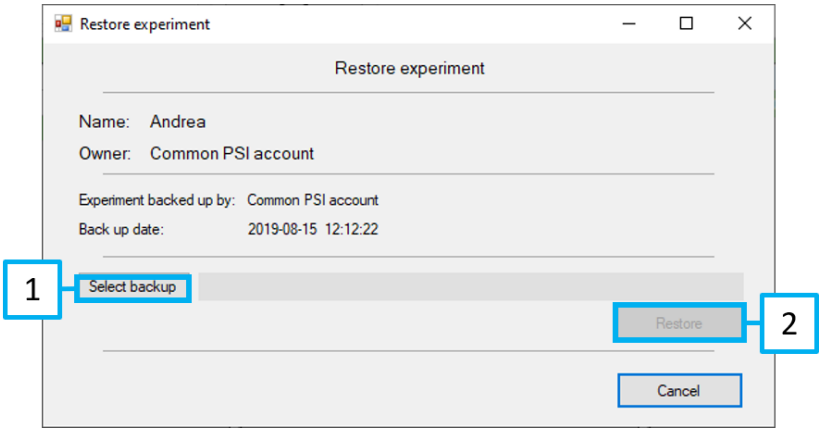


Fig. 28 Restore experiment

Progress is shown during operation in the dialog window (Fig. 29)

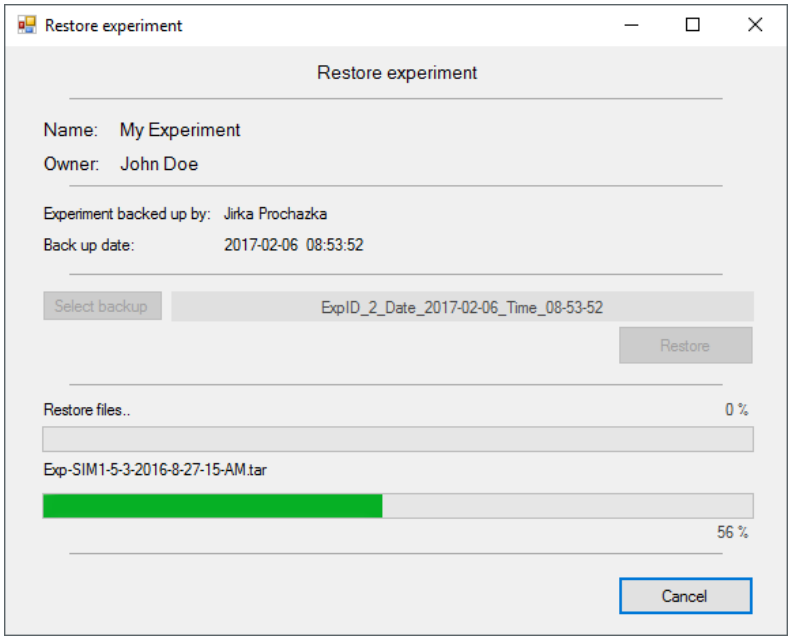


Fig. 29 Restore experiment in progress

2.8 EXPORT

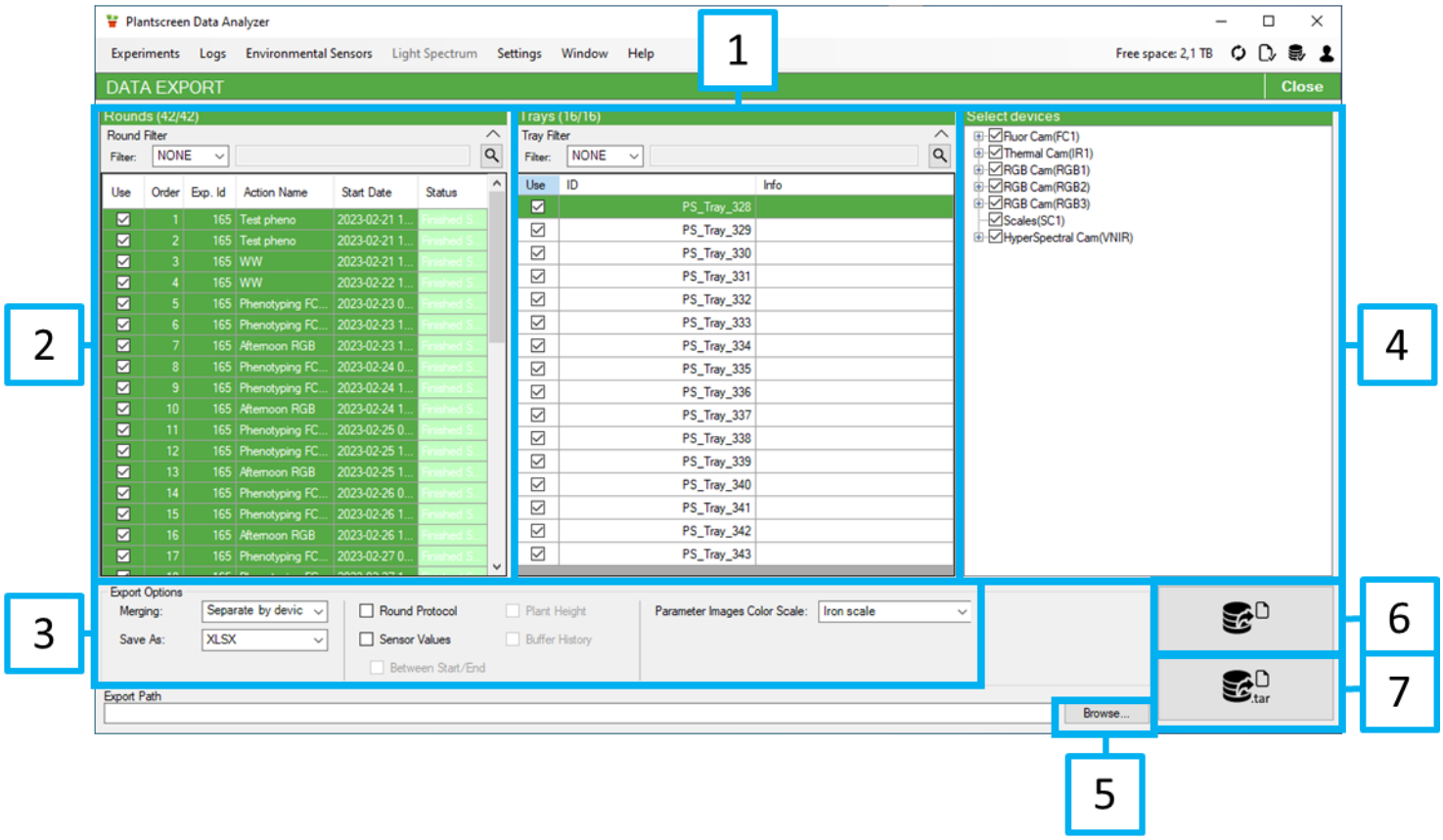


Fig. 30 Export Window

Export window enables export of the raw and analyzed data and measurement protocol from the selected experiments.
Round table (Fig. 30-2) and tray table (Fig. 30-1) enable data selection. All rounds and trays from the selected experiments are displayed; tables are closer described in the chapters 2.7.3 Round Table and 2.7.4 Tray Table.
Merging item in the Export Options (Fig. 30-3) defines how the exported data are organized. **Separate by devices** option exports data by measuring device (one file for each device), **Merge all** exports all data to one file. Both options do both types of export.
Save As item enables selection of exported file type. It can be either comma separated values format (.csv), or Excel spreadsheet (.xlsx). If .csv option is selected, *CSV Separator* defines what character is used as separator. It can be one of the following: semicolon, backslash, dot, tab, space, forward slash.
Export ***Round Protocol*** includes round protocols into the export, *Export* ***Sensor Values*** includes ambient sensors readouts. If *Between Start/End* checkbox is checked, then all sensor values between the first and the last selected round are exported, otherwise the closest (in terms of the measurement time) value is found and exported for each round.
Export Plant Height includes measured plants heights (if supported by the system). Height is stored if only one plant is registered to the tray.
Parameter Images Color Scale defines color scale, which is used when exporting parameters as images (FC, hyperspectral imaging) or for IR raw data export.
Buffer history option stores positions of all registered trays in the growing buffer before and after each measuring round (if supported by the system).
Select devices window contains tree view for data selection. It is closer described in the chapter 2.8.1 Data Selection Treeview**.**
Browse button shows dialog where the export path can be selected, *Export* button starts the export.

Export to files (Fig. 30-6)
The selected files are exported into individual folders and files. For each sensor, a separate folder is created. This folder contains a subfolder named "Analysis," which includes all analyzed data (files with calculated parameters), and a subfolder named "Measurement," which includes the raw data for that sensor.

Export to .tar (Fig. 30-7)

All selected files are archived into a single .tar file, which can be opened offline using the Plant Data Analyzer without needing a database connection. To open the generated .tar file, go to the Plant Data Analyzer login window, click **Open Local File**, and select the created .tar file. The data can then be repeatedly viewed, analyzed, and exported using the Plant Data Analyzer.

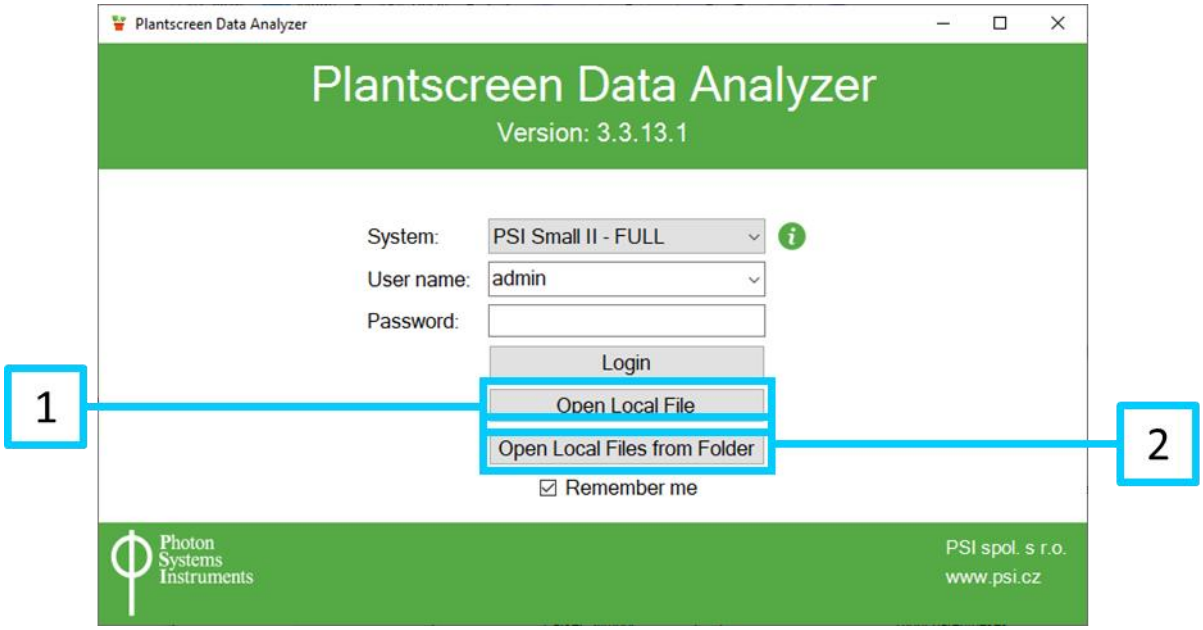


Fig. 31 Opening .tar

Multiple TAR files

Experiments can also be exported into multiple .tar files. These .tar files can be opened simultaneously using the **Open Local Files from Folder** button. The .tar files must be placed in the same folder, and for merging these .tar files, the condition is that the data must not overlap – individual .tar files should not contain the same measurement rounds.

2.8.1 Data Selection Treeview

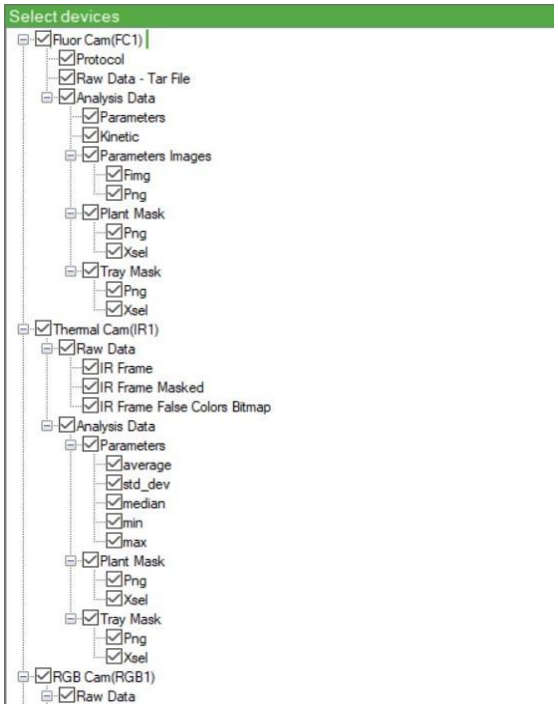


Fig. 32 Data Selection TreeView

Data selection treeview enabled detailed selection of the exported data. Top nodes correspond to the devices installed in the system, child nodes contain data available for export for given device.

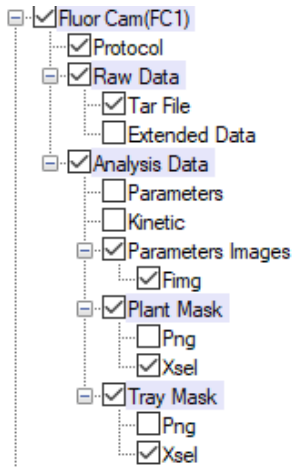


Fig. 33 Mixed Node State

State of the node can be selected/deselected, if the node and all child nodes in the tree hierarchy are selected/deselected. The state is mixed, when the selection state of at least one child node in the child nodes tree hierarchy is different from the other nodes. In that case, node is selected, but with background greyed out (Fig. 33).

2.8.1.1 TREEVIEW STRUCTURE

This chapter contains data selection tree view device nodes and child nodes description. Device node types are described. Depending on the system configuration, more devices of the same type can be installed in the system (RGB cameras, …). In that case, devices in the tree view structure are numbered.
If 2D, 3D or hyperspectral data are part of the export (parameter images, masks), it is possible to select export format by checking the corresponding checkbox. Structure of the data export formats is described in the
If data can be colored, but does not have native color scale (IR, hyperspectral parameters), color scale selected in the Parameter Images Color Scale (Fig. 30-3) is used.
Text data format is selected by the Save As (Fig. 30-3) selection.

FluorCam

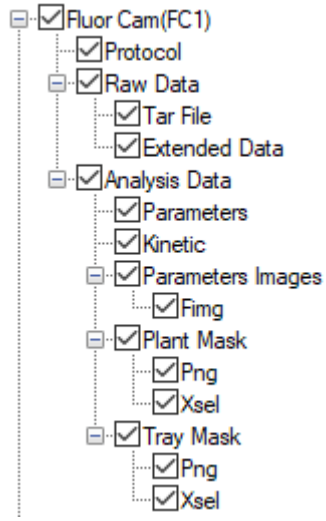


Fig. 34 FluorCam Export Tree

- Protocol – FluorCam measurement protocol
- Raw Data - Tar File – FluorCam data in the native tar format
- Analysis Data
  - *Parameters* – FluorCam parameters as text

- *Kinetic* – FluorCam kinetics
- *Parameters Images* – FluorCam parameters as images in raw – ".fimg" format
- *Plant Mask* – plant mask used for calculations
- *Tray Mask* – tray mask used for calculations

Thermal Cam

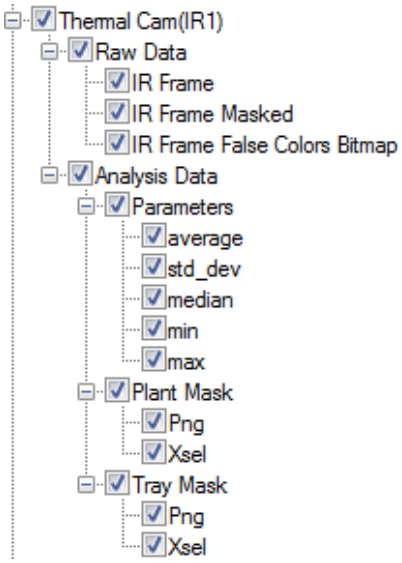


Fig. 35 Thermal Cam Export Tree

- Raw Data
  - *IR Frame* – raw IR data in the .raw format
  - *IR Frame Masked* – raw IR data converted to the color scale with plantmask overlay in .png format
  - *IR Frame Auto Scale Bitmap* – raw IR data converted to the color scale in .pngformat
- Analysis Data
  - *Parameters* – calculated parameters and results of basic statistical functionsover areas as text
  - *Plant Mask* – plant mask used for calculations
  - *Tray Mask* – tray mask used for calculations

RGB Cam

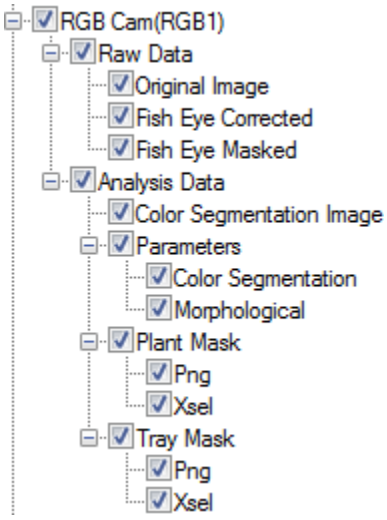


Fig. 36 RGB Cam Export Tree

- Raw Data

  - *Original Image* – raw data in .png format
  - *Fish Eye Corrected* – raw image after fisheye correction in .png format
  - *Fish Eye Masked* – raw image after fisheye correction with plant maskoverlay in .png format
- Analysis Data
  - *Color Segmentation Image* – color segmented image (colors are defined in the measurement protocol) with fisheye correction andplant mask overlay in .png format
  - *Parameters*
  - *Color Segmentation* – color segmentation as text
  - *Morphological* – morphological parameters as text
  - *Plant Mask* – plant mask used for calculations
  - *Tray Mask* – tray mask used for calculations

3D Scan

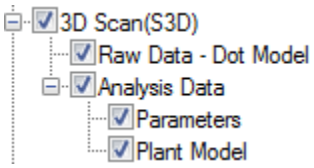


Fig. 373D Scanner Export Tree

- Raw Data - Dot Model – 3D model in the .pcd format
- Analysis Data
  - *Parameters* – computed parameters as text
  - *Plant Model* – colored segmented 3Din .ply format

Scales

Measured values as text

HyperSpectral Cam

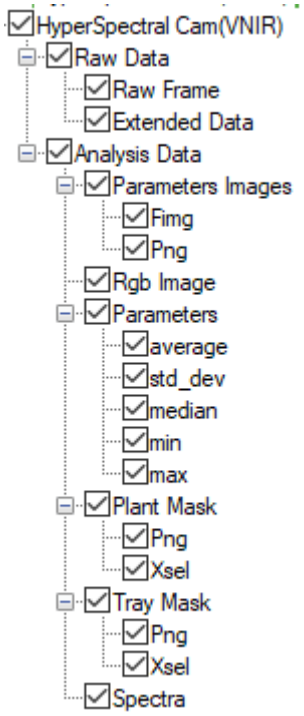


Fig. 38 Hyperspectral Cam Export Tree

- Raw Data - raw data in .hdr and .bil format

- Analysis Data
  - *Parameter Images* – parameters images as .fimg or .png format
  - *RGB Image* – RGB image reconstructed from the corresponding wavelengths(if possible) in .png format
  - *Parameters* – calculated parameters and results of basic statistical functionsover areas as text
  - *Plant Mask* – plant mask used for calculations
  - *Tray Mask* – tray mask used for calculations

MultiSpectral Cam

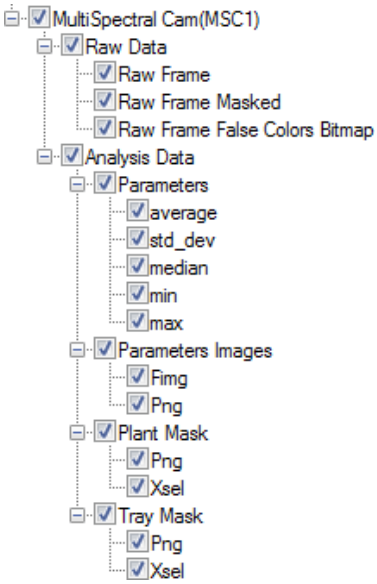


Fig. 39 MultiSpectral Cam Export Tree

- Raw Data
  - *Raw Frame* – raw data in the raw format
  - *Raw Frame Masked* – raw data converted to the color scale with plant maskoverlay in .png format
  - *Raw Frame False Colors Bitmap* – raw data converted to the color scalein .png format
- Analysis Data
  - *Parameters* – calculated parameters and results of basic statistical functionsover areas as text
  - *Parameters Images* – parameters images as .fimg or .png format
  - *Plant Mask* – plant mask used for calculations
  - *Tray Mask* – tray mask used for calculations

Thermo Color Cam

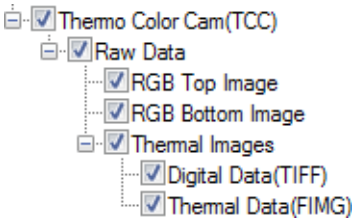


Fig. 40 Thermo Color Cam Export Tree

- Raw Data
  - *RGB Top Image* - raw data from Color top camera in the .png format
  - *RGB Bottom Image* - raw data from Color bottom camera in the .png format
  - *Thermal Images*
    - *Digital Data* - pixel intensities in the Tiff format
    - *Thermal Data* - temperatures [Kelvin] in the .fimg format

Root Cam

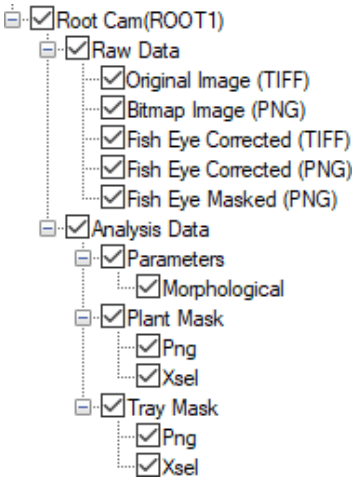


Fig. 41 Root Cam Export Tree

- Raw Data
  - *Original Image* – raw data in .tiff format
  - *Bitmap Image* – raw image in .png format
  - *Fish Eye Corrected* – raw image after fisheye correction in .tiff format
  - *Fish Eye Corrected* – raw image after fisheye correction in .png format
  - *Fish Eye Masked* – raw image after fisheye correction with plant mask overlayin .png format
- Analysis Data
  - Parameters
    - *Morphological* – morphological parameters as text
  - *Plant Mask* – plant mask used for calculations
  - *Tray Mask* – tray mask used for calculations

2.8.1.2 TREEVIEW STRUCTURE CONTEXT MENU

Right click on any TreeView node displays context menu Fig. 42.

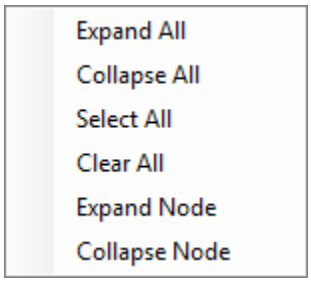


Fig. 42 TreeView ContextMenu

Expand All expands all nodes. Collapse All collapses all nodes up to the top device nodes.
Select All/Clear All selects/clears all nodes, including the collapsed ones.
Expand Node expands all children of the node, Collapse Node collapses all children of the node.

2.9 SELECTION PLACE

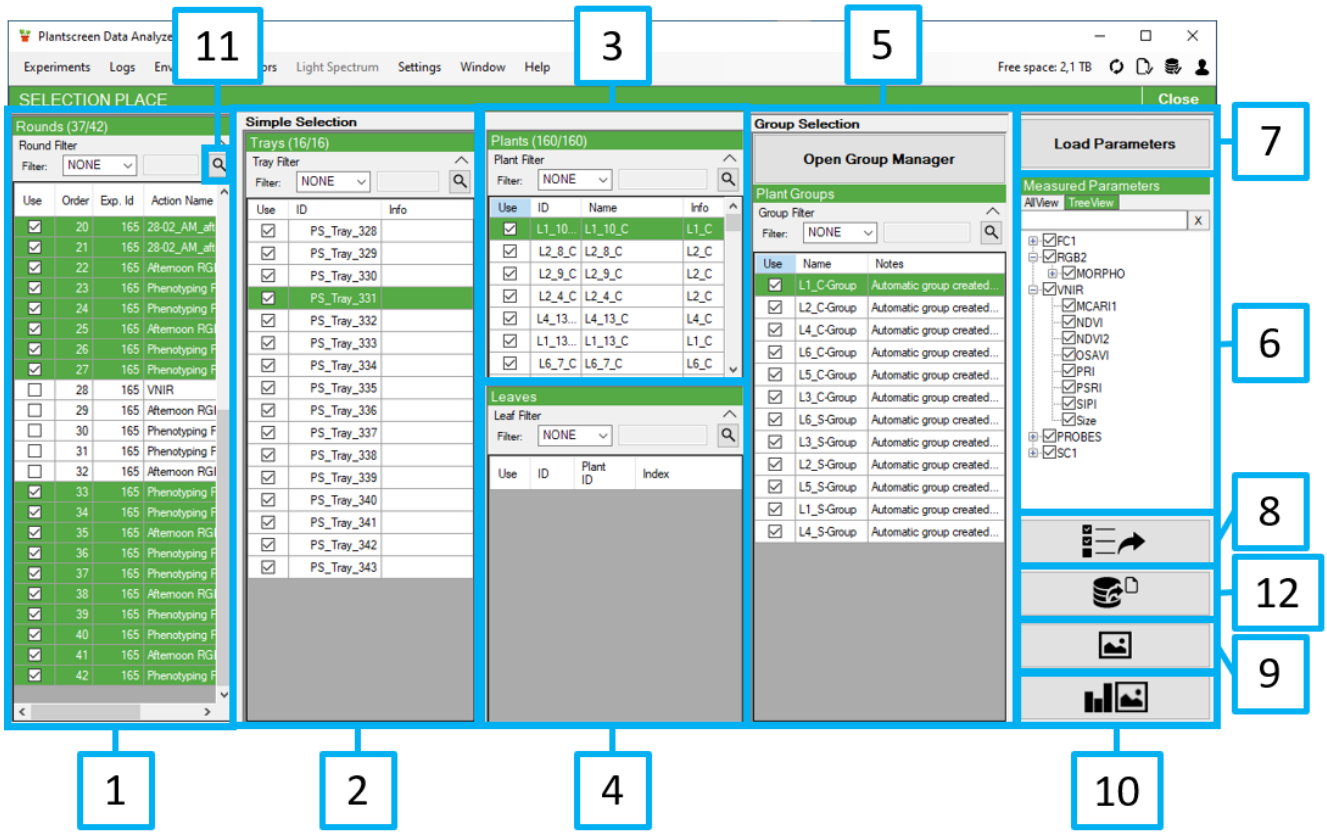


Fig. 43 Selection Place

Selection place is a window for selection of the data, which can be then visualized as image or chart.
Source for one chart entry can be plant group, plant or leaf. By default, each of these categories is displayed in the separate chart area, but it can be also opened and compared against each other in the 2.10.2 Common Chart. Sources for the imaging part of the data analysis are selected trays.
Selection place contains round table (Fig. 43-1) and tray table (Fig. 43-2), described in the chapters 2.7.3 Round Table and 2.7.4 Tray Table. Tables contain filter bars, analogous to the 2.9.1.1 Plant Table Filter Bar.
Plant table (Fig. 43-3) contains plants available for selection. It is dynamically changed based on the tray table, when no tray is selected, it is empty. It is further described in the chapter 2.9.1 Plant Table.
Leaf table (Fig. 43-4) contains leaves available for selection. It is dynamically changed based on the plant table, when no plant is selected, it is empty. It is further described in the chapter 2.9.2 Leaf Table.
Plant Group table (Fig. 43-5) contains list of named groups of plants, which are used as data source for charts and visualization. It is further described in the chapter 2.9.3 Plant Group Table.
Parameters selection for further visualization is done in the parameters selection window (Fig. 43-6) and it is described in the chapter 2.9.4 Parameters Selection Window. Window content is refreshed by clicking the Load features button (Fig. 43-7). Button is enabled only if at least one plant or group of plants is selected.
Export button (Fig. 43-8) saves current state of the window into the file. This file can then be later loaded to restore the window state, using the Load selection button on the main window (Fig. 8-1).
Imaging button (Fig. 43-9) opens working container (2.10 Working Container) with currently selected trays in imaging-only mode, where chart controls are hidden. Button is enabled if at least one round and tray are selected.
Imaging and Charts (Fig. 43-10) button opens working container (2.10 Working Container) with currently selected parameters, with both chart and image controls enabled. Button is enabled if at least one parameter is selected.
Search button (Fig. 43-11) opens window with advanced filter, which offers more possibilities for data filtering. Filter is described in chapter 2.9.5 Advanced filter.
Button Export User Selection to File (Fig. 43-12) export's user selection to zip file. The zip file contains local database and all data files and can be used as data source in any PlantScreen Data Analyzer software with version higher than 3.1.6.x. After opening the file, the software is connected to the local database and local cloud storage created from the opened zip file. Typical use case for this feature is to give measured data to external user who does not have access to the PlantScreen system.

2.9.1 PLANT TABLE

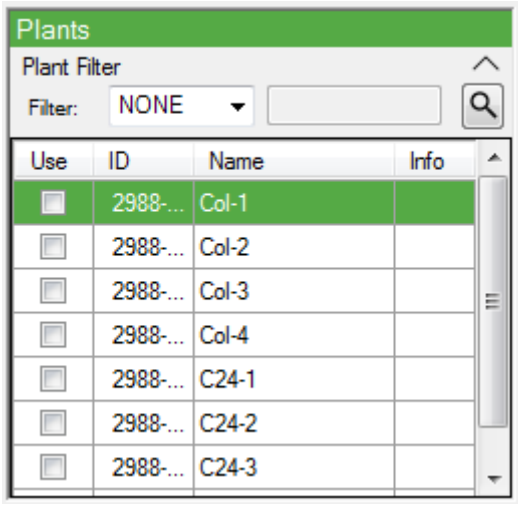


Fig. 44 Plant Table

Plant table displays list of plants from the selected rounds and trays, with plant ID, name andnote. Right mouse button displays context menu described in the chapter 2.6 Common Table Controls**.** Plants can be filtered by the 2.9.1.1 Plant Table Filter Bar**.**

2.9.1.1 PLANT TABLE FILTER BAR

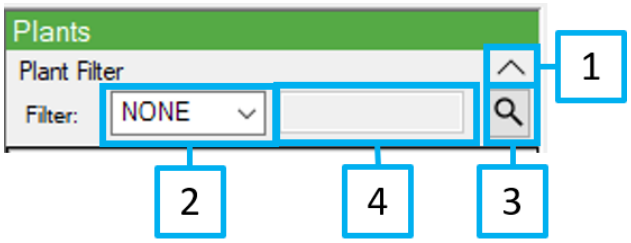


Fig. 45 Plant table filter bar

Plant table filter bar provides simple filtering of the available plants. Text from the keyword field (Fig. 45-3) is compared with the text from the plant column selected by the column selector (Fig. 45-2). If the text in the keyword field is found within the selected plant column text, corresponding plant passes the filter and is displayed. Button in Fig. 45-4 opens window with advanced filter described in chapter Advanced filter.
Filter can be hidden/shown by the Fig. 45-1 element.

	Filter is not applied if value NONE is selected in the column selector.

2.9.2 LEAF TABLE

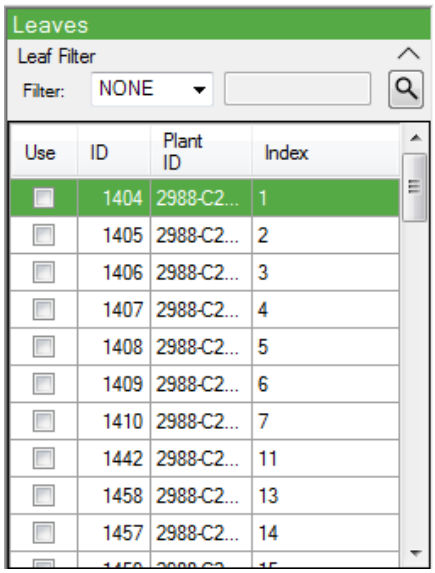


Fig. 46 Leaf Table

Leaf table displays available leaves from the Leaf Tracking module. If the feature is not available on the system, or was not enabled for the experiment, table is empty.
Right mouse button displays context menu described in the chapter 2.6 Common Table Controls. Leaves can be also filtered by the filter bar, analogous to the 2.9.1.1 Plant Table Filter Bar.

2.9.3 PLANT GROUP TABLE

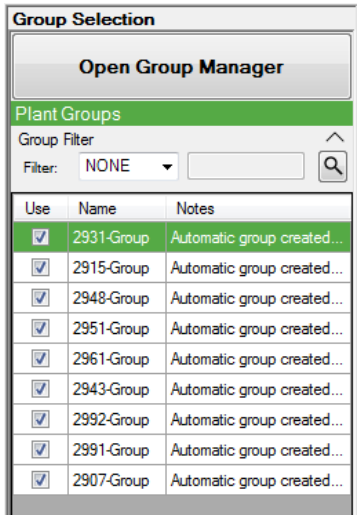


Fig. 47 Plant group table

Plant group table contains existing plant groups. Button Open Group Manager opens Group Manager window (2.9.3.1 Group) with tools to create or modify plant groups. Right mouse button displays context menu (Fig. 48), which contains common items Select All/Clear All, Remove Group to remove selected group, Remove All Groups to remove all and Open Group Manager to open Group Manager window.

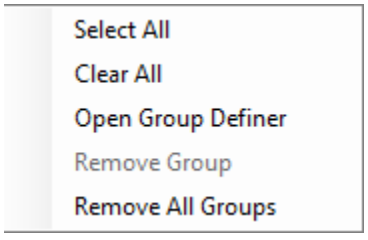


Fig. 48 Plant Group Table Context Menu

2.9.3.1 Group Manager

Group manager is window with tools to create group of plants, which can be further visualized in charts.
It contains list of trays (Fig. 49-5) selected on the 2.9 Selection Place on one side, and list of existing groups (Fig. 49-1) on the other side of the window.
Middle section contains controls for automatic group generation based on the selected criteria (Fig. 49-2), controls for manual group adding (Fig. 49-3) and controls for group editing (Fig. 49-4).
Changes are saved by the OK button, or discarded by the Cancel button.
Automatic group generation section (Fig. 50) offers various filters, which enable creating one or more groups at once. Filtering type is selected by the filter combo box (Fig. 50-1), text field (Fig. 50-2) is used for parameter if filter requires one. Brief description of the filter behavior is displayed in the tooltip or after click in window (Fig. 50-4). Groups are generated and added to the list by pressing the Add Automatic Groups button.

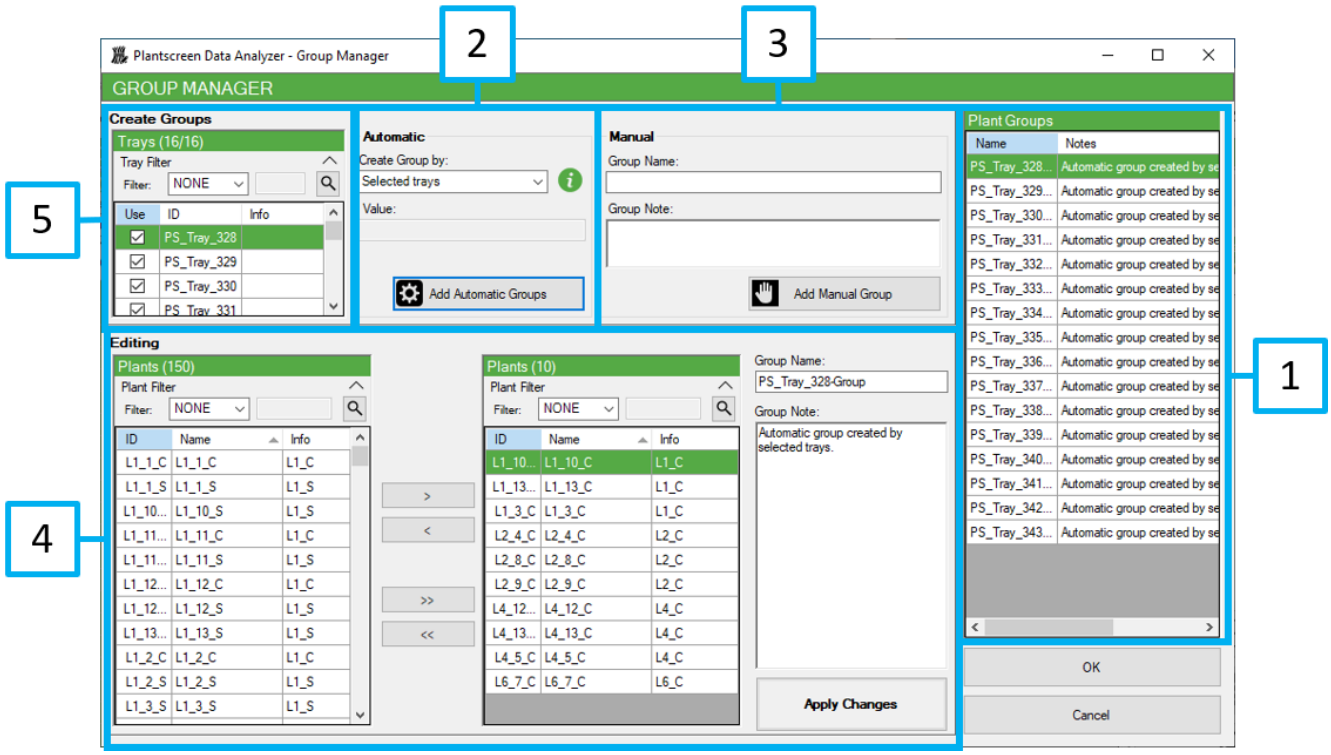


Fig. 49 Group Manager

Possible filtering options are:

- Selected Trays – group is created for each selected tray
- Plant Name– group is created for each set of plants with the same Plant Name
- Plant Info– group is created for each group of plants with the same Plant Info
- Tray Info – group is created for each group of plants with the same Tray Info
- Text in Plant Name– one group is created, all plants with filter parameter text contained in the Plant Name are included
- Text in Plant Info– one group is created, all plants with filter parameter text contained in the Plant Info are included
- Text in Tray Info– one group is created, all plants with filter parameter text contained in the Tray Info are included

	Only the Selected trays option is influenced by tray selection (Fig. 49-5). For the other options plants from all trays selected on Selection Place are used, the tray selection on the Group Manager (Fig. 49-5) doesn't influence the automatic group creation.

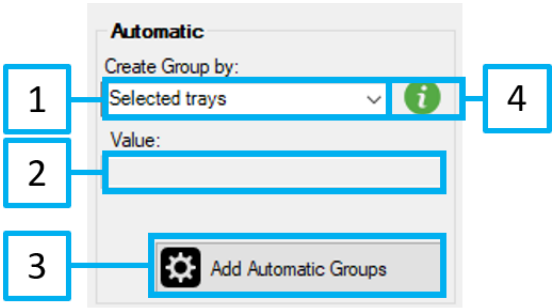


Fig. 50 Automatic Group Generation

Groups can be added manually using the *Add Manual Group* button. Both *Group Name* and *Group Note* fields has to be filled.

Fig. 51 Manual Group Adding

Groups can be edited in the section for group editing. Content of the selected group is displayed in the right plant table (Fig. 52-2), all other plants from selected trays are displayed in the left plant table (Fig. 52-1). Arrow buttons (Fig. 52 Group Editing-5, Fig. 52 Group Editing-6) are used for moving (removing/adding) plants between plant tables. Simple arrows (Fig. 52 Group Editing-5) moves selected plants, double arrows (Fig. 52 Group Editing-6) moves all plants. Plant tables are described in the chapter 2.9.1 Plant Table. *Group Name* and *Group Note* (Fig. 52-4) can be changed in the corresponding fields.

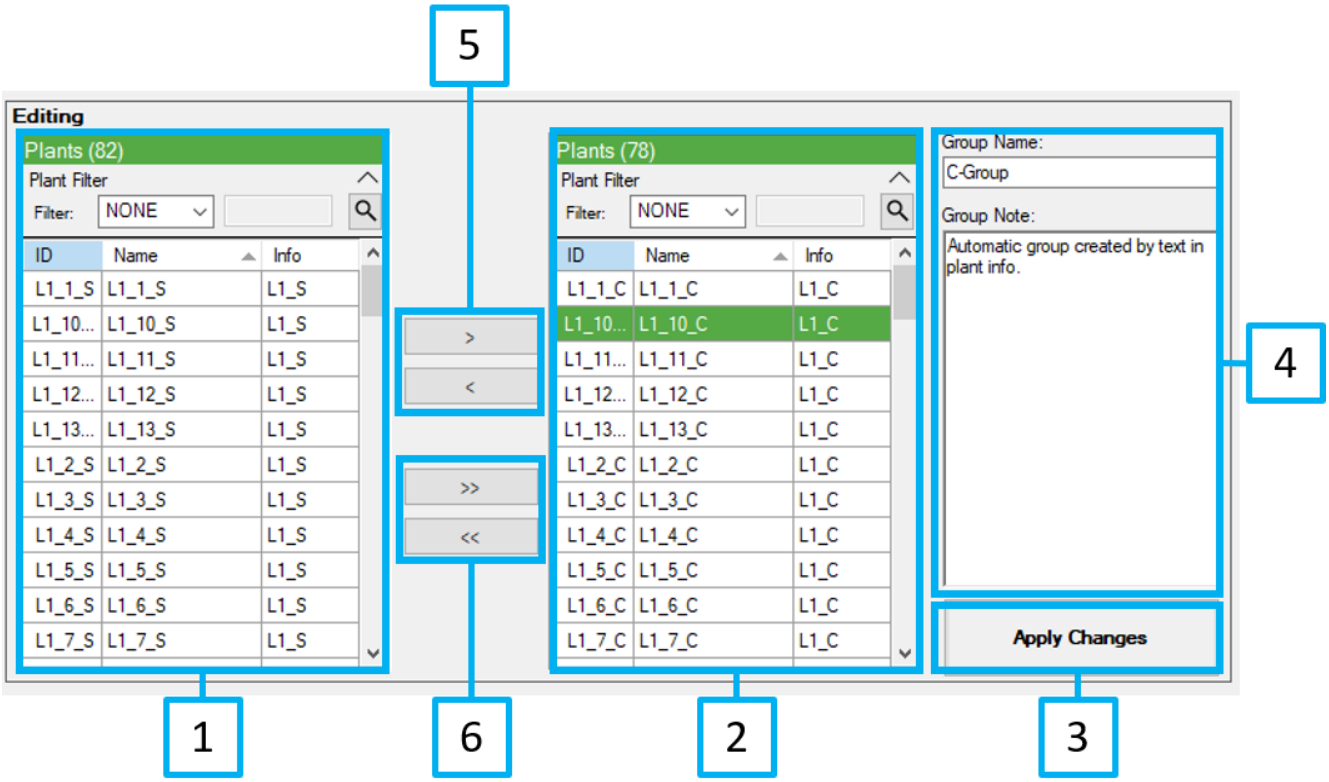


Fig. 52 Group Editing

Pending changes to the group are signalized by the blue background of the Apply Changes button (Fig. 53). Changes are confirmed by pressing the button. If another group is selected while changes are pending, they are discarded.

Fig. 53 Pending changes

2.9.4 PARAMETERS SELECTION WINDOW

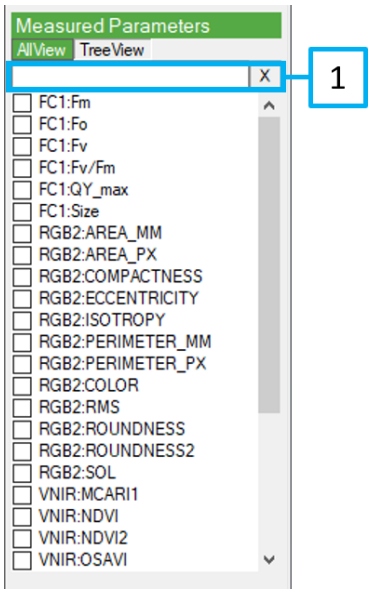


Fig. 54 List

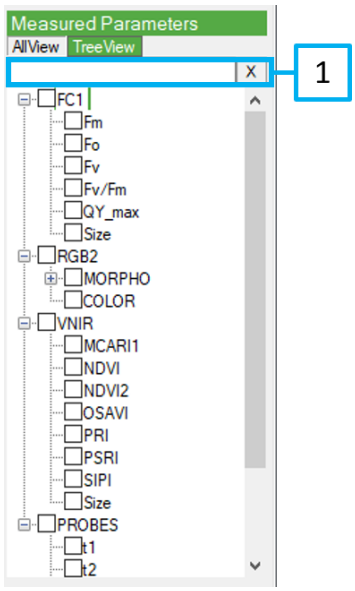


Fig. 55 TreeView

Parameters selection window displays parameters, which were measured at least once forthe selected rounds and selected plants or leaves.
There are two modes of view. The first one is alphabetically sorted list (Fig. 54), the secondone treeview with the measurement devices structure (Fig. 55). Modes are switched by clicking the corresponding tab.
Text window (Fig. 55-1) enables text filtering in the displayed parameters. If the textis found in the name of the measurement device (RGB, IR, FC), the item is displayed.
Right mouse button displays context menu described in the chapter 2.6 Common TableControls**.**

2.9.5 Advanced Filter

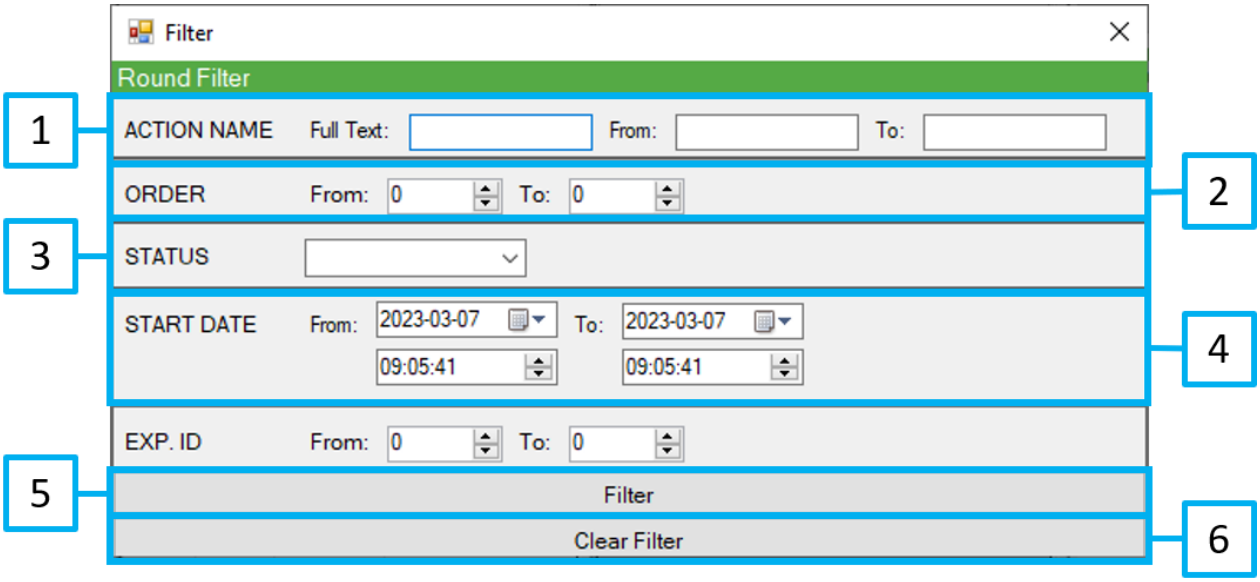


Fig. 56 Advanced Filter

Filter window provides advanced filtering options for the available data. Structure of the filter is generated automatically from the input data type where each row of the filter corresponds to column of the input type.
Text values can be filtered by full text or by lexicographical string comparison (Fig. 56-1).
Number and time values are filtered by setting a range (Fig. 56-2, Fig. 56-4), border points are included in the selection.
Constants are selected from the combobox (Fig. 56-3).
Button *Filter* applies the filter on data (Fig. 56-5) and button *Clear filter* clears all filter settingsand shows all data.

2.10 Working Container

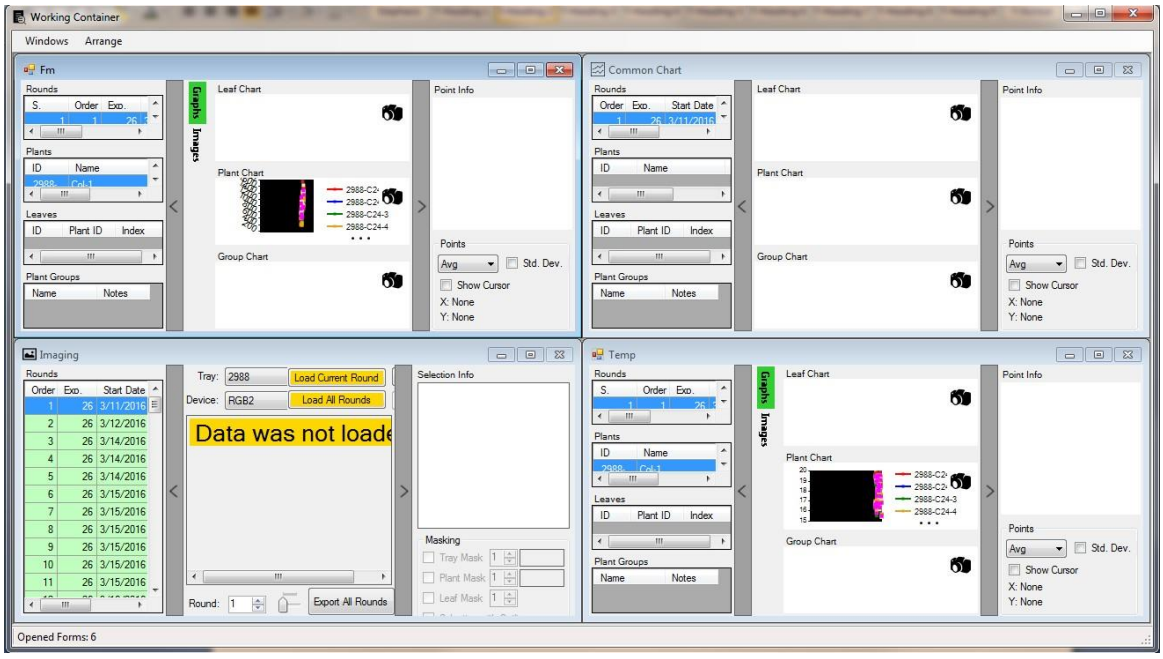


Fig. 57 Working Container.

Working Container is a top level window, where child windows with data controls areplaced. Its goal is to keep the child windows organized.

Child windows can be of the following types:

- 2.10.1 Single Parameter Window
- 2.10.2 Common
- 2.10.3 Imaging
- 2.10.4 3D Imaging

Working Container menu is located in the window menu bar. *Windows* menu item contains list of all opened windows (Fig. 58). Icon next to the window name shows window status – visible (Fig. 58-1) or hidden (Fig. 58-2).
Each window item has a submenu (Fig. 59) with four items. *Show* and *Hide* change status of the window, *Rename* allows to give window custom name, and *Minimize*.
Menu item *Arrange* gives standard layout options for opened windows arrangement.

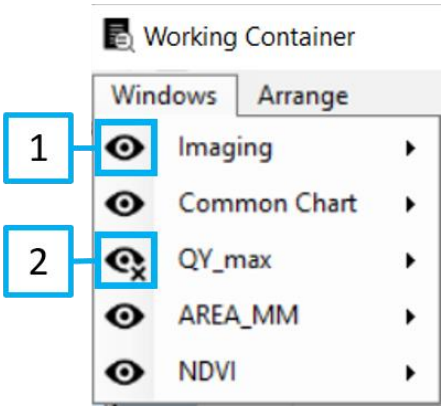


Fig. 58 Opened Windows List

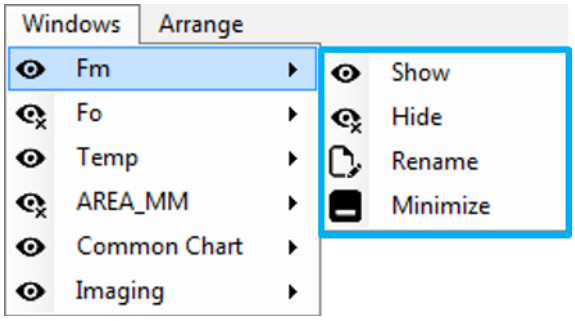


Fig. 59 Window Item Submenu

	Parameter window cannot be closed, it can be only hidden. When the window close system menu button (right top corner button) is clicked, window is hidden instead and can be made visible again from the Windows menu.

2.10.1 Single Parameter Window

Single Parameter Window is created in the *Working Container* for each parameter selectedin the 2.9.4 Parameters Selection Window.

Fig. 60 Single Parameter Window

Window contains information section on the left (Fig. 60-1), where data source is visualized. Middle section holds parameter charts (2.10.1.1 Charts) and images (2.10.3 Imaging), currently displayed content is selected by the page control (Fig. 60-2). Right part of the window contains tools for chart and image control. Side parts of the window can be shown/hidden by the corresponding controls (Fig. 60-3).

2.10.1.1 Charts

Chart section displays measured/analyzed parameters in time series. Three different chartsare displayed.
Leaf Chart (Fig. 61-1) shows data for individual leaves, each series in the chart represents oneleaf. Name of the series is concatenation of the plant name and leaf index, separated by a dash.

Fig. 61 Single Parameter Window - Chart Part

Plant Chart (Fig. 61-2) shows data for individual plants. Plants contained in any of the plant groups are also included, their color matches the color of the originating plant group and their name is preceded by the name of the originating plant group.
Plant Group Chart (-3) shows data for selected plant groups. Series points are computed from the series of the plants in the group, using the selected function (Fig. 61-6).
Screenshot button (Fig. 61-4) enables capturing of the chart images.
Any point in any of the charts can be selected by clicking on it. *Point Info* area (Fig. 61-5) then shows detailed information about the selected point.
Chart controls 6 - 9 control different options of data visualization. *Points* control (Fig. 61-6) determines how the points of the chart are calculated for series representing more than one object (plant groups). Options are *Avg* and *Median*. Additional data range information can beshow for both options by checking the corresponding checkbox, it is standard deviation for
Avg and minimal and maximal value for *Median*. If *Median* value is selected, but cannot be displayed (it is not computed for the given parameter), the chart is blank.

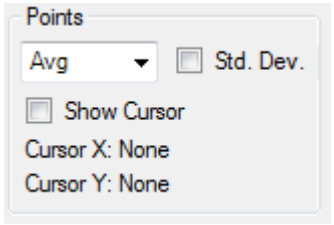


Fig. 62 Points Control, Avg

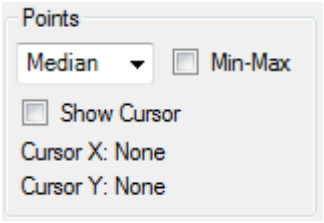


Fig. 63 Points Control,Median

Show Cursor can be triggered for both options. If enabled, cursor line is displayed in the charts and selected point coordinates are displayed in the *Points* control.

***X-axis* control (Fig. 61-7) selects units for charts X axes. It can be either *Dates* or *Rounds*. For *Dates* option, X axis ticks interval are selected by combination of *Interval* and selected units. For *Rounds* option, only *Interval* field is enabled.**

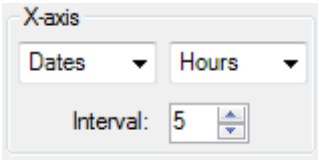


Fig. 64 X-axis Control, Dates

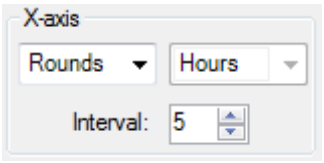


Fig. 65 X-axis Control, Rounds

Y-axis control (Fig. 61-8) can be used to manually define Y-axis minimal and maximal values.

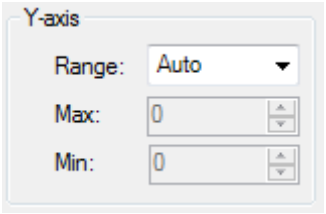
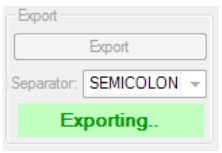


Fig. 66 Y-axis Control

Zoom is done by selecting a rectangle in the chart, zoom out is done by mouse wheel. Button
Zoom Reset (Fig. 61-9) restores default view to all of the charts.
Visibility control (Fig. 61-10) shows/hides corresponding chart types. When the chart type is hidden, visible charts are expanded (Fig. 67).

Fig. 67 Visibility Control – Hidden Chart

Labels control (Fig. 61-11) shows/hides chart legends, titles and axes description.
Series from Group checkbox (Fig. 61-12) triggers visualization of the plants from the plant groups in the *Plant Chart* (Fig. 61-2).
Export button (Fig. 61-13) opens dialog box for export to file. Charts, chart values and experiment information are exported. Supported file formats are either .csv, or .xlsx. Forthe .csv, it is possible to select data separator.

	Plant Chart and *Plant Group Chart* data are linked. If a whole plant series or series point is deleted from the *Plant Chart* and the plant belongs to any of the plant groups, series for the plant group is recomputed and *Plant Group Chart* is updated. Similarly, if a series from the *Plant Group Chart* is deleted, all series belonging to the plants in the plant group are deleted as well. Points and series operations are closely described in the chapter 2.10.1.1 Points and Series in the Chart.
	Do not open exported files until the export is completed. If the file(s) are opened during the export process, the data files may be damaged or incomplete. Running export is marked by the green *Exporting* label (Fig. 68).  **Fig. 68 Export in Progress**

Points and Series in the Chart

Each chart point in any series can be selected by clicking the left mouse button. Selectedpoint is highlighted and its details are shown in the *Point Info* area (Fig. 69).

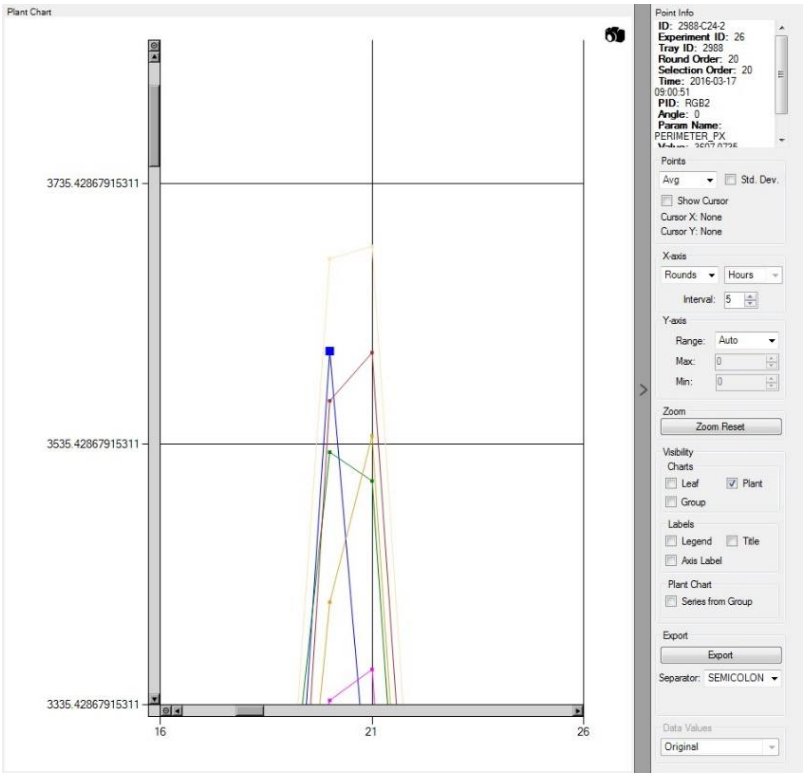


Fig. 69 Highlighted Point

If a highlighted point is clicked by a right mouse button, context menu pops up (Fig. 70). Itcontains following items:

- Clear Selection–cancels the point selection
- Remove Point–clears the point from the chart
- Remove Series–clears the series from the chart
- Add Series to Common–adds series to the Common Chart
- Add All Series to Common–adds all series from the chart to the Common Chart

	If a plant belongs to a plant group, its series alone cannot be added to a common chart, but whole plant group series has to be added instead.

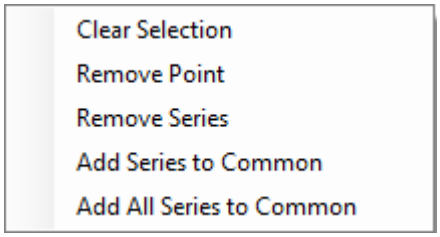


Fig. 70 Highlighted Point Context Menu

Series in the charts can be also selected by clicking the corresponding item from the left plant/leaves/plant groups windows (Fig. 71). Checking/unchecking the item checkbox shows/hides the series from the charts (Fig. 72-1).

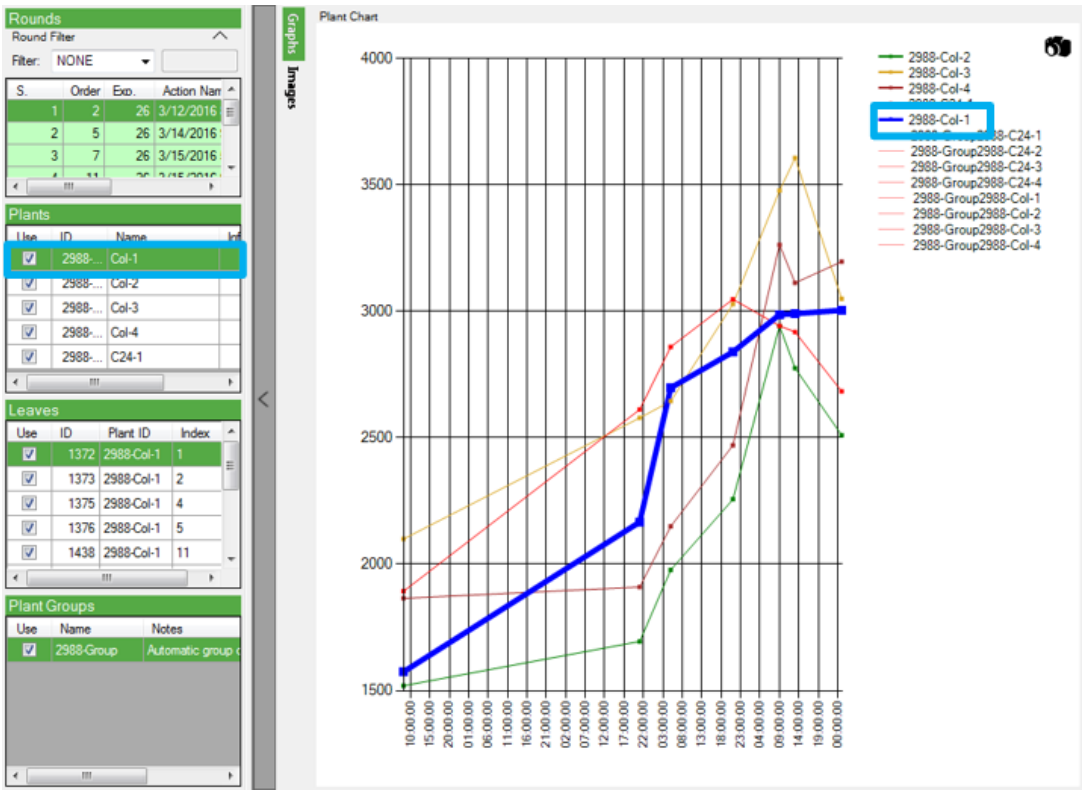


Fig. 71 Selecting Series

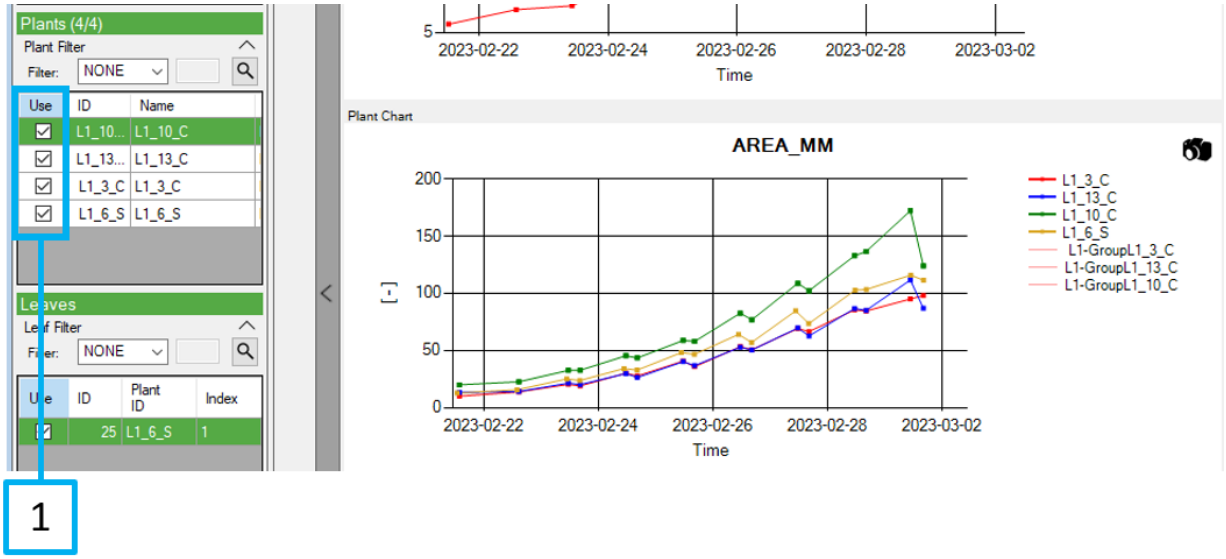


Fig. 72 Hiding Series

2.10.1.2 Color Segmentation Charts

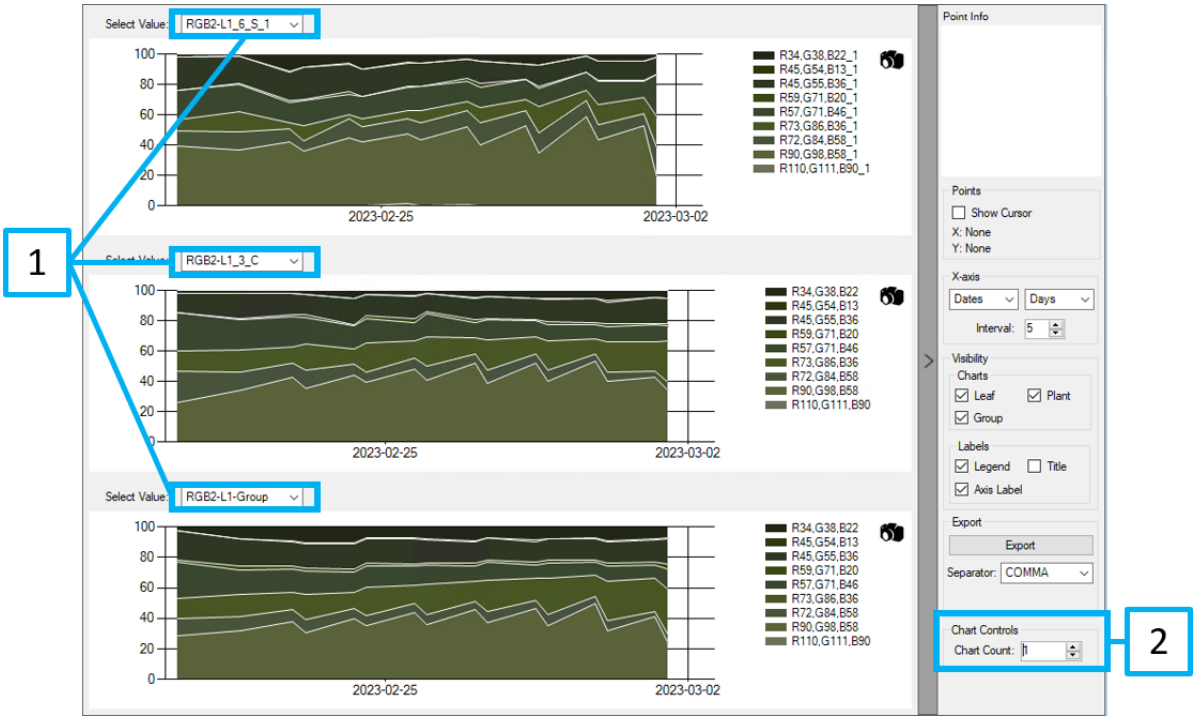


Fig. 73 Color Segmentation Charts

Color segmentation parameters are displayed in a 100% stacked area charts. *Select value* combobox (Fig. 73-1) with selection of items is assigned to each of the charts. Items are leaves, plants or plant groups, depending on the chart type. Series from stacked area chart cannot be added to the *Common Chart*. To compare series against each other, up to 9 stacked area charts can be displayed for each chart type (Fig. 74). Number of displayed chartsis defined in the Chart Controls section (Fig. 73-2).

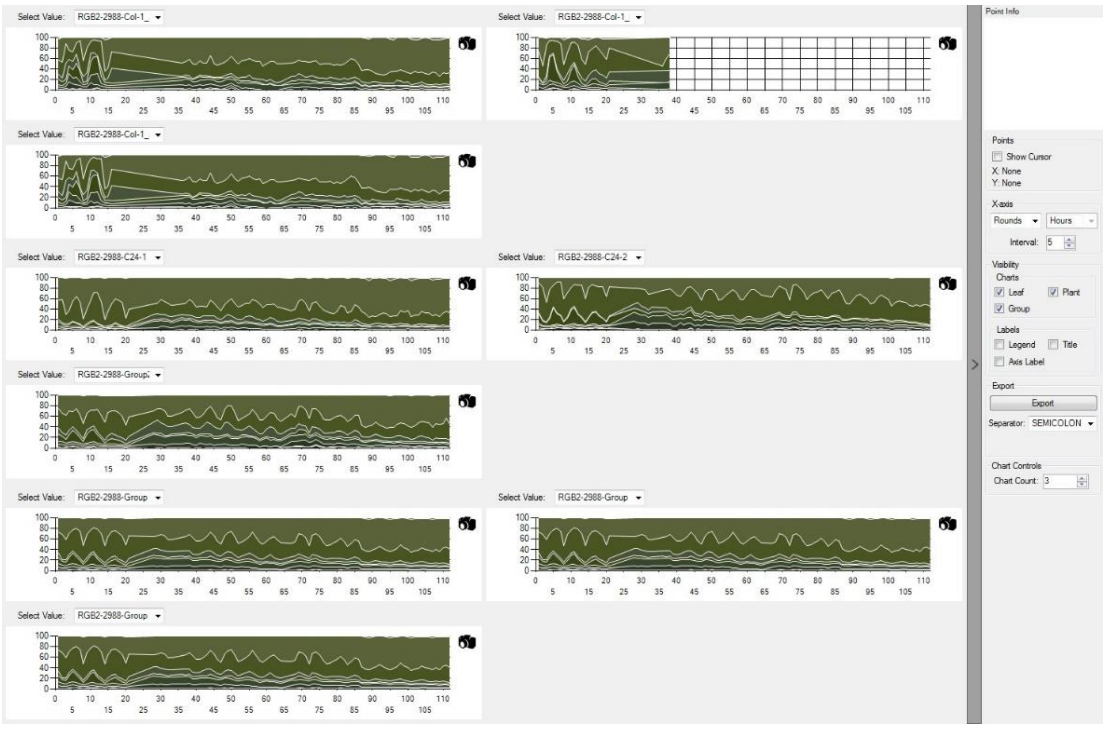


Fig. 74 Multiple Color Segmentation Charts

2.10.1.3 Parameter Imaging

Imaging tab is identical to the window opened by the *Imaging* button (Fig. 43-10) from the *Selection Place,* with the limitation that the source data are defined from the *Selection Place* and cannot be changed. Imaging is closely described in the chapter 2.10.3 Imaging.

2.10.2 Common Chart

Common Chart is designed to enable comparison of trends in data series of differentparameters or even different measurement stations.

Common Chart window (Fig. 75) is similar to the regular chart, with few exceptions:

- Information part of the window (Fig. 75-1) displays data shown in the chart
- Context menu (Fig. 75-2) contains common items - Clear Selection, Remove Point, Remove Series, described in the chapter 2.10.1.1 Points and Series in the Chart. Two new items are Change Series Color, which displays color selection dialog, and Change Axis, which assigns series to the primary/secondary Y-axis.
- Data Values control (Fig. 75-3) toggles between Original and Normalized mode. In Original mode, units of the series are preserved, in Normalized mode, series are recomputed to the <0,1> interval.

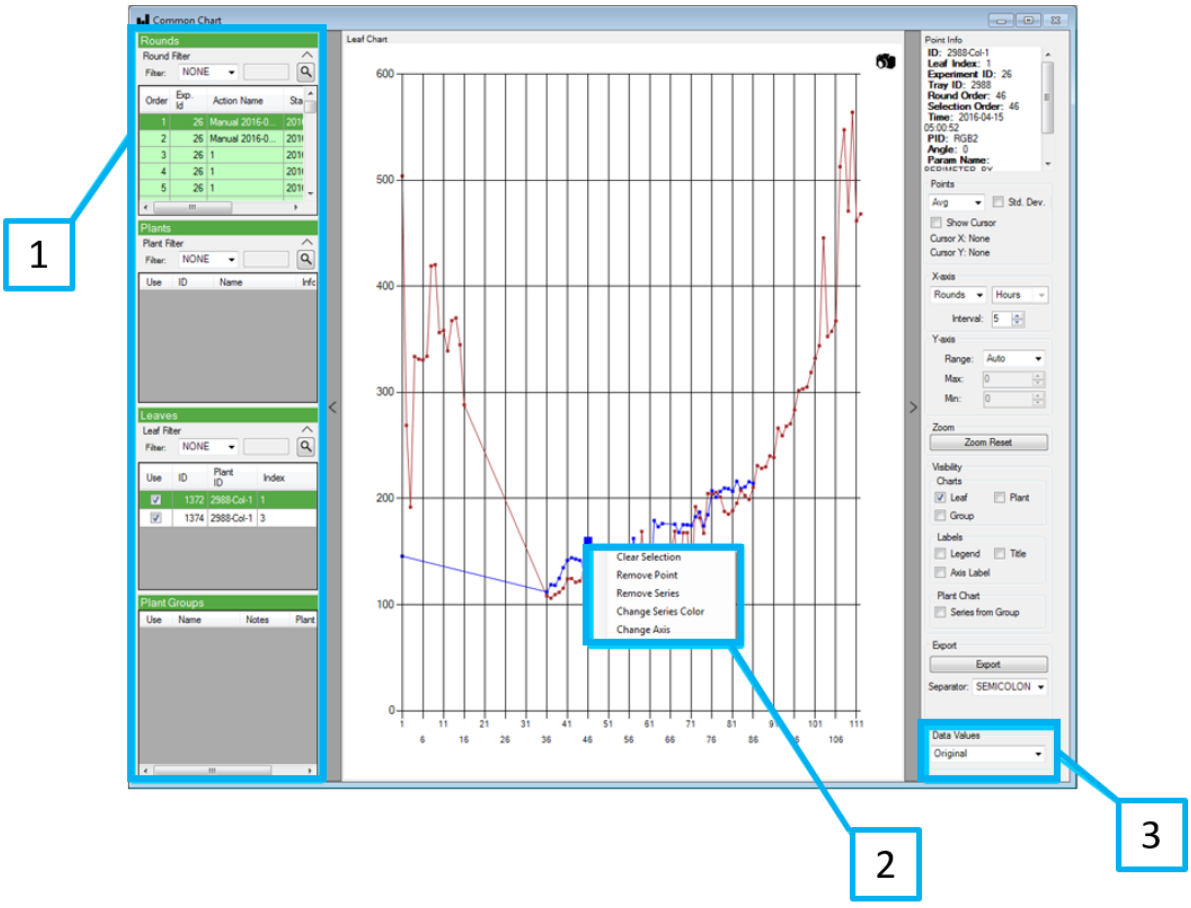


Fig. 75 Common Chart window

2.10.3 IMAGING

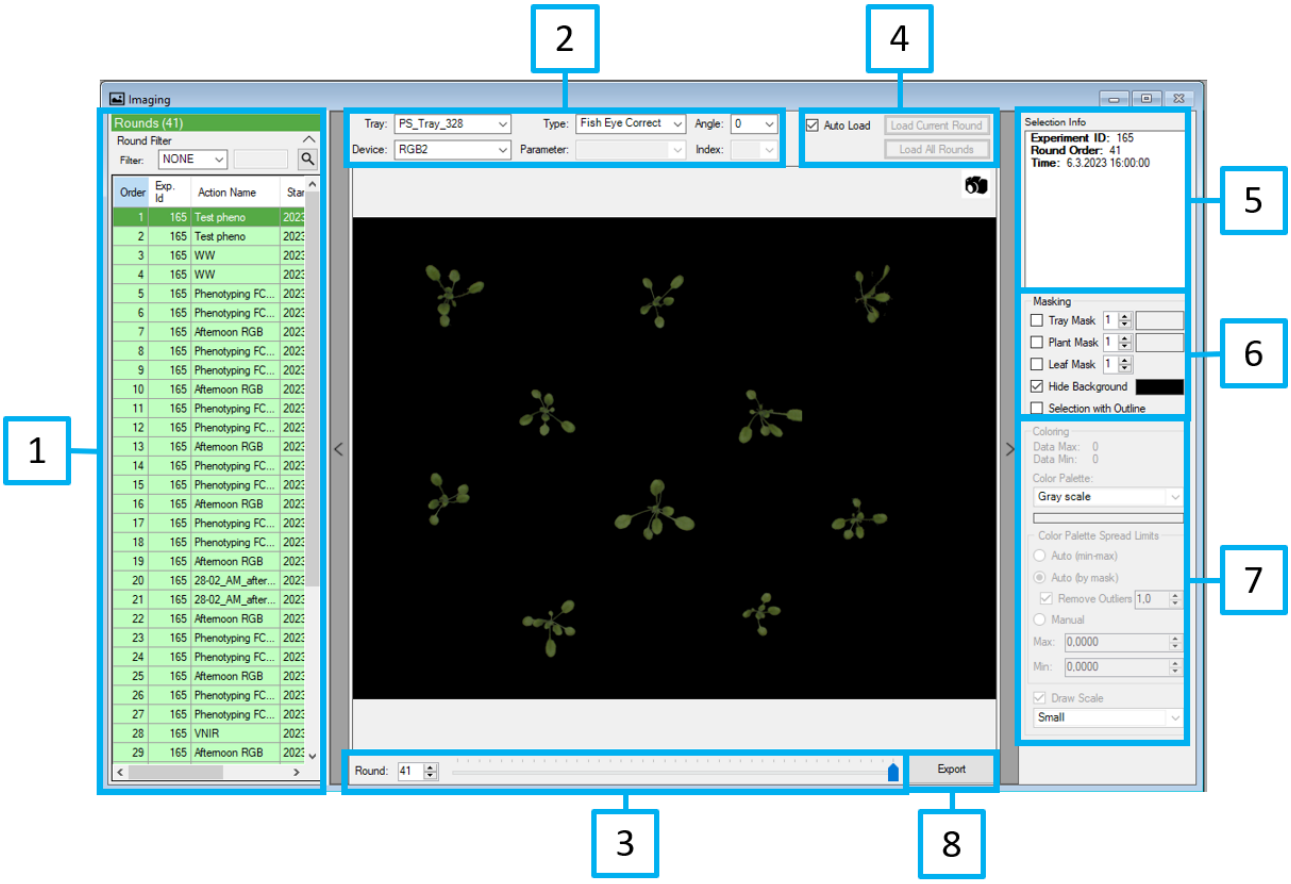


Fig. 76 Imaging

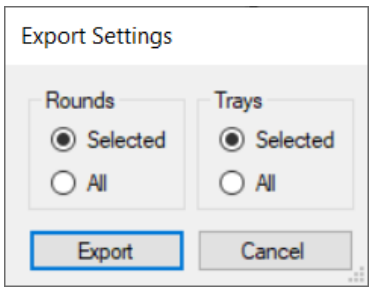


Fig. 77 Export Settings

Imaging window (Fig. 76) enabled displaying images from different cameras, work with the computed masks and export of the data. *Round table* (Fig. 76-1) displays information about the selected rounds.
Data Selection Toolbar (Fig. 76-2) contains controls for displayed image selection. *Tray* item defines tray, *Device* defines station where the image was taken. *Parameter* item defines displayed parameter and is used only if *Parameter* option is selected from the *Type* combo box. Items *Angle* and *Index* define displayed parameter, angle of the measurement table and index of the image in the series, in case a protocol was used for measuring (IR, …). *Type* item selects displayed image type, it is one of the following:

- Original Bitmap – raw captured image, without any corrections, masks cannot be displayed with this option.
- Fish Eye Corrected – raw image after fisheye correction, source for plant/leaf mask computation
- Color Segmented – image with color segmentation defined in the measurement protocol
- Parameter – image of the computed parameter
- Thermal Image
- RGB Image

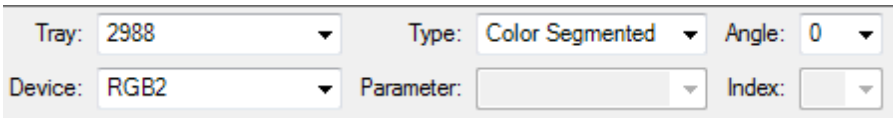


Fig. 78 Data Selection Toolbar

Round selection section (Fig. 76-3) contains tools to select round, for which the images are displayed. It can be defined either by a trackbar, or by an input field.
When any item of the *Data Selection Toolbar* is modified, displayed data are cleared and notification that there are no actual data is displayed (Fig. 79). Data are loaded by one of the load buttons (Fig. 76-4) – either for the selected round, or for all rounds of the selected experiment. If the data load process is successful, image is displayed. If not, notification that no data was found (Fig. 80) for the given selection is displayed. This usually happens when data are requested from a round where the corresponding measuring station was not used.

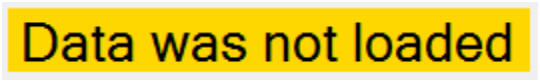


Fig. 79 No Data Loaded

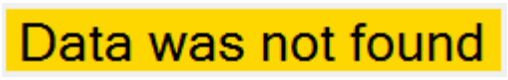


Fig. 80 Data Not Found

Selection Info (Fig. 76-5) displays detailed information about selected object – more on objectselection in the chapter0 Object Selection.
Masking area (Fig. 76-6) contains controls for displaying mask overlay over the original images. Displayed mask section enables to display different mask types (Fig. 81-1) with selected line thickness (Fig. 81-2) and color (Fig. 81-3). Areas, which are not part of the tray mask, can be painted by selected color by checking the *Hide Background* checkbox (Fig. 81- 4). Selected objects can be highlighted by *Selection with Outline* checkbox (Fig. 81-5).

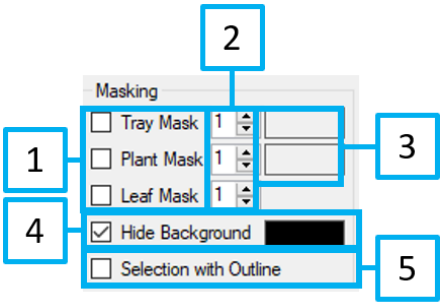


Fig. 81 Mask Controls

Coloring area (Fig. 76-7) contains controls for scale management. It is enabled only for false colored images – images of computed parameters or images from sensors with non-RGB output (IR,…). Minimal and maximal pixel value from the whole image is displayed in the section Fig. 82-1. Scale type is selected by the *Color Palette* combobox (Fig. 82-2), it can be one of the *Gray Scale*, *Color Scale* or *Iron Scale*. Background color of the whole image can set by clicking the panel Fig. 82-3.

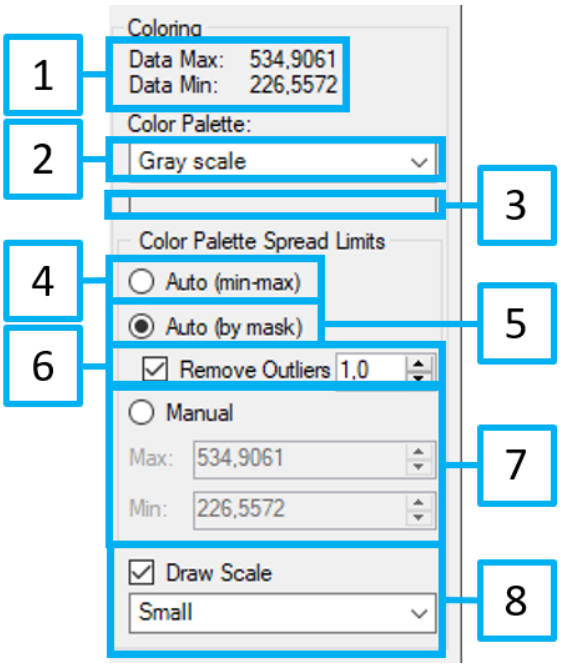


Fig. 82 Scale Management

Color palette limits can be set to one of the following options:

- Auto (min-max) – scale is set from min to max value from the whole image
- Auto (by mask) – scale is set from min to max value from the plant areas of the image. Plant mask must be computed for this option. Remove Outliers option (Fig. 82- 6) removes points from the edges of the point values histogram from the scale min-max computation.
- Manual – scale min-max is set to user defined values Scale can be enabled/disabled or resized by the Fig. 82-7 controls.

Export button (Fig. 76-6) exports all images from the selected rounds. Images are exported asthey are displayed at the moment. For example, if tray mask overlay is displayed, all images are exported with the overlay.

Object Selection

Any object in the image, defined by the masks, can be selected by clinking on it (Fig. 83). This object is then highlighted and the selection is active even if the source image is changed. This can be used for example to track leaf between the rounds during the leaf tracking experiment.

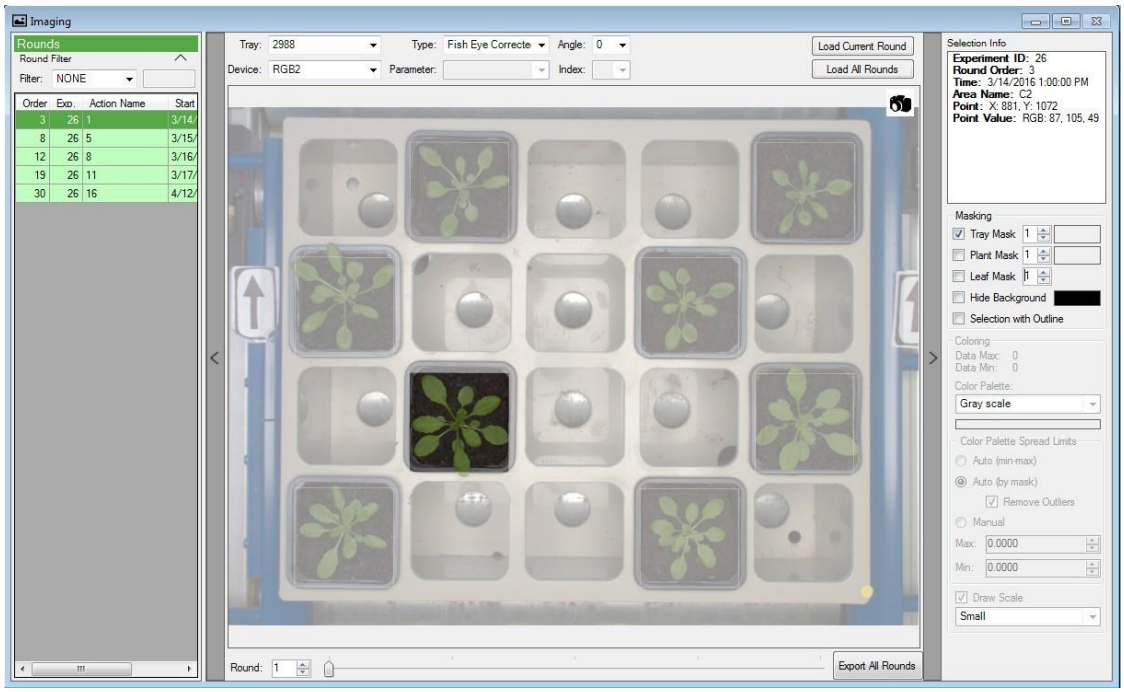


Fig. 83 Object Selection

Fig. 84 Highlighted Object Round 1

Fig. 85 Highlighted Object Round 2

2.10.4 3D IMAGING

3D Imaging window (Fig. 86) is available for the systems with 3D scanner support. It is designed to display measured and analyzed models and their computed masks. It alsocontains tools enabling projection of the images from other devices (RGB, IR, ...) to the model's surface and exporting the acquired textured models.

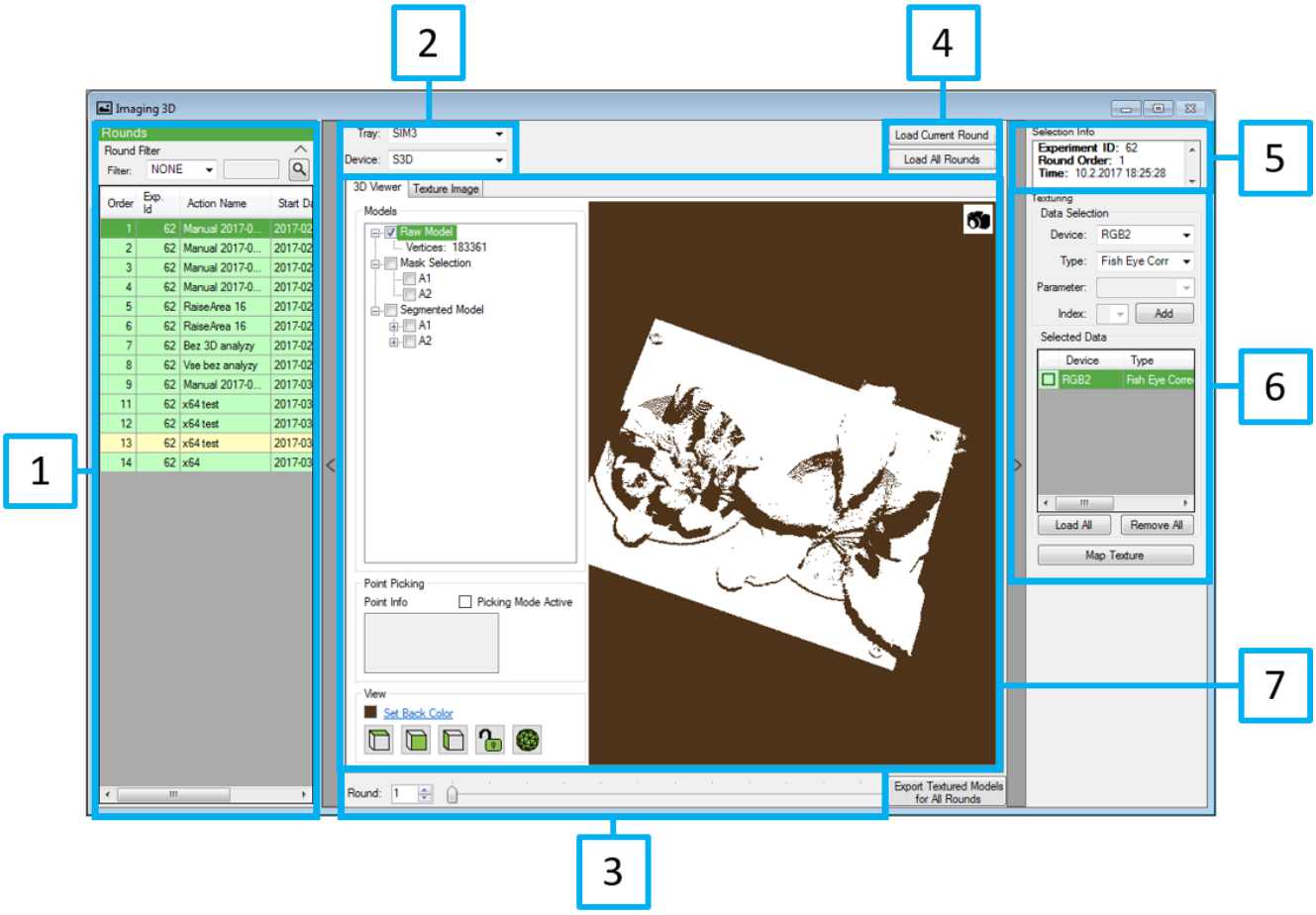


Fig. 86 3D Imaging Window

Round Table (Fig. 86-1) displays information about the selected rounds.
Data Selection Toolbar (Fig. 86-2) contains controls for displayed model selection. *Tray* item defines tray, *Device* defines station where the model was taken.
Round Selection section (Fig. 86-3) contains tools to select round which the models aredisplayed for. It can be defined either by a track bar, or by an input field.
When any item of the *Data Selection Toolbar* is modified, displayed data are cleared and notification that there are no actual data is displayed (Fig. 79). Data are loaded by one of the load buttons (Fig. 86-4) – either for the selected round, or for all rounds of the selected experiment. If the data load process is successful, models are prepared for displaying. If not, notification that no data was found (Fig. 80) for the given selection is displayed. This usually happens when data are requested from a round where the corresponding measuring station was not used.
Selection Info (Fig. 86-5) displays basic information about selected data.
Texturing section (Fig. 86-6) provides controls for the texture mapping process – more on thissection in the chapter 2.10.4.2 Texture Image.
Visualization section (Fig. 86-7) is divided by tab control to *3D Viewer* part and *Texture Image* part – both parts are separately described in the following two chapters.

2.10.4.1 3D VIEWER

3D Viewer provides visualization of the measured, analyzed and textured models. 3D viewer is switchable by clicking the corresponding tab (Fig. 87-1) in *Visualization* section.

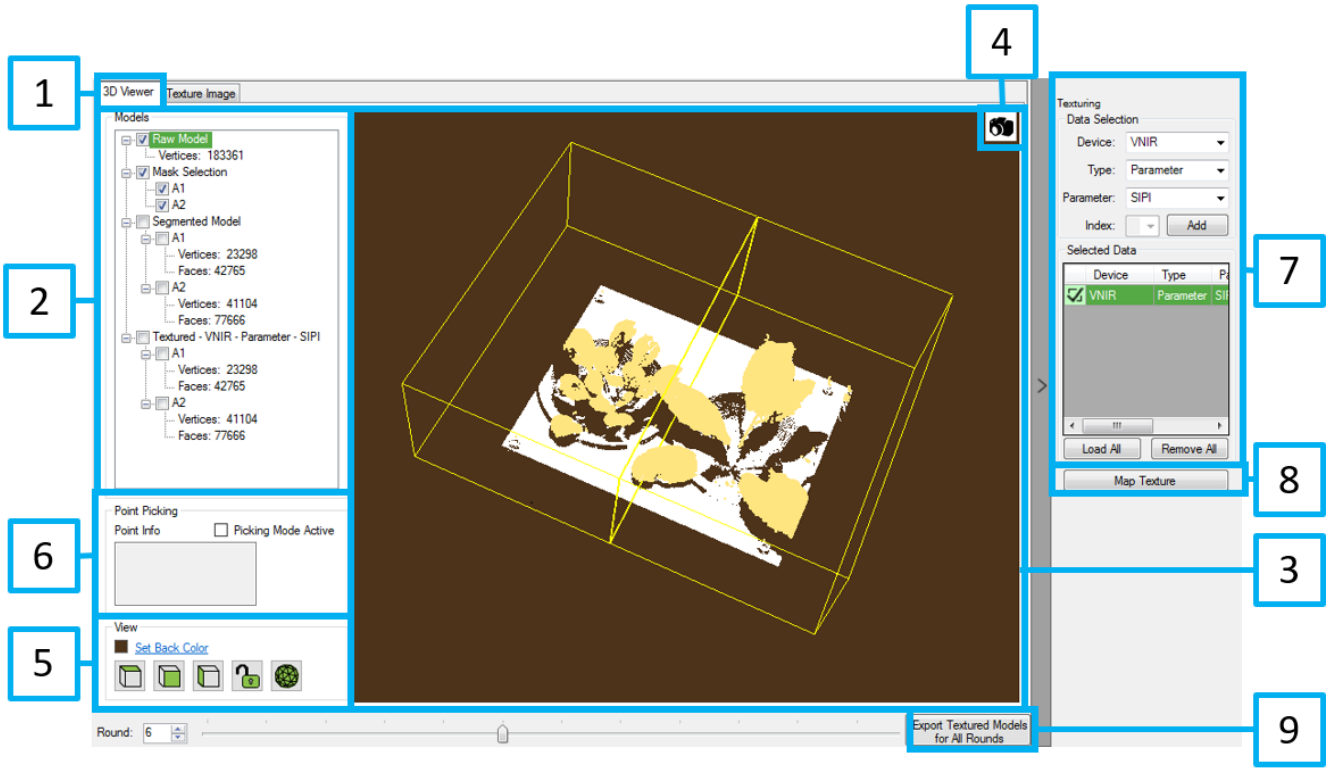


Fig. 87 3D Viewer

Models tree view (Fig. 87-2) contains a list of the models prepared to display. Typical tree view structure (Fig. 88) is following:

- Raw Model – the output of 3D scanning represented by a point cloud model, with number of vertices
- Mask Selection – parts of the point cloud model split by their belonging to areas of the mask, sorted by the area name. Boundary of the areas are shown when the model is displayed. (Shown mask shape is always rectangular and corresponding to the bounding box of the area shape.)
- Segmented model – the output of 3D analysis represented by triangulated models, sorted according to belonging to the mask area, with number of vertices and faces. This node is displayed only if the 3D analysis was computed.
- Textured "x-x-x" – the output of texture mapping represented by triangulated models, sorted according to belonging to the mask, with number of vertices and faces. Part "x-x-x" in the title is variable and defines source data used for mapping.

Right mouse button click on any checkable node displays the common context menu (Fig. 89-1) with option to save the selected model. Supported format is .pcd file format for point cloud models and .ply file format for triangulated models.
Models checked in the tree view are displayed in the *Render Panel* (Fig. 87-3). Models manipulation in 3D space is possible by dragging its part by mouse.

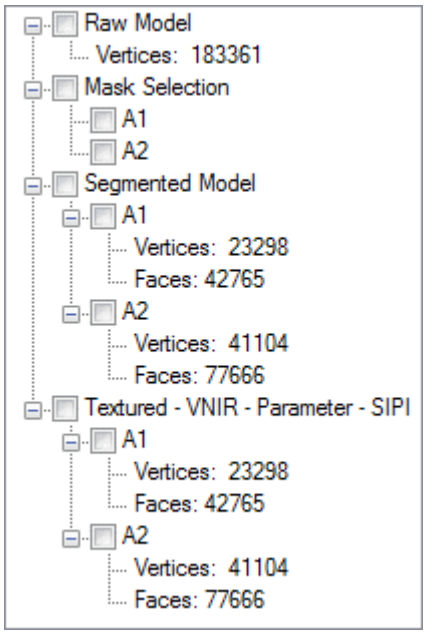


Fig. 88 3D Viewer - Models Tree View Structure

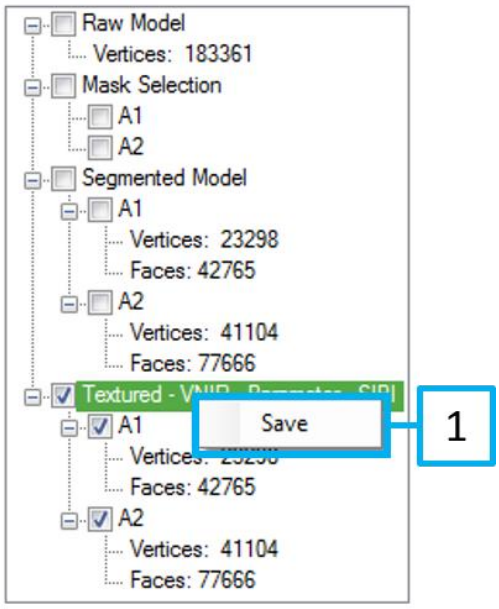


Fig. 89 3D Viewer - Common Context Menu

Screenshot button (Fig. 87-4) enables capturing of the *Render Panel*.The basic *View* controls are available for rendering (Fig. 87-5).

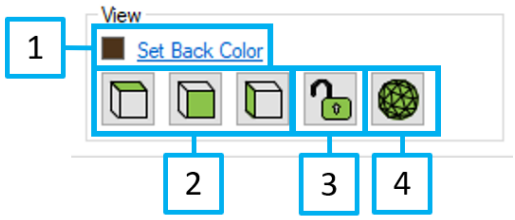


Fig. 90 View Control

Render Panel background color may be changed (Fig. 90-1).

Buttons for setting the camera to one of the three basic camera positions (Fig. 90-2) arefollowing:

-  Top View
-  Front View
-  Left Side View

Camera View button (Fig. 90-3) is switchable between two states:

-  *Unlocked* – camera view resets when a 3D model is loaded
-  Locked – camera view is locked for resetting when a 3D model is loaded

There are two options how can be triangulated models shown, selection is done by switchable button (Fig. 90-4) with two states:

-  *Face Model* – model is rendered with full surface (Fig. 91)
-  *Wireframe Model* – model is rendered with edges only (Fig. 92)

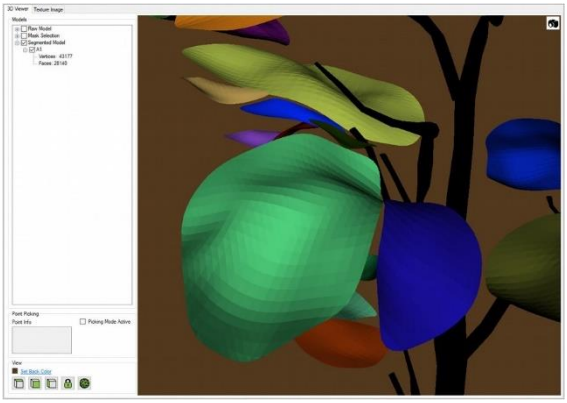


Fig. 91 Face Model

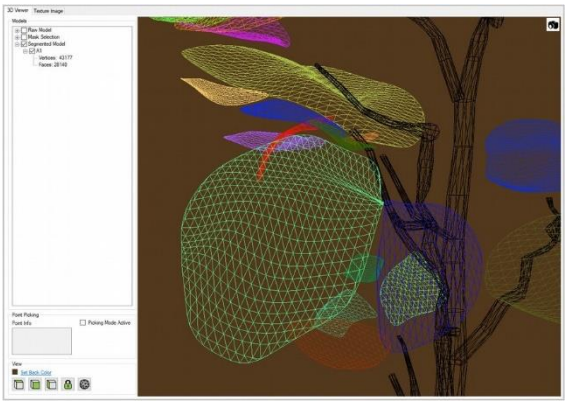


Fig. 92 Wireframe Model

Render Panel allows to get information about the selected point (Fig. 87-6). The picking modeis activated by the check box *Picking Mode Active* (Fig. 93-1). When active, the information bar at the top of the *Render Panel* appears (Fig. 93-2). Point is selected by he right mouse button and is graphically indicated by a small white sphere in the model (Fig. 93-3). Point X, Y,Z coordinates and RGB

values of its color are displayed, if available (Fig. 93-4). If the picked point belongs to some parts of the analyzed model, the information about the corresponding segment of the model is also displayed (Fig. 93-5).
Texturing section (Fig. 87-7) is formed by *Data Selection* section *and Selected Data* section – detailed description for both of them is in the chapter 2.10.4.2 Texture Image.
Button *Map Texture* (Fig. 87-8) starts the process of the texture mapping for the selected model. Data image used for the mapping is defined by the selected row in the table in *Selected Data* section. Button is enabled only if segmented model is available in the tree view. Newly formed textured model is placed into the tree view to the other models.
Export Textured Models for All Rounds button (Fig. 87-9) is enabled only if some texture data are selected (more about data selection in the chapter 2.10.4.2 Texture Image). Export takes texturing information (texture image type, parameters) according to the settings in each round and applies it to 3D models. Texturing information is taken from selected round as a template and is applied to 3D model for rounds which has not yet been loaded and are loaded during export. Resulting textured models are then saved to selected directory.

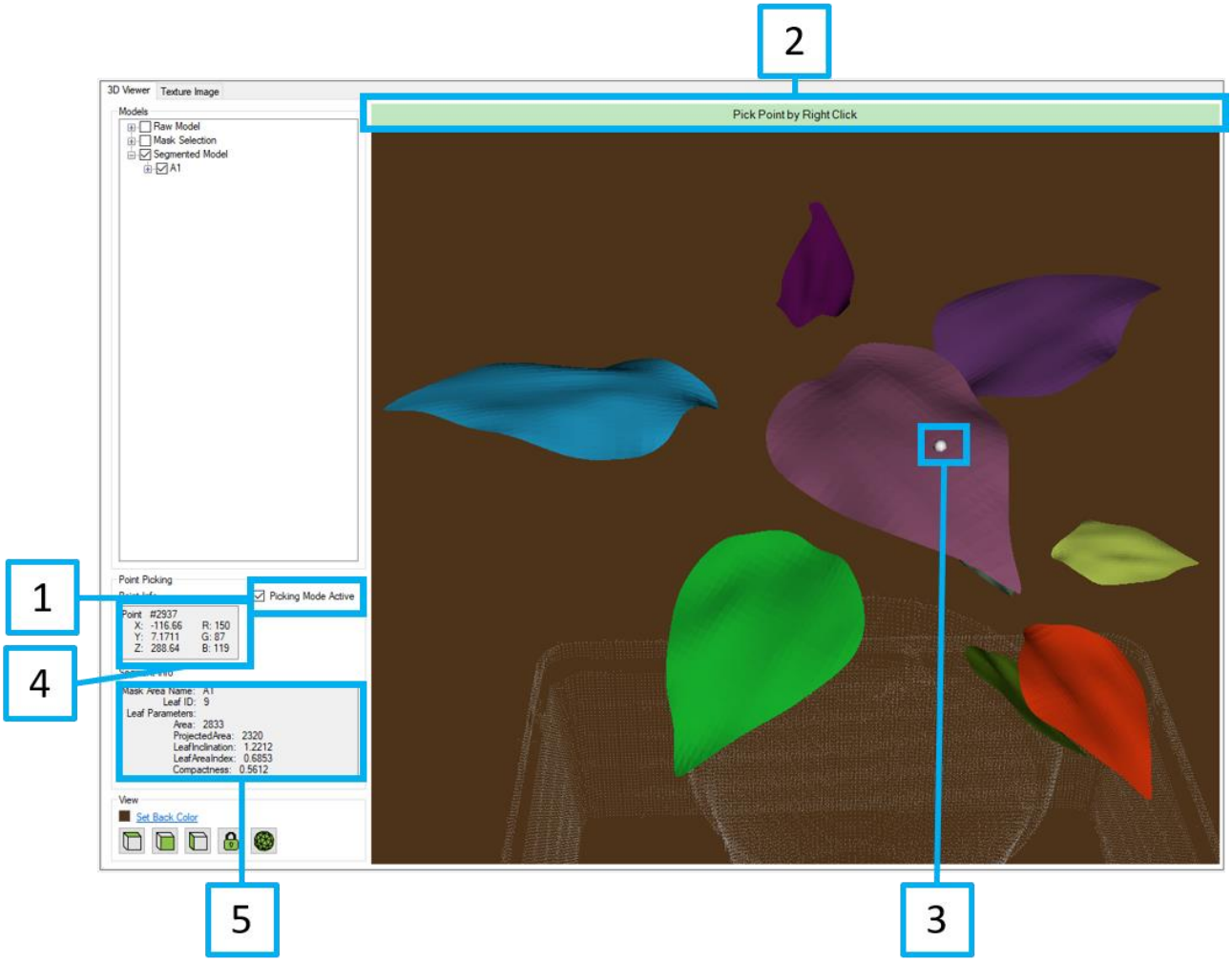


Fig. 93 Point Picking

2.10.4.2 TEXTURE IMAGE

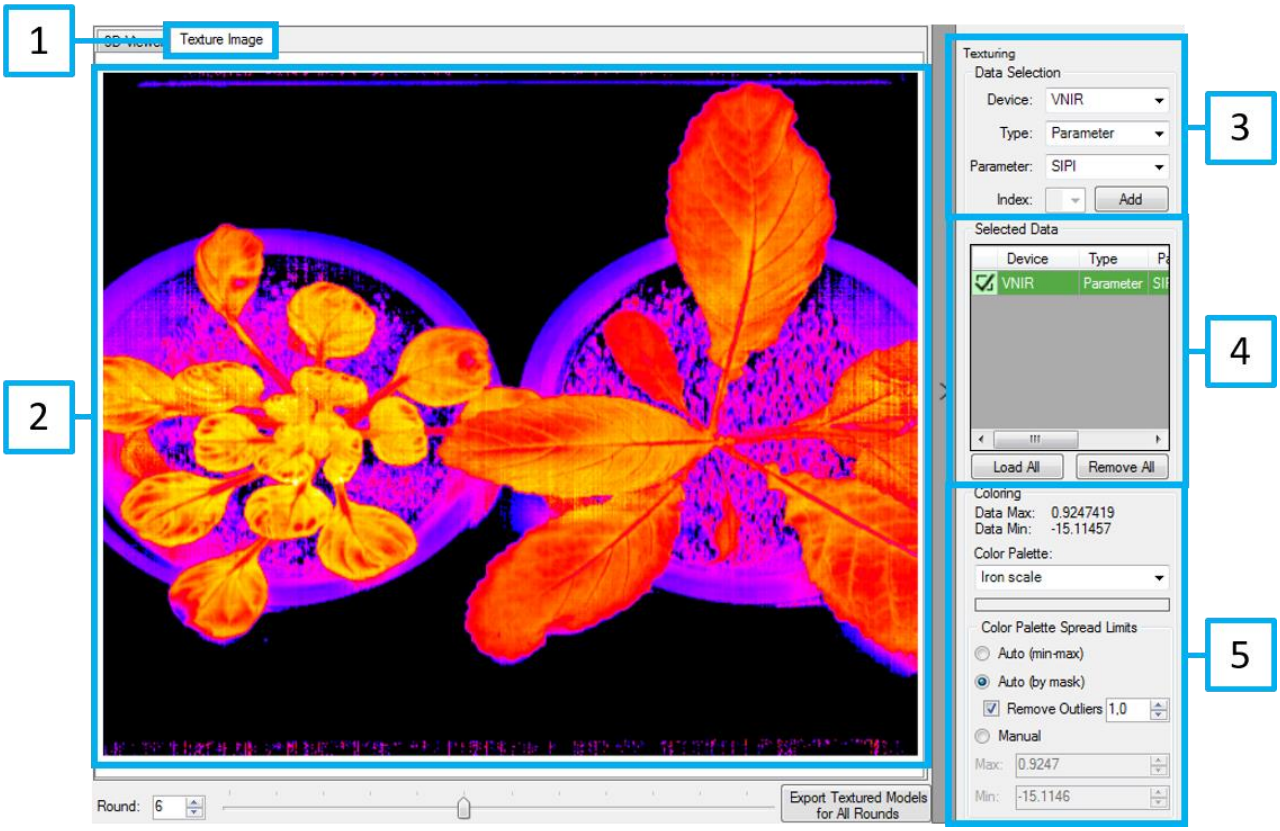


Fig. 94 Texture Image

Texture Image tab (Fig. 94-1) in *Visualization* section contains displaying panel (Fig. 94-2) with preview of the image for texture mapping.
Texturing Section contains controls for selection of the source data and is formed by *Data Selection* section (Fig. 94-3), *Selected Data* section (Fig. 94-4) and *Coloring* section (Fig. 94-5).
Data Selection section (Fig. 94-3) contains controls for selection of the texture image (Fig. 95 1). *Device* defines station where the image was taken. *Parameter* item defines displayed parameter and is used only if *Parameter* option is selected from the *Type* combo box. *Index* item defines index of the image in the series, in case a protocol was used for measuring (IR,…). *Type* item selects displayed image type, it is one of the following:

- Fish Eye Corrected – raw image after fisheye correction
- Color Segmented – image with color segmentation defined in the measurement protocol
- Parameter – image of the computed parameter
- Thermal Image
- RGB Image

Selection is confirmed by the *Add* button (Fig. 95-2).

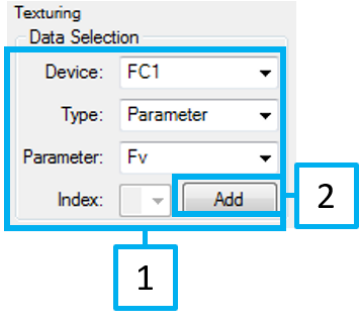


Fig. 95 Texturing Section - Data Selection

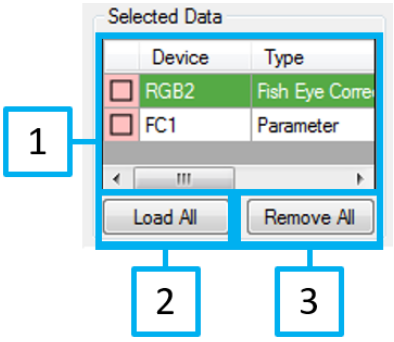


Fig. 96 Texturing Section - Selected Data

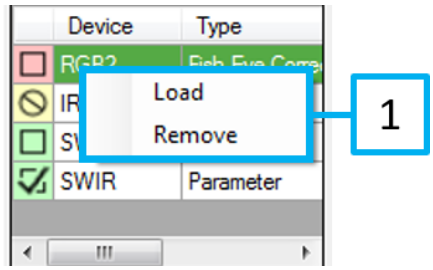


Fig. 97 Selected Data - Common Context Menu

Selected Data section (Fig. 96) contains a table holding selected texture data (Fig. 96-1) and two buttons for bulk load (Fig. 96-2) or removal (Fig. 96-3) of all rows in the table. Right mouse click on any row displays common context menu (Fig. 97-1), with options to load/remove only the current row. First column of the table gives information about image availability.
There are 4 possibile states:

- Data was not loaded – initialization state
- *Data was not found* – data loading process was not successful (This usually happens when data are requested from a round where the corresponding measuring station was not used.)
- *Data was not mapped* – data are successfully loaded, but are not mapped on 3D model
- *Data was mapped* – data are successfully mapped on 3D model

Texture mapping is enabled for the last two states. Mapping of an image can be done repeatedly. This is typically used for testing changes of the coloring settings. However, only the last used settings is reflected in the final mapping output.
Coloring Section (Fig. 94-5) with controls for image scale and color management is the same as described in the chapter 2.10.3 Imaging. The selected settings is applied to all rounds.

	Typical process of color mapping involves the following steps: 1) Selection of the experiment round (Fig. 86-3) 2) Selection of the data for texture mapping (Fig. 94-3) 3) Loading of the texture data (Fig. 96-2) or (Fig. 97-1) 4) Adjustment of the texture scale and color (Fig. 94-5) 5) Mapping of the texture (Fig. 87-9)

2.11 Local Analysis

Local analysis is module that allows to repeatedly analyze raw data saved in the system database. Results from the local analysis are not stored back to the system database, but arestored locally as the zip archive instead. Zip archive can be transferred to another computer and reopened with the PlantScreen Data Analyzer software, using the Open Local Analysis button from the 2.3 Log In screen.
Local Analysis part is divided into four parts:

- 2.11.1 Settings
- 2.11.3 Preview
- 2.11.4 Run
- 2.11.5 Finish

2.11.1 SETTING

Local Analysis settings part contains elements for choosing local analysis protocol, which canbe different from the protocol used during the measurement. It is also the only place where the tray type (size, number and placement of the areas on the tray) can be changed.

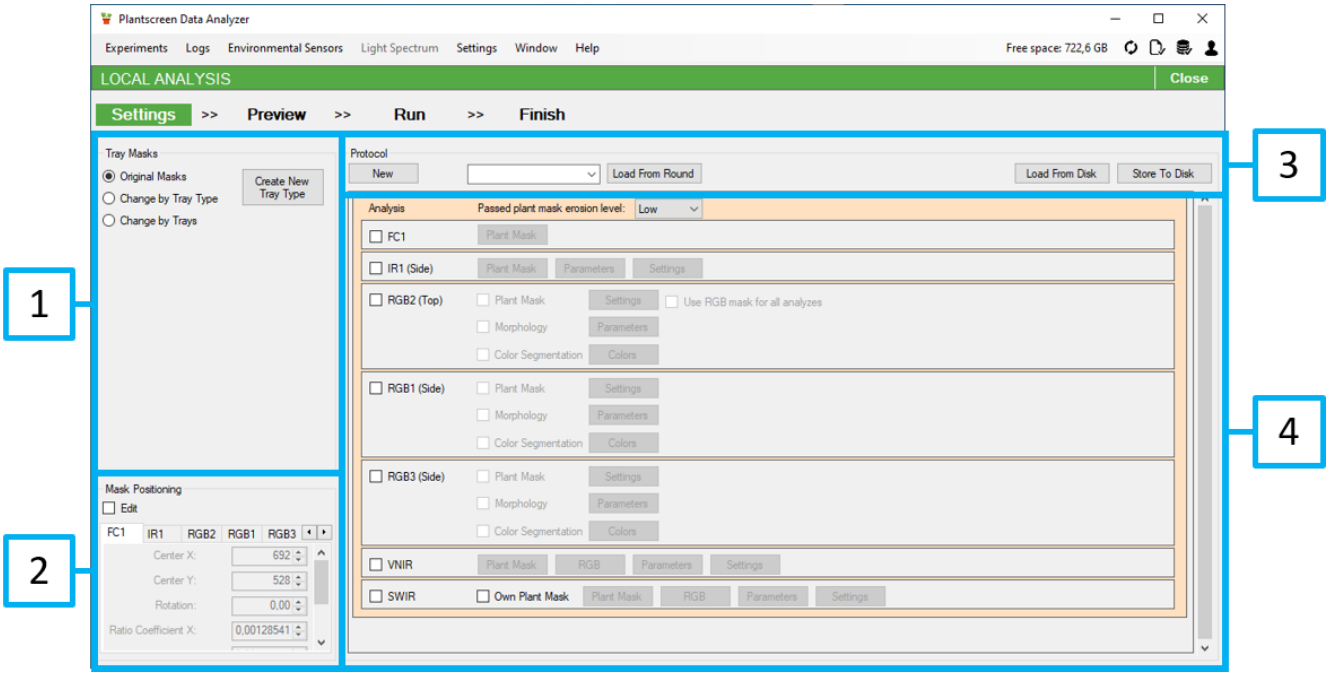


Fig. 98 Settings

Tray Mask controls (Fig. 98-1) allow to change tray mask for local analysis. It is used in the local analysis only, tray masks saved in the system are not affected. Options are following:

- Original Masks– uses original tray mask assignment from the database.
- Change by Tray Type– allows to change mask of each of the tray types used in the selected experiments to another type defined in the system
- Change by Trays– allows changing mask of each of the trays used in the selected experiment individually. Choosing a tray type in All Trays field changes the tray type for all displayed trays.

Draw New Mask button opens *Mask Builder* window, where new tray masks can be created.More about the *Mask Builder* in the chapter 2.11.2 **Mask Builder.**

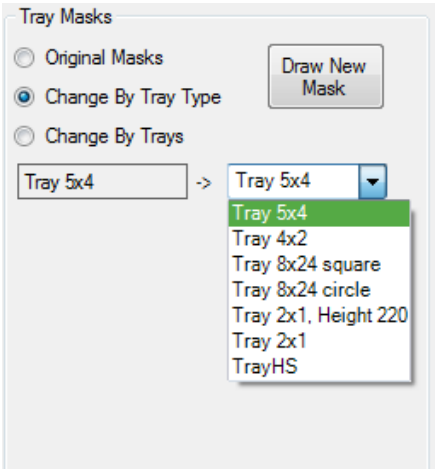


Fig. 99 Change by Tray Type

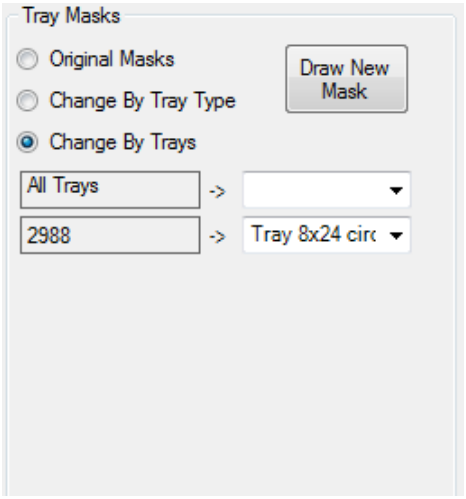


Fig. 100 Change by Tray

Mask Positioning group box (Fig. 98-2) allows changing mask position, rotation and ratio coefficient. It is useful when the original system calibration does not precisely fit. *Center X/Y* fields define position of the center of the masks in the image, *Rotation* sets the mask rotation around the center point and *Ratio Coefficient* affects the pixel size calculation, which is used to calculate mask size and parameters, which work with real world units (mm, mm^2, …).
Analysis block (Fig. 98-4) contains list of available analysis modules for the system. Analysis protocol can be loaded from disk, stored to disk or loaded from the database by round selection (Fig. 98-3). Some analyses need analysis result from another measurement unit; these dependencies are checked automatically. Analysis dependencies:

RGB analysis

- Morphology needs mask from the Plant Mask from the same RGB analysis – e.g. Morphology for RGB Top camera needs Plant Mask for the RGB Top camera
- Color Segmentation needs mask from the Plant Mask from the same RGB analysis.

IR analysis

- Both RGB Top measurement and RGB Top Plant Mask analysis are required

SWIR analysis

- If the VNIR camera is installed, VNIR analysis is required.
- If RGBS camera is installed, RGBS Plant Mask is equired.

MSC analysis

- Both RGB Top measurement and RGB Top Plant Mask analysis are required

Passed plant mask erosion level combo box allows setting plant mask edges erosion level. It isused when a mask is passed between the analyses which work with data from different sensor, for example when mask is transferred from the RGB analysis to the IR analysis. In thiscase, plant mask from RGB can be thanks to the different resolution slightly bigger than
required and points outside of the plant on IR image would be selected. Plan mask erosion algorithm cuts off some points from the plant mask edges, making it fit better to the IR data. *None* option is not recommended, as it is designed mainly for testing purposes and generallyprovides the worst mask fit.
Check box **Use RGB mask** for all analyses from RGB section of the analysis protocol allows to use RGB plant mask for all other devices (device accepts plant mask from RGB and does not create its own). It is similar to the *Leaf Tracking* behavior, except that *Leaf Tracking* passes leaf mask, whereas *Use RGB mask for all analyses* passes the plant mask.
Most of the analyses have parameters which are possible to edit by the *Plant mask* button.
The names and descriptions of the analysis settings can be found in tables (Tab. 7 RGB Color SegmentationTab. 4 RGB Morphology Parameters to Tab. 17 SWIR Settings) and illustrated in figures (Fig. 101 FC Plant Mask to Fig. 118 ROOT Plant Mask).
Further details regarding the image analysis pipeline and the settings of individual parameters are elaborated upon in Appendix 2 Automated image processing pipeline.

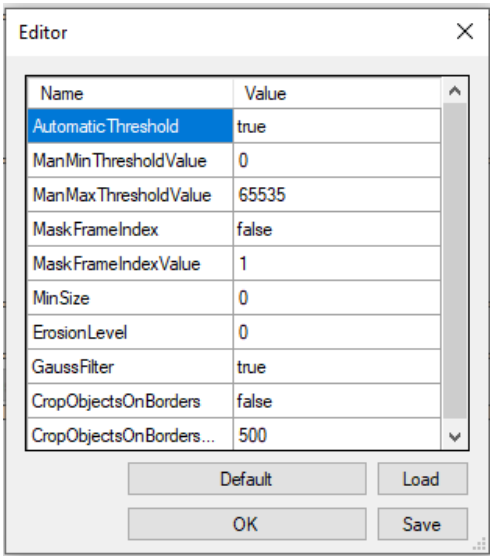
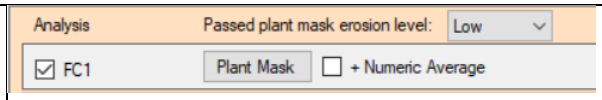
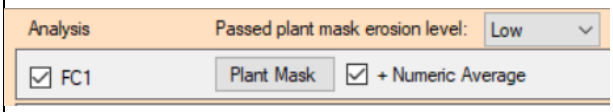


Fig. 101 FC Plant Mask

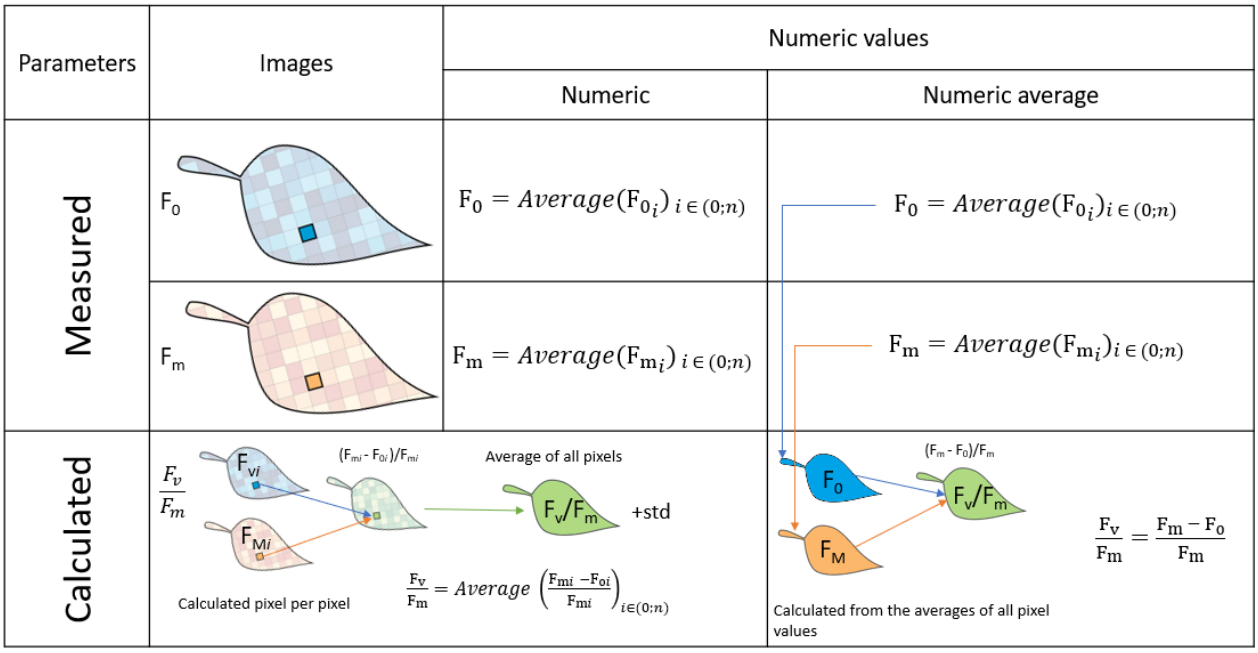
Parameter	Description
Automatic Threshold	true – Plant segmentation is performed automatically false - Plant segmentation is performed based on user-defined thresholds
ManMinThresholdValue	Minimum threshold value. Used only when Automatic Threshold is false.
ManMaxThresholdValue	Maximum threshold value. Used only when Automatic Threshold is false.
MaskFrameIndex	True - For plant mask detection the frame with user defined index (MaskFrameIndexValue) is used False - For plant mask detection the TimeVisual frame is used
MaskFrameIndexValue	Index of frame to use for plant mask detection. Used only when MaskFrameIndex is True.
MinSize	Minimal size of the mask element [px]
ErosionLevel	Parameter defining number of iterations for morphological operation – erosion. This step removes N pixels from outside of the objects / regions of interest. This is useful considering that border pixels (plant tissue and soil transition) can influence the parameter statistics.
GaussFilter	Activation/deactivation of the Gaussian filter in the image segmentation step [true/false]. Smoothing with a Gaussian filter can help to reduce noise and minor fluctuations in intensity, leading to a more uniform appearance along object borders. This can enhance object definition by reducing the impact of small-scale variations in intensity that may obscure the true object boundaries. Convenient to use for larger object (for small objects excessive smoothing can blur important details and compromise the definition)
CropObjectsOnBorders	Flag to crop small mask elements on the borders of the tray mask area [true/false]
CropObjectsOnBordersSize	Minimum size of objects that will not be removed even if they are on the edge of the area specified by the tray mask (objects smaller than this value will be cropped on the borders) [px]

Tab. 2 FC Plant Mask settings

Numeric average checkbox	Description
Frames numeric	For the calculated parameter, the calculation is performed individually for each pixel, and then averaging across pixels is applied to obtain the final value for the entire object. If the checkbox for "numeric average" is not checked, the user will only receive **numeric** values in the resulting parameters.

	
Numeric average	For the calculated parameter, all individual parameters used in the calculation are first averaged across all object pixels before the calculation defined by the parameter formula is performed. If the checkbox 'numeric average' is checked, the user will receive both versions in the resulting parameters - numeric frames and numeric average. 
Recommendation:	In general, we would always recommend to use numeric average. FvFm measurement can serve as an example for explanation. If frame numeric is used, you use pixel by pixel fluorescence values to calculate FvFm and then you average the FvFm value over the area that you selected, means over all pixels selected. In case of numeric average, you take Fo value over all area selected (all pixels selected) and Fm value over all area selected and use this F0 and Fm value to calculate FvFm. If you analyse object with strong signal and you do not integrate any noise, you will not see any difference between the two results. If you have weaker signal and you have some noise in your measurement, the average numeric will be always more powerful with less noisy pixels included.

Tab. 3 Numeric, Numeric average difference



n – number of pixels per object

Fig. 102 Numeric, numeric average scheme

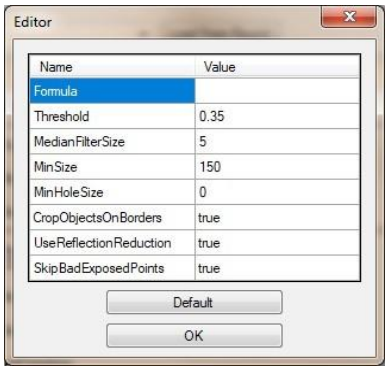


Fig. 103 RGB Plant Mask

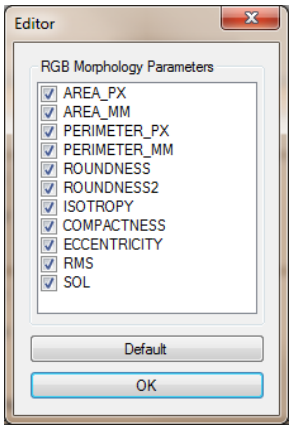


Fig. 104 RGB Morphology Parameters

Parameter	Description
AREA_PX	Object area [px]
AREA_MM	Object area[mm^2]
PERIMETER_PX	Object perimeter[px]
PERIMETER_MM	Object perimeter [mm]
ROUNDNESS	Roundness of the object, computed as a ratio of area and perimeter(4Pi x Area) / $Perimeter^2$
ROUNDNESS2	Roundness of the object, computed as a ratio of area and convex hullperimeter (4Pi x Area) / $Perimeter^2$
ISOTROPY	Isotropy of the object, computed as ratio of area and perimeter of the polygoncreated by object vertices (4Pi x Area) / $Perimeter^2$
COMPACTNESS	Compactness of the object, computed as ratio of the object area and area ofthe object convex hull.
ECCENTRICITY	Eccentricity of the object, computed as difference between the object convexhull area and area of the circle with its center in the object center
RMS	Rotational symmetry of the object, based on the fitting of the ellipsis withidentical second central moment as the analyzed object.
SOL	Slenderness of the leaves
WIDTH_PX	Object width [px], side view camera only
WIDTH_MM	Object width [mm], side view camera only
HEIGHT_PX	Object height [px], side view camera only
HEIGHT_MM	Object height [mm], side view camera only

Tab. 4 RGB Morphology Parameters

Parameter	Description
Formula	Formula definition for object mask generation. Formula can contain constants(1, 2, 3, …), operators (+, -, *, /, min, max, ln, log, sqrt, ^) and variables (R, G, B), which define color component used.
Threshold	Threshold for the object mask generation
MedianFilterSize	Size of the median filter, used for object mask generation, odd number only
MinSize	Minimal size of the mask element [px]
MinHoleSize	Minimal size of holes in the mask element [px]
CropObjectOnBorders	Flag to crop small mask elements on the borders of the mask area [true/false]
CropObjectsOnBordersSize	Minimum size of objects that will not be removed even if they are on the edge of the area specified by the tray mask (objects smaller than this value will be cropped on the borders) [px]
UseReflectionReduction	Flag to use different mask generation algorithm. Works better if reflectionsand dark spots are present in the image [true/false]
SkipBadExposedPoints	Flag to crop over/under exposed pixels from the plant mask [true/false]. Bad exposed pixel has at least one color channel (R/G/B) set to ist minimum or maximum (0 – 255 for 8 bit per channel format)

Tab. 5 RGB Plant Mask

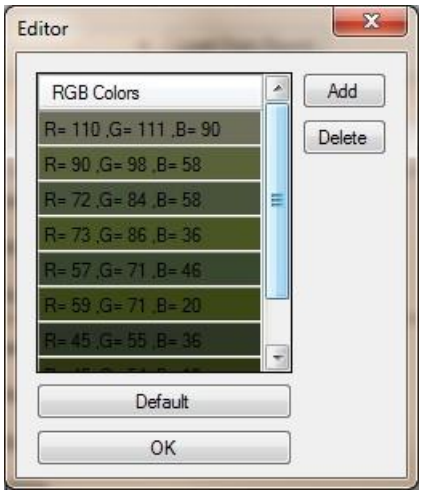


Fig. 105 RGB Color Segmentation

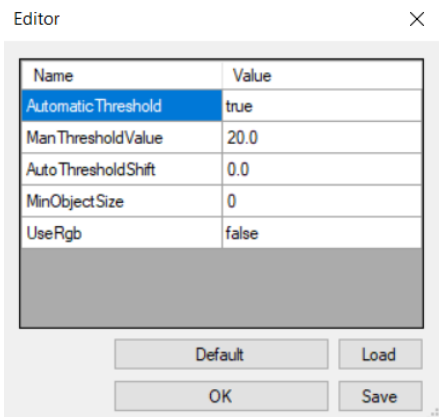


Fig. 106 IR Plant mask settings

Parameter	Description
Automatic Threshold	true – Plant segmentation is performed automatically false - Plant segmentation is performed based on user-defined threshold (ManThresholdValue)
ManThresholdValue	Manual threshold value. Used only when Automatic Threshold is false. Pixels with value lower than this threshold are evaluated as plant specific
Auto Threshold Shift	Automatically determined threshold can be shifted according to requirements
Min Object Size	Minimal size of the mask element [px]
Use RGB	If true, mask from RGB is used for image segmentation. [true/false]

Tab. 6 IR Plant mask *applicable for side view

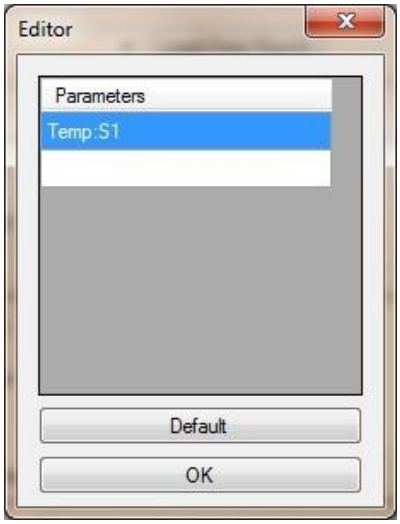


Fig. 107 IR Parameters

Parameter	Description
R	Red subcomponent of the color, range <0,255>
G	Green subcomponent of the color, range <0,255>
B	Blue subcomponent of the color, range <0,255>

Tab. 7 RGB Color Segmentation

Parameter	Description
SmoothSpan	Range of smoothing plant outline before local extremes finding. Removes small teeth on plant border so that this noise won't divide the plant to false leaves. Too low value can cause division the plant to more leaves than expected, too high value can miss some leaves division.
CropNearPeaksDistance	Distance for cropping near peaks (local extremes) of the same type(leaves tipsor leaves joints)
CropNearPeaksMinMax	Distance for cropping near peaks (local extremes) of the opposite type (leavestips and leaves joints)
MinObjSize	Minimum object size to keep [px]. Removes separate objects of plants andleaves smaller than the given value
PathTolerance	Tolerance for finding path from plant centroid to nearest point of separated leaf. Too low value can cause dissapearance of some separated leaves. Too high value can cause joint of more separated leaves into one.

MinOverlay	Minimal overlay to identify leaf compliance [px]. Too low value can cause assignment of a new leaf to some different old leaf from previous image instead of new leaf index creation. Too high value can cause disagreement of the same leaf between two images and wrong new leaf index creation.
CenterHoleDiam	Diameter of hole which will crop found leaves from the plant center

Tab. 8 Leaf Tracking Settings

Parameter	Description
Temp:S1	User defined parameters. Name of the parameter is before the colon, equation for its computation after the colon. Equation can contain constants (1,2,3,…), operators (+, -, *, /, min, max, ln, log, sqrt, ^) and variables (S1, S2, ...), which define number of the frame used for computation.

Tab. 9 IR Parameters

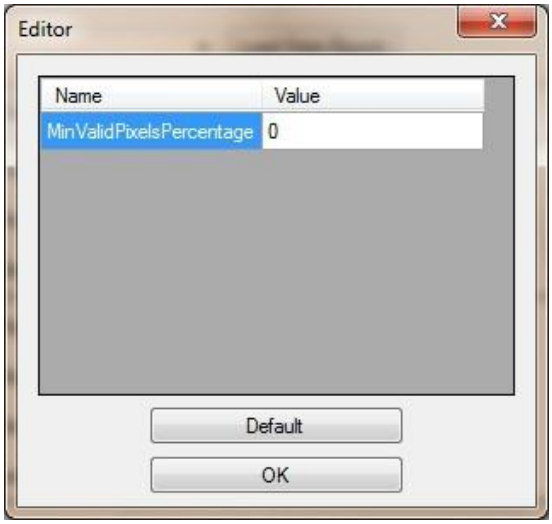


Fig. 108 IR Settings

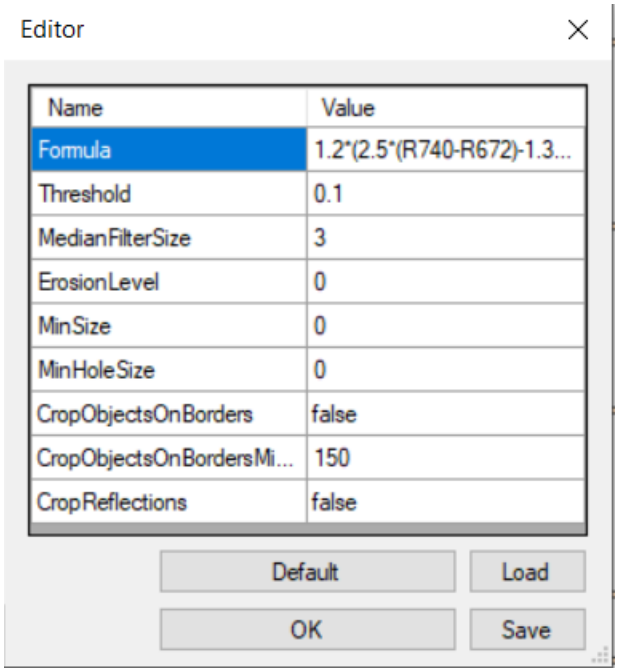


Fig. 109 VNIR Plant Mask

Parameter	Description
MinValidPixelsPercentage	Minimal percent of the valid pixels for computation. Invalid pixel is defined as pixel, for which the equation gives invalid result (division by zero, …). These pixels are discarded from the parameter computation. If the valid pixel percentage is lower than the threshold, whole computation of the corresponding parameter is flagged as failed. If 0 is set, any number of invalid pixels is accepted. If 100 is set, all pixels have to be valid.

Tab. 10 IR Settings

Parameter	Description
Formula	Formula definition for object mask generation. Formula can contain constants(1, 2, 3, …), operators (+, -, *, /, min, max, ln, log, sqrt, ^) and variables (R740, R672, ...), which define wavelength used. Variables wavelengths must be fromvalid range defined by the camera.
Threshold	Threshold for mask generation. Formula results are compared with this value.
MedianFilterSize	Size of the median filter, used for object mask generation
ErosionLevel	level of morphological operation (erosion) applied on detected plant mask
MinSize	Minimal size of the mask element [px]
MinHoleSize	Minimal size of holes in the mask element [px]
CropObjectOnBorders	Flag to crop small mask elements on the borders of the mask area [true/false]
CropObjectsOnBordersSize	Minimum size of objects that will not be removed even if they are on the edge of the area specified by the tray mask (objects smaller than this value will be cropped on the borders) [px]
CropReflections	Pixels whose values are close to the white calibration values are cropped.

Tab. 11 VNIR Plant Mask

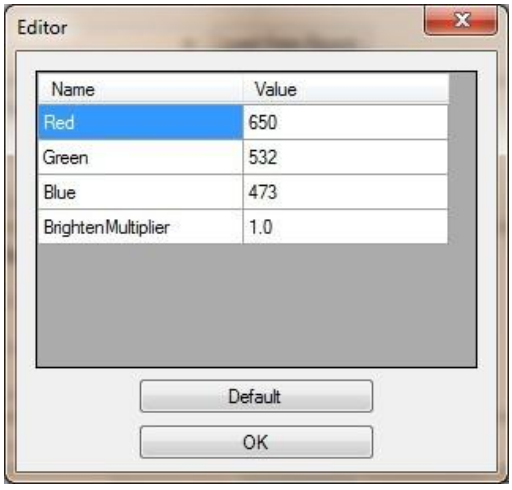


Fig. 110 VNIR RGB

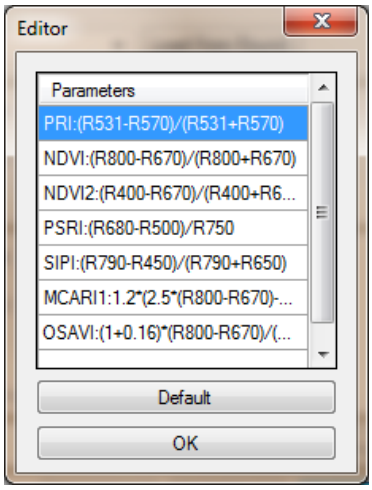


Fig. 111 VNIR Parameters

Parameter	Description
Red	Wavelength used as red color for RGB image
Green	Wavelength used as green color for RGB image
Blue	Wavelength used as blue color for RGB image
BrightenMultiplier	RGB value multiplier. If greater than 1, image is brighter, if lower, image is darker.

Tab. 12 VNIR RGB

Parameter	Description
PRI, …	User defined parameters. Name of the parameter is before the colon, equation for its computation after the colon. Equation can contain constants (1, 2, 3, …), operators (+, -, *, /, min, max, ln, log, sqrt, ^) and variables (R740, R672, ...), which define wavelength used. Variables wavelengths must be fromvalid range defined by the camera.

Tab. 13 VNIR Plant Mask

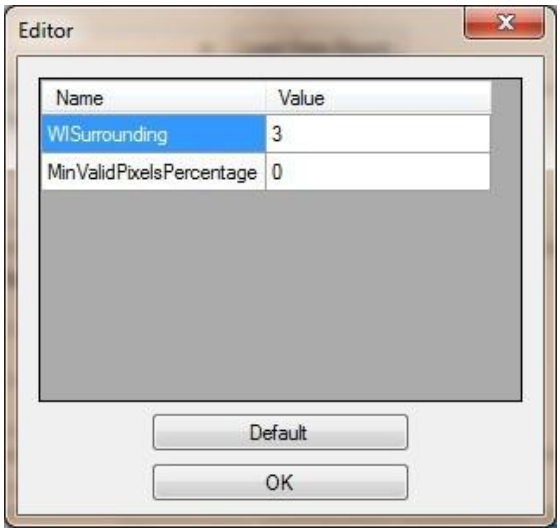


Fig. 112 VNIR Settings

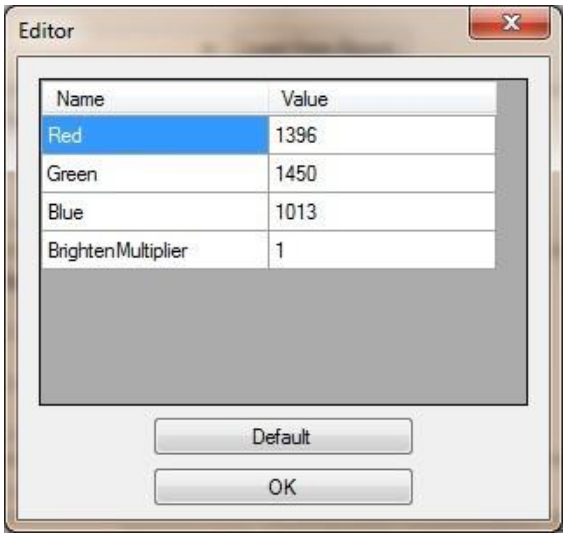


Fig. 113 SWIR RGB

Parameter	Description
WISurrounding	Parameter for camera noise reduction. Defines number of neighboring pixels(both in spectral and spatial dimensions), which are averaged and resulting value is used for the parameter computation. If set to 0, the original pixel value is taken.
MinValidPixelsPercentage	Minimal percent of the valid pixels for computation. Invalid pixel is defined as pixel, for which the equation gives invalid result (division by zero, …). These pixels are discarded from the parameter computation. If the valid pixel percentage is lower than the threshold, whole computation of the corresponding parameter is flagged as failed. If 0 is set, any number of invalid pixels is accepted. If 100 is set, all pixels have to be valid.

Tab. 14 SWIR RGB

Parameter	Description
Red	Wavelength used as red color for RGB image
Green	Wavelength used as green color for RGB image
Blue	Wavelength used as blue color for RGB image
BrightenMultiplier	RGB value multiplier. If greater than 1, image is brighter, if lower, image isdarker.

Tab. 15 VNIR Settings

Fig. 114 SWIR Parameters

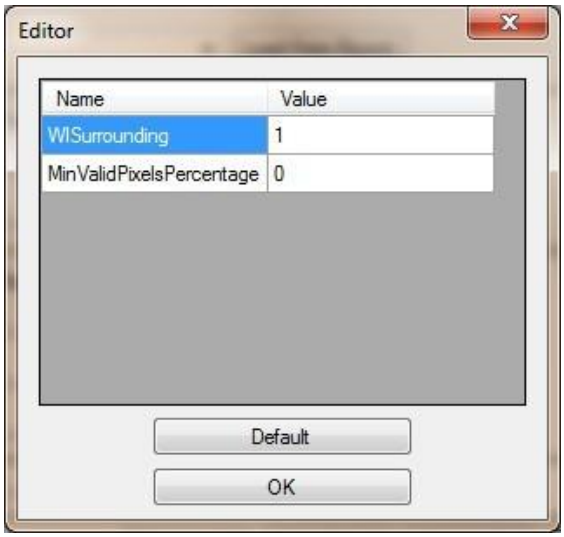


Fig. 115 SWIR Settings

Parameter	Description
WATER1:R1440/R960	User defined parameters. Name of the parameter is before the colon, equation for its computation after the colon. Equation can contain constants (1, 2, 3, …), operators (+, -, *, /, min, max, ln, log, sqrt, ^) and variables (R740, R672, ...), which define wavelength used. Variables wavelengths must be fromvalid range defined by the camera.

Tab. 16 SWIR Parameters

Parameter	Description
WISurrounding	Parameter for camera noise reduction. Defines number of neighboring pixels (both in spectral and spatial dimensions), which are averaged and resulting value is used for the parameter computation. If set to 0, the original pixel value is taken.

Tab. 17 SWIR Settings

Parameter	Description
WATER1:S1/S2	User defined parameters. Name of the parameter is before the colon, equation for its computation after the colon. Equation can contain constants (1,2,3,…), operators (+, -, *, /, min, max, ln, log, sqrt, ^) and variables (S1, S2, ...), which define image (by lightset id) used for computation.

Tab. 18 MSC Parameters

Parameter	Description
MinValidPixelsPercentage	Minimal percent of the valid pixels for computation. Invalid pixel is defined as pixel, for which the equation gives invalid result (division by zero, …). These pixels are discarded from the parameter computation. If the valid pixel percentage is lower than the threshold, whole computation of the corresponding parameter is flagged as failed. If 0 is set, any number of invalid pixels is accepted. If 100 is set, all pixels have to be valid.

Tab. 19 MSC Parameters

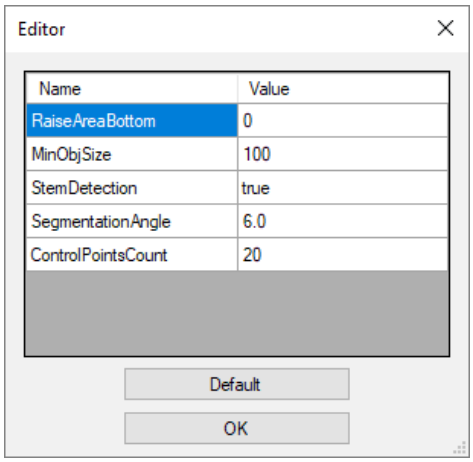


Fig. 116 3D Settings

Parameter	Description
RaiseAreaBottom	Offset for the tray cut-off. It is the distance from the tray cover to top of the pot [mm].
MinObjSize	Minimum object size in the point cloud model that will can be taken as a leaf [number of points].
StemDetection	Flag for stem detection in the model [true/false]
SegmentationAngle	The angle between normals used as the threshold value for point cloud segmentation [°], the parameter is only available for Experimental Leaf Type, more detailed in Appendix 2 Automated image processing pipeline.
ControlPointsCount	The number of points that will be used during triangulation to smooth the edges of the leaves [number of points], the parameter is only available for Experimental Leaf Type, more detailed in Appendix 2 Automated image processing pipeline.

Tab. 20 3D Settings

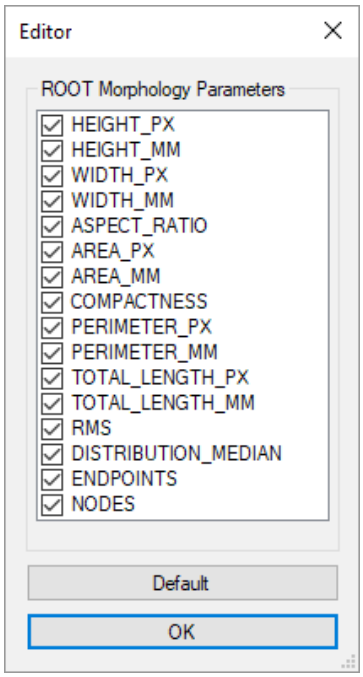


Fig. 117 ROOT Morphology Parameters

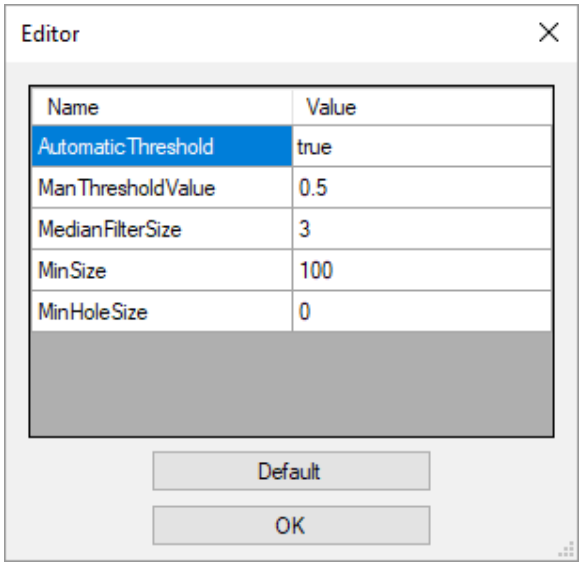


Fig. 118 ROOT Plant Mask

Parameter	Description
HEIGHT_PX	Object height [px].
HEIGHT_MM	Object height [mm].
WIDTH_PX	Object width [px].
WIDTH_MM	Object width [mm].
ASPECT_RATIO	Ratio between the width of the object and the height of the object.
AREA_PX	Object area [px].
AREA_MM	Object area [mm^2].
COMPACTNESS	Compactness of the object, computed as ratio of the object area and area ofthe object convex hull.
PARIMETER_PX	Object perimeter [px].
PERIMETER_MM	Object perimeter [mm].
TOTAL_LENGTH_PX	The number of pixels in the skeleton of the object (wide roots reduced to onepixel) [px].
TOTAL_LENGTH_MM	The number of pixels in the skeleton of the object (wide roots reduced to onepixel) converted to millimeters [mm].
RMS	Rotational symmetry of the object, based on the fitting of the ellipsis withidentical second central moment as the analyzed object.
DISTRIBUTION_MEDIAN	The median number of object pixels in each row of the image.
ENDPOINTS	The number of root pixels that adjoins only one pixel.
NODES	The number of object pixels that have more than two neighbors.

Tab. 21 ROOT Morphology Parameters

Parameter	Description
AutomaticThreshold	Using automatic threshold for the object mask generation [true/false].
ManThresholdValue	Manual threshold for the object mask generation.
MedianFilterSize	Size of the median filter, used for object mask generation, odd number only.
MinSize	Minimal size of the mask element [px].
MinHoleSize	Minimal size of holes in mask element.

Tab. 22 ROOT Plant Mask

2.11.2 Mask Builder

Mask is a list of named areas on the tray, which are used to define areas of the image where plant specific features are extracted. Using a mask allows to put more objects on the tray and distinguish them in the analysis, thus computing separate set of parameters for each of the objects.

	On the PC hard drive, mask is an XML file with list of areas. Area parameters are name, type, and coordinates.

Tray type is a pack of name and top and side mask.
Standard tray types are pre-defined in the system. The types cover standard tray types supplied by the PSI. In case new tray type needs to be created, or if an existing tray type needs to be modified, software contains *Mask Builder* graphical tool.
Mask Builder window (Fig. 119) allows to create top and side mask and save them as a tray type. Radio buttons Fig. 119-1 are used to switch between top and side tray mask.
Background image is loaded using the *Template Image* controls (Fig. 119-2). After the round, tray and imaging device is selected, *Load Image* button loads the background image from the

If modifying an existing tray type, tray mask can be loaded from the database or from the fileusing Template Mask controls (Fig. 119-3).
Color scale of the false-colored image can be changed by the Coloring controls. This dialog is identical to the one described in the chapter 2.10.3 Imaging, Fig. 76-7.
Main part of the window is graphical tool for creating and editing masks (Fig. 119-4) described in chapter2.11.2.1 Mask Builder Graphical Tool.
Area Fig. 119-6 contains tools to store new masks or tray types. Single mask can be saved to the file by the *Save Mask to File* button. After the *Tray Type Name* is filled, new tray type is saved by clicking the *Store Tray Type* button. It is at first saved only to the local memory. If it is used in the analysis, it is then saved to persistent local database and can be reused later. Ifit is not used in the analysis, it is discarded when the PlantScreen Data Analyzer is closed.

	New tray types are for local use only, they are not passed to the system database and cannot be used for measurement.

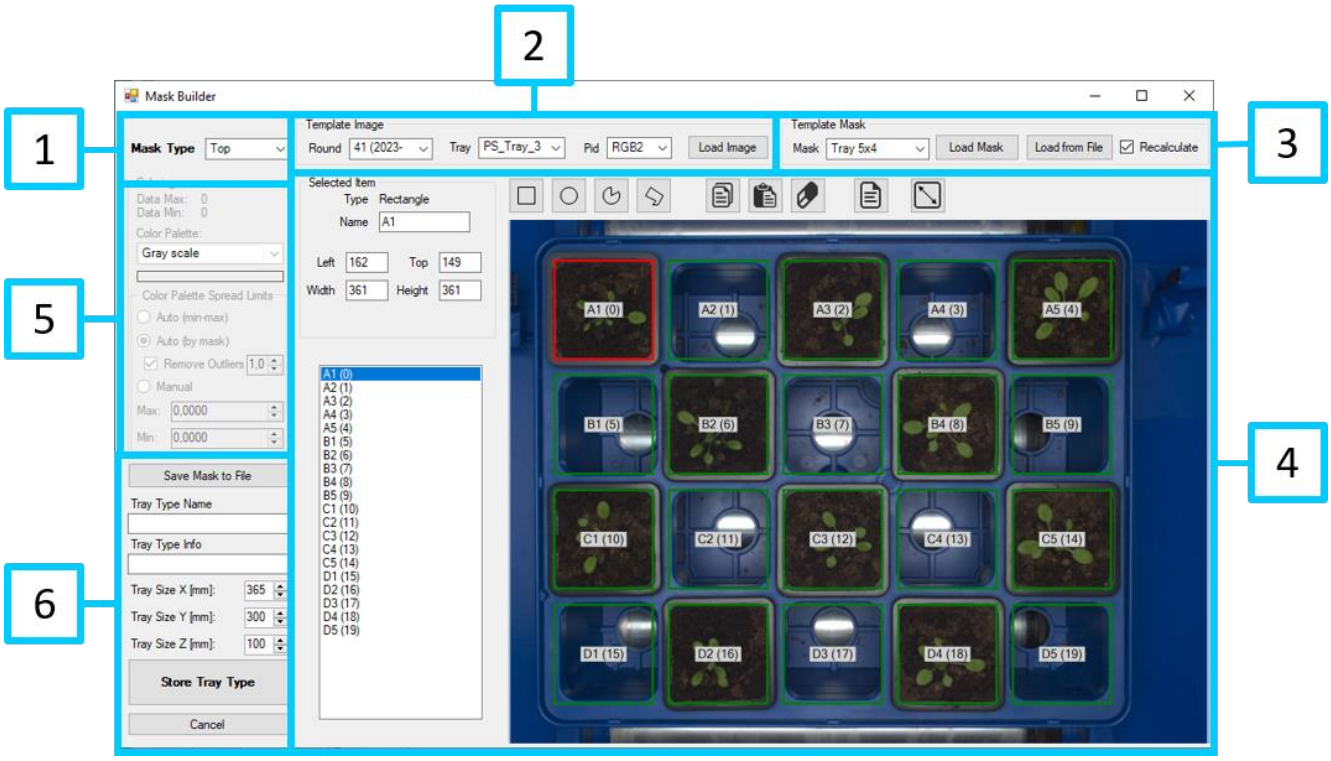


Fig. 119 Mask Builder Window

	If only top mask or only side mask is created and Store Mask button is clicked, the other mask is generated automatically as mask with no areas.
	During analysis, plants are identified within specified area(s) of the tray type as prescribed in the registration file. In case the areas in once measured trays do not match actual requirements, they can be changed by means of reanalysis with a newly defined tray type. When drawing a new tray mask with the Mask Builder tool in local analysis, each area must be named equally to the original area name as defined by registration. The local analysis fails to retrieve plant related information, when area names used for local analysis and registration do not match.

2.11.2.1 Mask Builder Graphical Tool

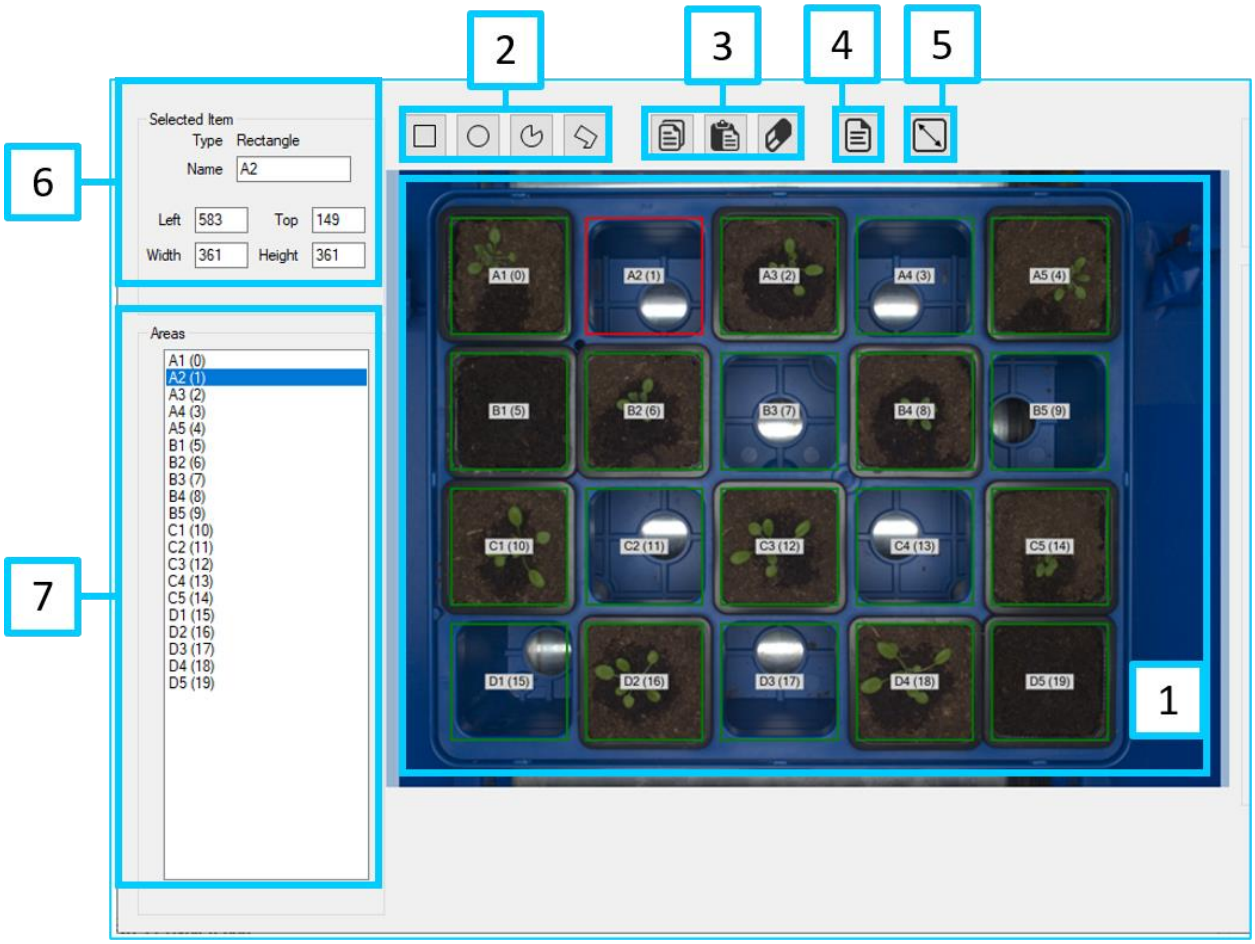


Fig. 120 Mask Builder

There are four basic area types available (Fig. 120-2):

- rectangle
- ellipse
- pie
- polygon

Drawing mode is activated by selecting one of the area types. New area is created by clickingand holding the left mouse button and moving the mouse over the drawing window (Fig. 120-1). It is possible to create more areas of the same type until the drawing mode is deactivated; this is done by clicking the right mouse button.
Custom shape is drawn in a little different way. Selection of the custom area type activates the drawing mode, and clicking of the left mouse button adds single point on the position of the mouse pointer. When right mouse button is clicked, area is closed if it contains at least three points – the last point is connected with the first one. If the three point's condition is not met, area is discarded. Custom shape drawing mode is then deactivated.
If drawing mode is not active, existing areas can be selected by clicking the left mouse button. More areas can be selected by holding the SHIFT key while clicking. When mouse cursor is placed over the selected area(s), it is changed to action icon corresponding to the cursor position in the area, allowing it to be moved or resized.

	If more areas are selected, the operation is applied to each item from the selection. If CTRL key is pressed while changing the area dimensions, area width and height are equalized, so perfect square or circle is created instead of rectangle or ellipsis.

Set of function buttons is available (Fig. 120-3):

-  actual selection is copied to the clipboard
-  clipboard content is pasted to the drawing area
-  actual selection is deleted
-  toggles the area names display

Content of the actual selection is displayed in the *Area* field (Fig. 120-5) and details of the selected areas in the *Selected Item* group box (Fig. 120-4). Name and parameters can be changed by typing the value to the corresponding field and pressing the ENTER key.

	If more areas are selected, the parameters in the Selected Item group box are displayed only if the selected areas are of the same type. Values of the parameters are displayed only if they are identical across the all selected areas. If parameter is changed, it is changed for all selected areas.

Area name has to be unique in the mask scope. A check is done before the mask is saved, if the condition is not met, areas with the same name are put to a selection and warning dialogis displayed.

2.11.3 PREVIEW

Local analysis preview contains elements for displaying results of the local analysis. It is designed to enable quickly adjust analysis settings (2.11.1 Settings) and fine tune mask transfer settings (leaf tracking, IR, ..) on one measurement of one tray before running the analysis on whole experiment.
Preview Data Selection (Fig. 121-1) contains controls for round and tray selection.

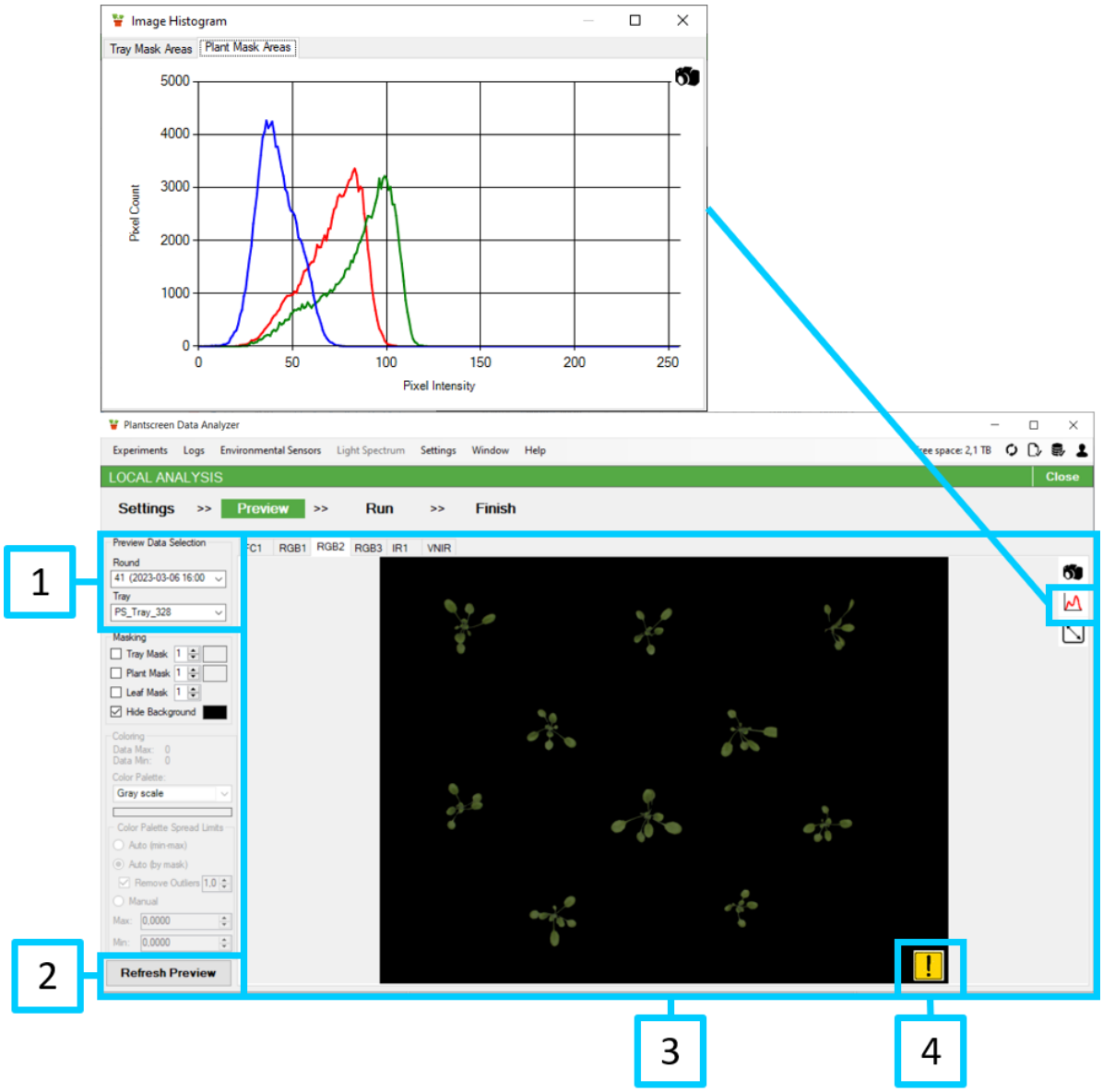


Fig. 121 Local Analysis Preview

Local analysis preview for selected round and tray is computed when *Refresh Preview* button(Fig. 121-2). Results of the analysis are displayed in the main section (Fig. 121-3).
Buttons for switching between measurement stations are in the lower part of the main section. If measured data doesn't exist for selected round, tray and device, *The selected image was not found* is displayed in the main section.
Warning tool tip (Fig. 121-4) displays various messages related to the analysis computation.There are some general classes of the messages:

- Analysis for the selected device is not on in the protocol–clicked tab does not contain any results because the analysis was not selected in the 2.11.1 Settings
- Missing top plant mask – RGB/RGB lines can data for the selected tray was not measured, so analysis depending on it cannot be computed
- Analysis crash debug messages

2.11.4 Run

Run section contains controls to start analysis with the settings from the 2.11.1 Settings onselected data. Rounds and trays for analysis are selected in the right part of the window.

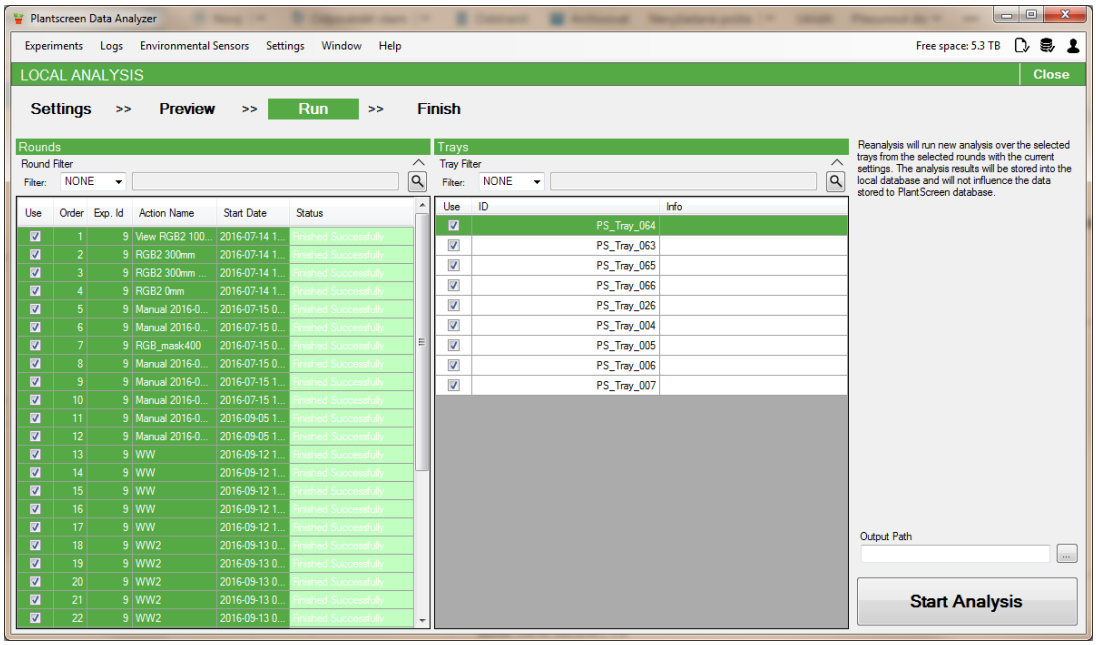


Fig. 122 Local Analysis Run

Clicking the *Start Analysis* button start the analysis. The analysis results are stored in thelocal database and does not influence data stored in the PlantScreen database.

	When the analysis run, it creates folder structure with temporary files. Do not open these files until the analysis is completed. If the file(s) are opened during the analysis process, the analysis may be corrupted or incomplete.

2.11.5 FINISH

Finish section contains analysis summary, error log and shortcut to display analyses data.

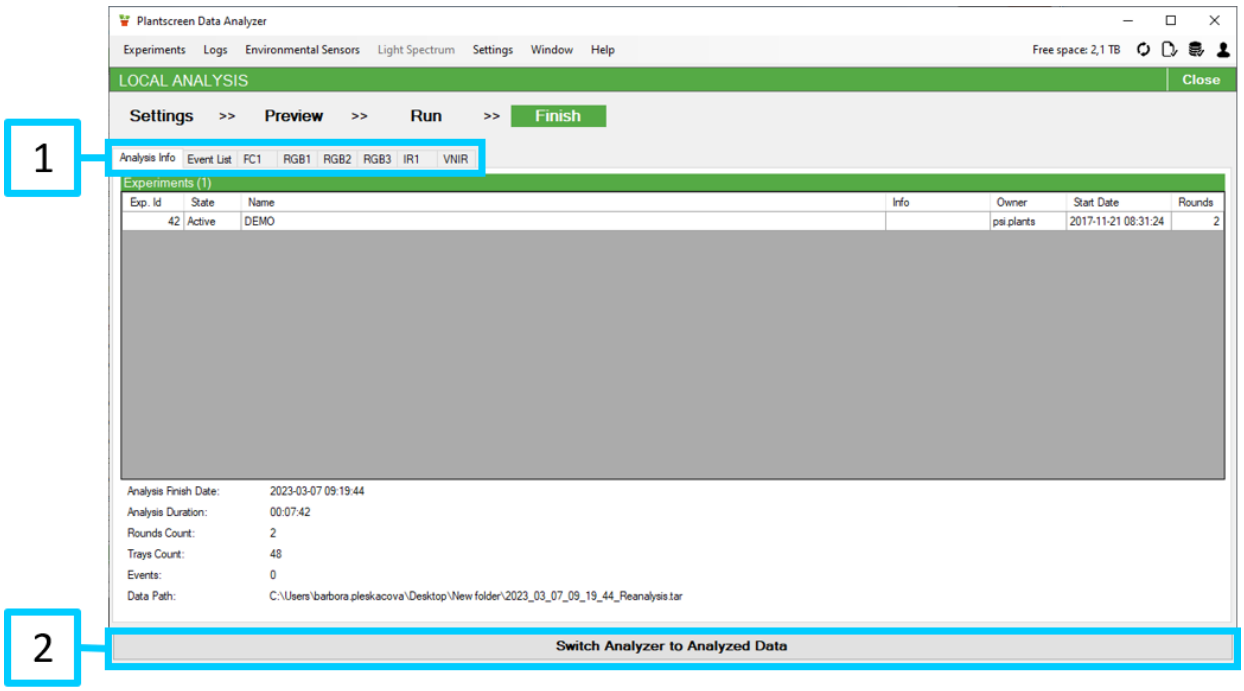


Fig. 123 Local Analysis Finish

Tab control (Fig. 123-1) contains tabs with analysis summary, event list and detailed device-based results.
Analysis summary (Fig. 123) shows basic information about the analysis process – usedexperiments and analysis statistics.
Event list (Fig. 124) displays events caught during the analysis run.

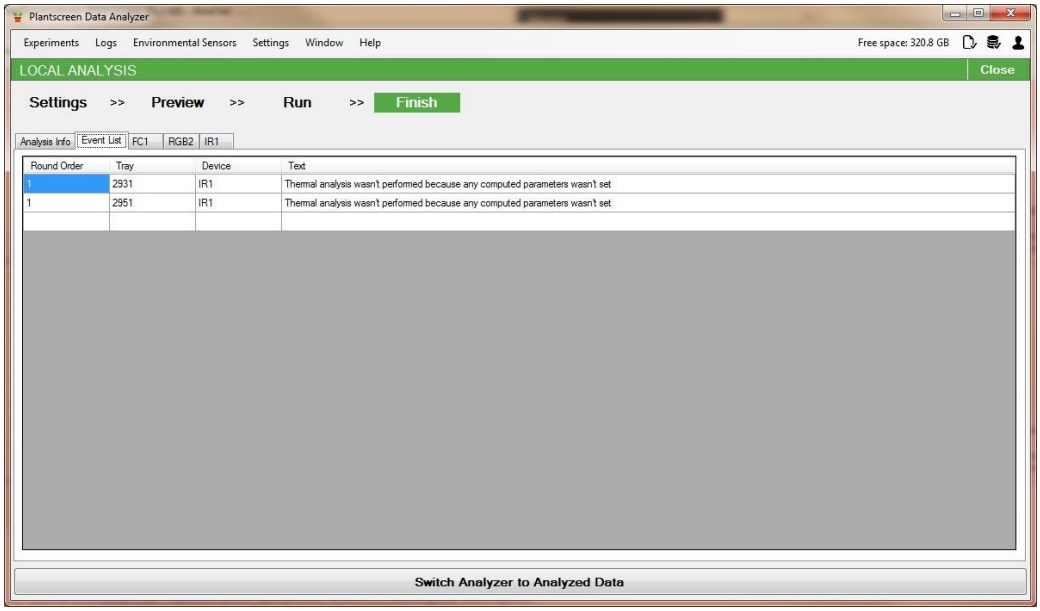


Fig. 124 Events List

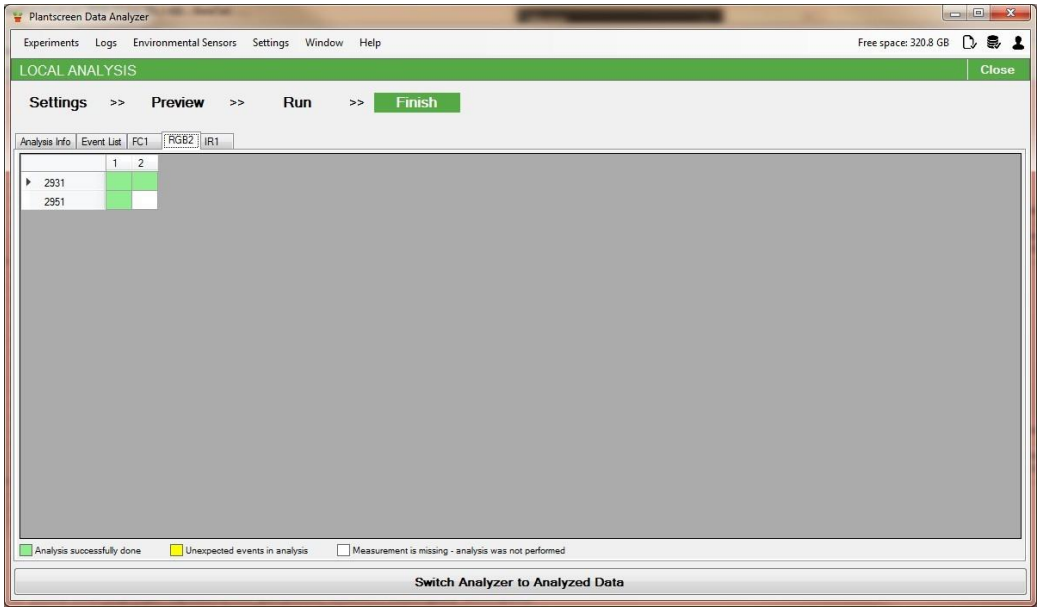


Fig. 125 Local Analysis Device Information

Device tabs (Fig. 125) contains graphical result for each tray and each round used in the analysis. Legend is located in the bottom part of the window.
Button *Switch Analyzer to Analyzed Data* (Fig. 123-2) switches application to the Local Analysis mode (Fig. 126) and opens 2.7 Experiments window with the currently analyzed data.

Fig. 126 Local Analysis Mode

2.12 POSTANALYSIS

Postanalysis is a module that allows allows to combine the outputs of individual analyzes. Based on user define mathemathical operations user can calculate new parametres from the measured and/or calculated parametres saved in the PS system database. Postanalysis tool can process either the raw data saved in system database or results from the local analysis, which are stored locally as tar files. Current version of the postanalysis tool is designed solely for numerical values, however future extension will be developped also for calculations done based on image input data (e.g. fluorescence images).
For initiation of the postanalysis for a given experiment (Fig. 127-1), select the experiment and click the postanalysis button (Fig. 127-2).

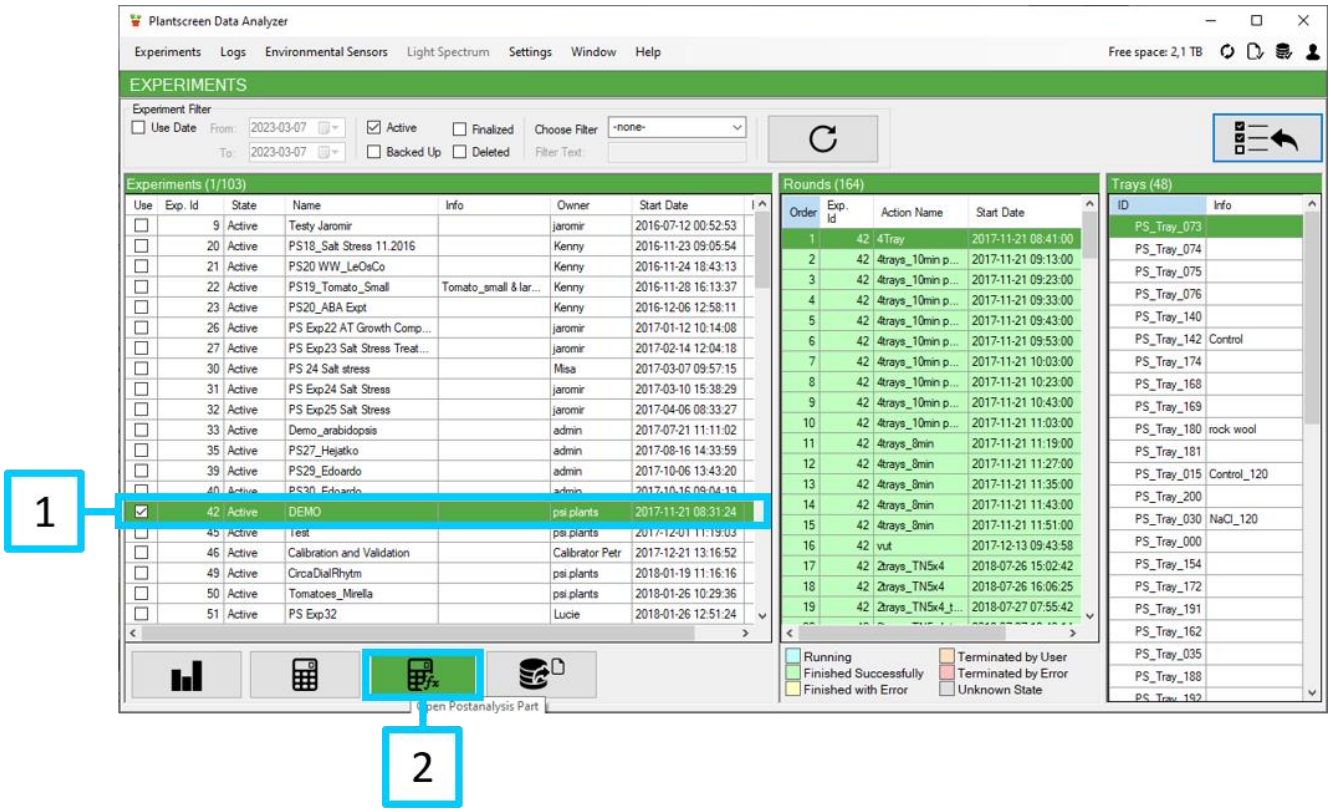


Fig. 127 Experiment selection for postanalysis

As well as Local Analysis part procedure, also Postanalysis is divided into four sections reffering to 4 succesive operation steps:

2.12.1 Settings
2.12.2 Preview
2.12.3 Run
2.12.4 Finish

2.12.1 SETTINGS

Postanalysis settings part contains two windows – ***ROUNDS*** – for choosing the rounds with the given data to be included in postanalysis and ***PARAMETRES*** for defining new parameters to be counted (Fig. 128).

2.12.1.1 ROUNDS

Window used for defining the given rounds to be used as source for selection of parametres utilised for postanalysis calculation. In the *ROUNDS* window (Fig. 128-1) you can decide if the newly defined parameters will be calculated based on the numerical data available **within the individual rounds of measurement** referring to *SINGLE ROUNDS* (Fig. 128-2) option or if the they are obtained as a combination of data outputs **between different measurement rounds** – *ROUND GROUPS* (Fig. 128-3) option.

Single Rounds option

Combines outputs of analyzes within individual rounds. In the left part of the window all the available experimental rounds are displayed in *All Free Rounds* section. Selected rounds can be moved to *SELECTED ROUNDS* (Fig. 128-4) table by clicking the right arrow button (Fig. 128-5). The postanalysis process will be then applied only to the rounds in *SELECTED ROUNDS* table (Fig. 128-6).

	New parameters can be then calculated only from data contained in the selected rounds.

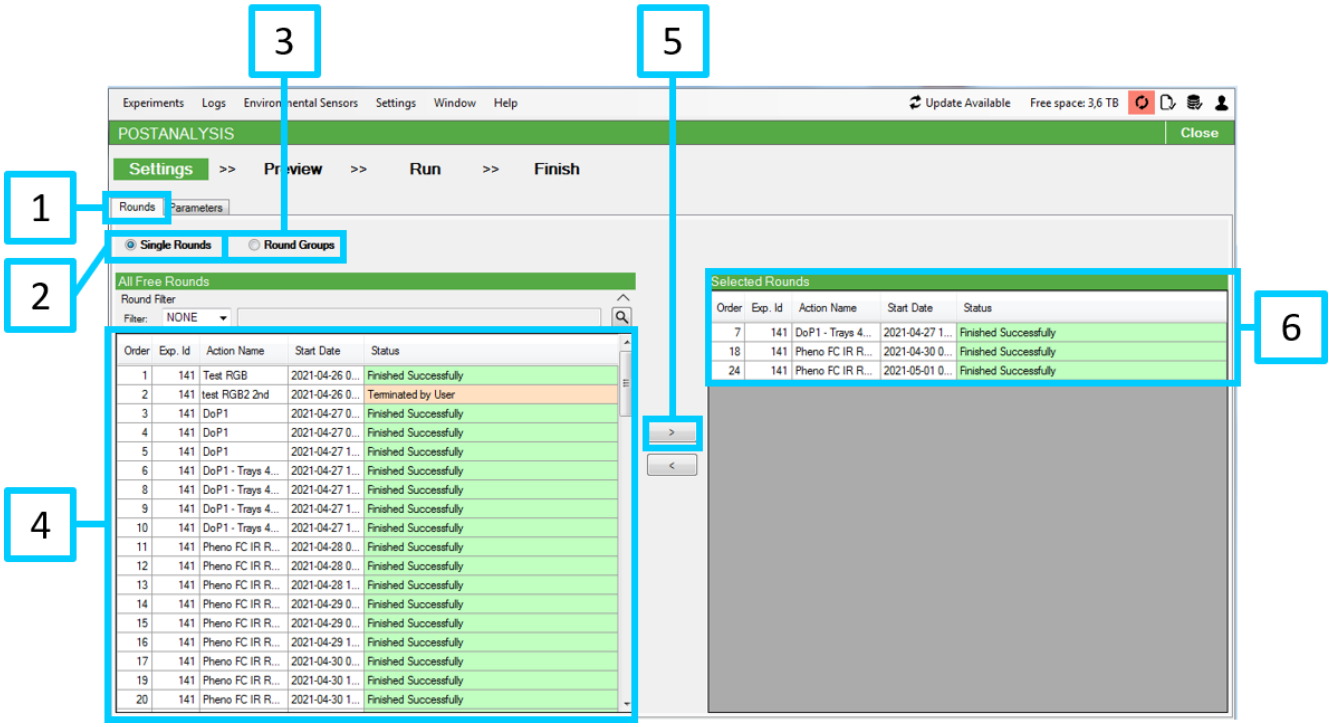


Fig. 128 Single rounds option

Round Group Option

Round Groups option enables to combine results between measuring rounds. From the list of measured rounds (Fig. 129-1) user defines the set of rounds that are grouped into groups (Fig. 129-2). Using this function, rounds can be divided into groups and only rounds belonging to the same group, i.e. *Rounds in Group,* can be combined for the new parameter calculations (Fig. 129-3).

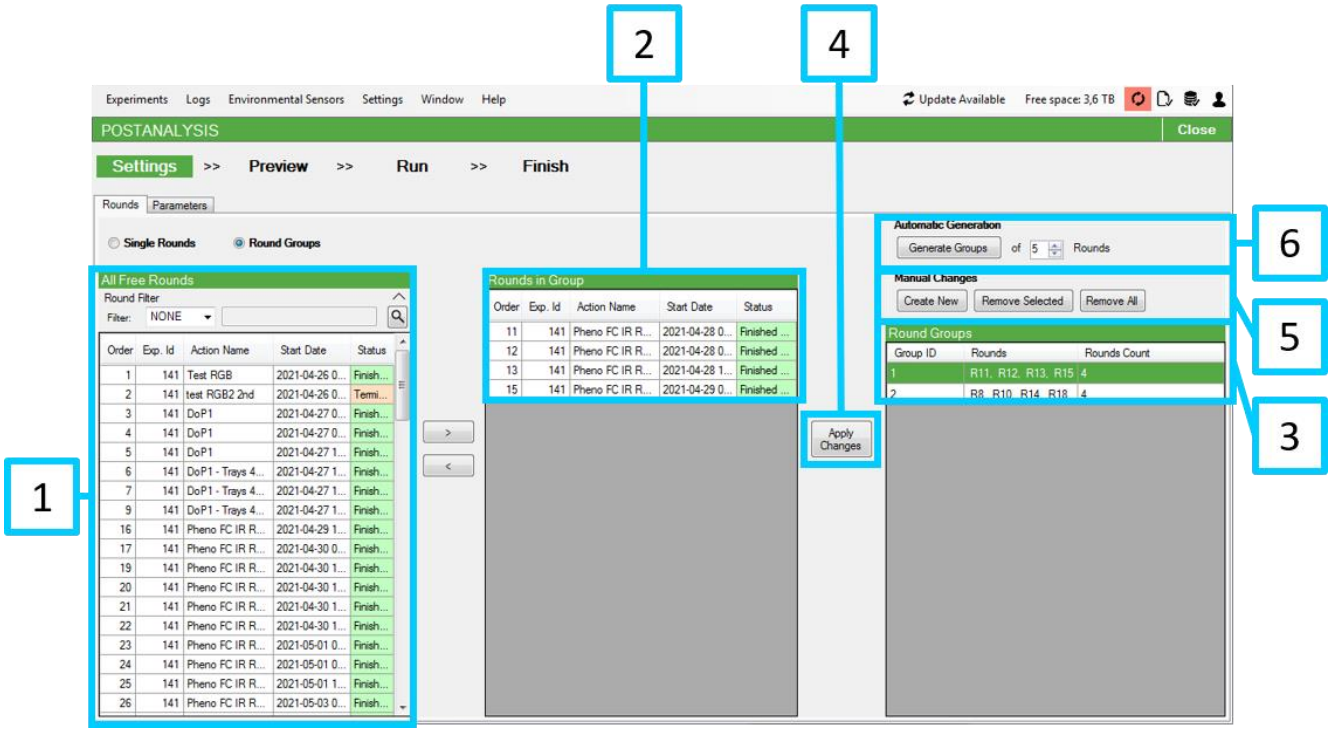


Fig. 129 Rounds Groups option

	All changes must be saved by clicking button Apply Changes (Fig. 129-4).

Groups can be added **manually** by *Manual Changes* mode using *Create New* tab (Fig. 129- 5) or can be generated **automatically** with *Automatic Generation* mode by *Generate Groups* tab (Fig. 129-6) with option to define total number of *Rounds* in the group. In this case, all available rounds are divided into groups of selected number of rounds in chronological order.

	Postanalysis will be applied and new parametres will be calculated only from the rounds within the Group assigned by the given Group ID (Fig. 129-3).

The Rounds within one *Group ID* must contain rounds with measured and/or calculated parameters that will be used for the new parameter calculation. There is no notification occuring if this is not the case.

2.12.1.2 Parameters

In the parameters window user defines the mathematical formulas for calculating new parametres from the original measured and/or calculated parameters saved in the PS system database.
The *Parameters* window is divided into 5 parts:

- *Rounds table* (Fig. 130-1) - read-only table containing previously selected rounds/groups
- *Original Parameters Selection* (Fig. 130-2) - window with table containing available parameters which were measured/calculated in the selected rounds and that can be used in the newly defined formulas
- *Parameters* (Fig. 130-3)- window for creating new formulas
- *Keyboard* (Fig. 130-4) - Option for displaying keyboard with mathematical operation symbols and Syntax Hint
- *List of new parameters* (Fig. 130-5)- List of newly defined parameters

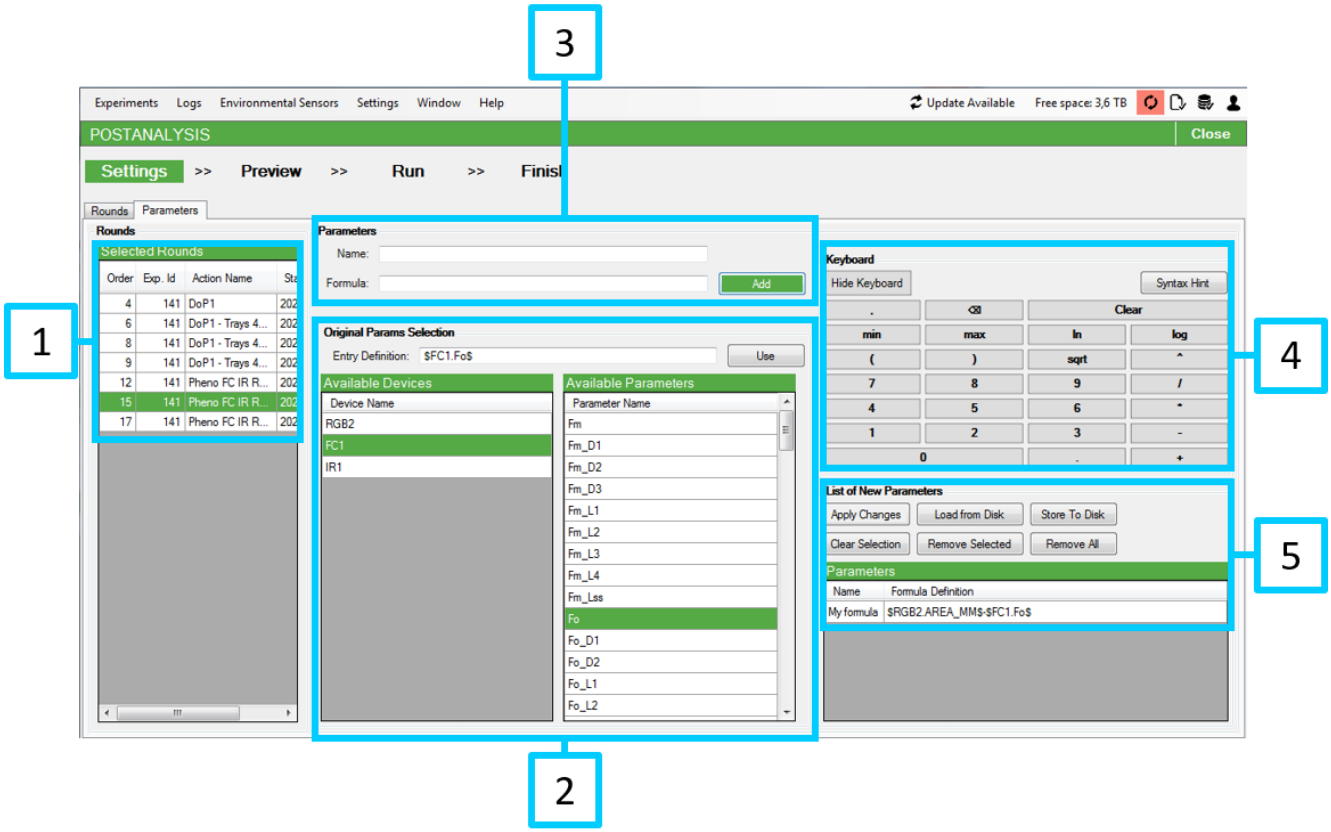


Fig. 130 Parametres window for Single Round option

Original Parameters Selection

In the *Original Parameters Selection* (Fig. 131) window is shown list of all *Available Devices* (Fig. 131-1) used to obtain the *Available Parametres* in the *Selected Rounds* (Fig. 131-2). The list of *Available Parametres* (Fig. 131-3) displays parametres that were measured and/or calculated at least in one round from all *Selected Rounds (*Fig. 131-*3)*. The parameters calculated within the analysis for the individual rounds are automatically determined from the DB and displayed.

- Available Devices - window with list of Device Names for all the sensors used for the measurement in the selected Rounds or Round Groups (Fig. 131-1)
- Available Parametres - window with list of Parameter Names for all the parametres measured and/or calculated at least in one round from the selected Rounds or Round Groups (Fig. 131-3). Available Parametres for the given Device are shown.

	In addition to image-based parametres measured parametres from all environmental sensors that are stored in RB are always displayed in the list of available parametres (Fig. 131-7)

- Available Rounds ID - window with list of Round ID in Group (Fig. 131-4). Round ID in Group represents the chronological order of the round within groups. Selected ID represents the order of the round within a group and it allows the user to select from which round the desired parameter has to be taken (Fig. 131-5; Area_MM parametr obtained by RGB2 device was measured in 1st round).
- Entry Definition – window displaying the syntax definition for the selected parameter from the given round. For using the given parameter in a new formula, it must be added to the formula window by Use button (Fig. 131-5).
- Example of definition syntax:
- For “Single Round”: $pid.parametr$ e.g.: $RGB2.AREA_MM$
- For “Round Groups”: $pid.parametr.roundID$ e.g.: $RGB2.AREA_MM.R3$

	It is not possible to type parameters directly into the formula window.

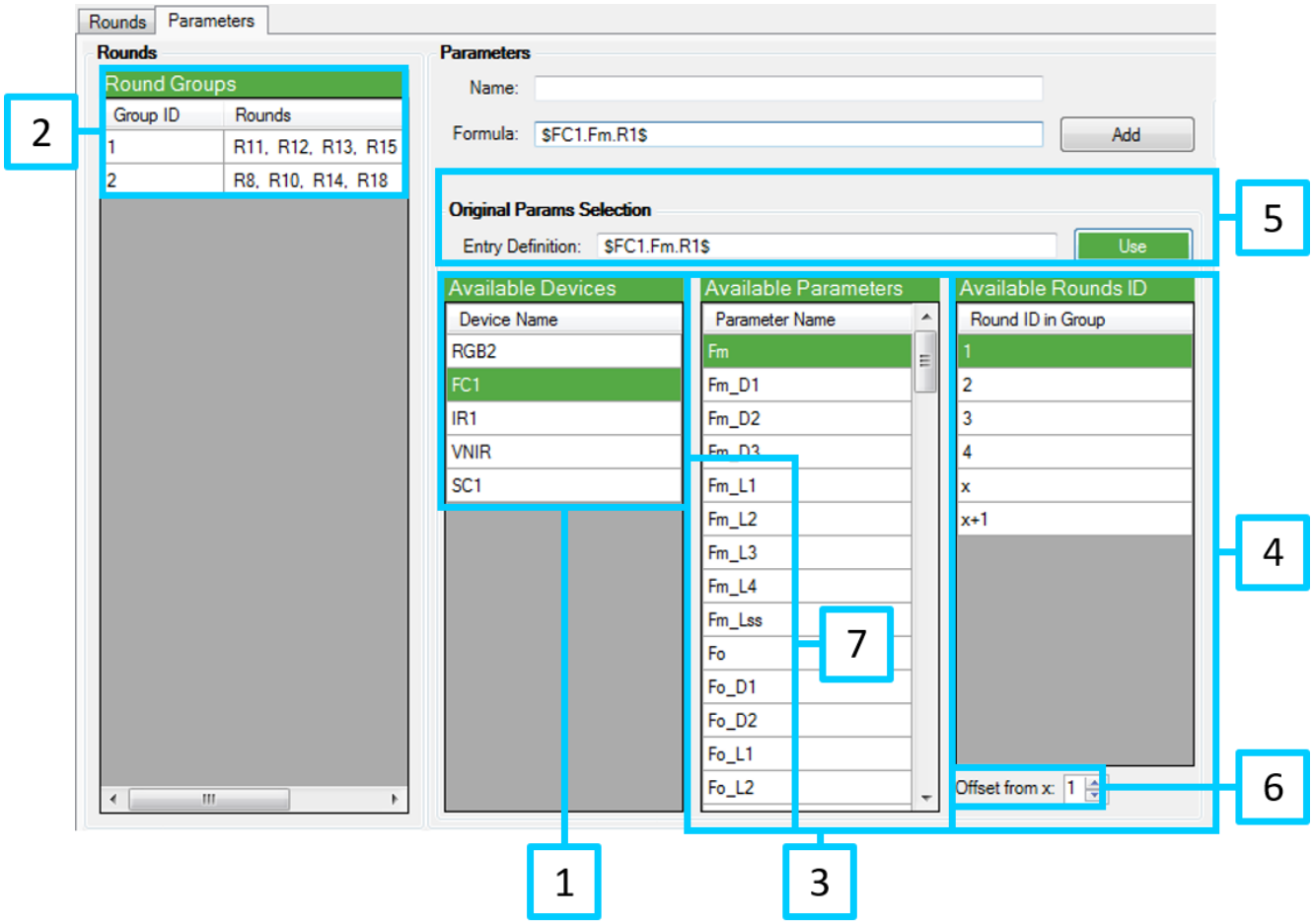


Fig. 131 Parametres window for Round Groups option

- Offset from index x – "x" and Offset from variable x feature provides index function for selection of the Rounds (Fig. 131-6).
- For option Rx, the calculation for x will gradually substitute the individual round indices, i.e. ID numbers of all the individual rounds in the group are substituted with x in the formula. Similarly for option Rx +/- offset round indices with a given offset from x will be substituted.

	The result of the calculation is always saved to the round that currently represents x.

Example of the *Offset from index* feature:
The group contains the rounds R1 R2 R3 R4 (=> The Round IDs in the group are 1, 2, 3, 4)

Data from original analysis:

R1… measured at 10:00	Light on	device FC1 parameter Q0 = 0.25
R2… measured at 10:30	Light on	device FC1 parameter Q0 = 0.30
R3… measured at 11:00	Light on	device FC1 parameter Q0 = 0.35
R4… measured at 11:30	Light off	device FC1 parameter Q0 = 0.05

New parameter definition:
To calculate a value corresponding to Q0 for each round measured in the light divided by Q0 measured in the dark. This ratio can be named MY_PARAM with formula:
MY_PARAM = $FC1.Q0.Rx/FC1.Q0.R4$

Corresponding calculation is as follows:
for x= 1 ... MY_PARAM = $FC1.Q0.R1/FC1.Q0.R4$ =0.25/0.05 =5 .. saved to R1
for x= 2 ... MY_PARAM = $FC1.Q0.R2/FC1.Q0.R4$ =0.30/0.05 =6 .. saved to R2
for x= 3 ... MY_PARAM = $FC1.Q0.R3/FC1.Q0.R4$ =0.35/0.05 =7 .. saved to R3
for x= 4 ... MY_PARAM = $FC1.Q0.R4/FC1.Q0.R4$ =0.05/0.05 =1 .. saved to R4

Parameters

Window for creating new formulas from the available parameters originating from given *Round ID* (Fig. 132-1).
To include *Entry Definition* of the selected parameter to the newly generated formula use button *USE* (Fig. 132-2). Unlike the parameters, which must be added to the formula by clicking on them in the *Original Params Selection* table, an operation on parameters can be written down or selected from keyboard table (Fig. 132-3). The resulting formula in the parameters window (Fig. 132-4) must be named with unique name and saved by ***Apply changes*** button (Fig. 132-5). The new parameter is then listed in new *Parameters* window (Fig. 132-6).

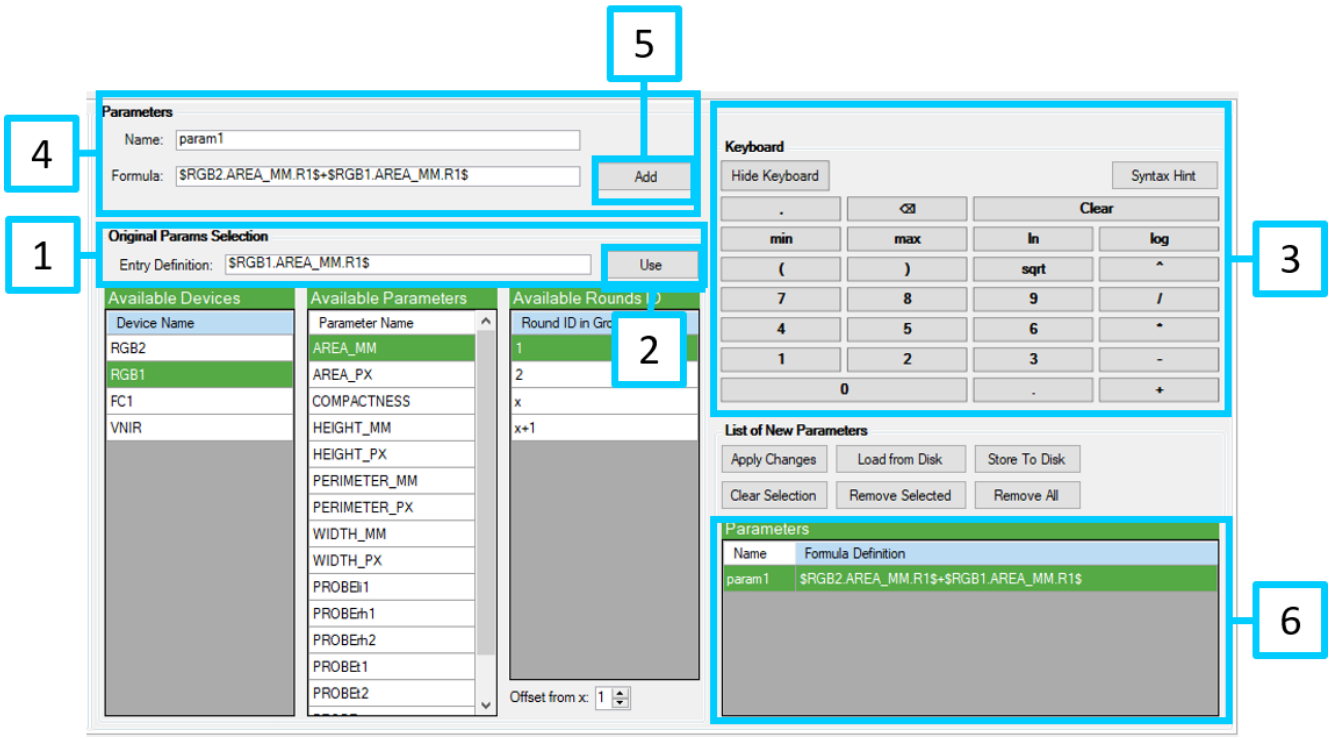


Fig. 132 Parametres window for Round Groups option

During the designing of a new formula, the Syntax of the equation is being checked for errors (Fig. 133-1). Invalid equation is notified by a red exclamation mark. Possible syntax help can be displayed via the "Syntax Hint" button (Fig. 133-2). List of new parametres can be Saved, Deleted, etc. Modifications in existing formulas can be made. To store the change use button Apply changes (Fig. 133-3).

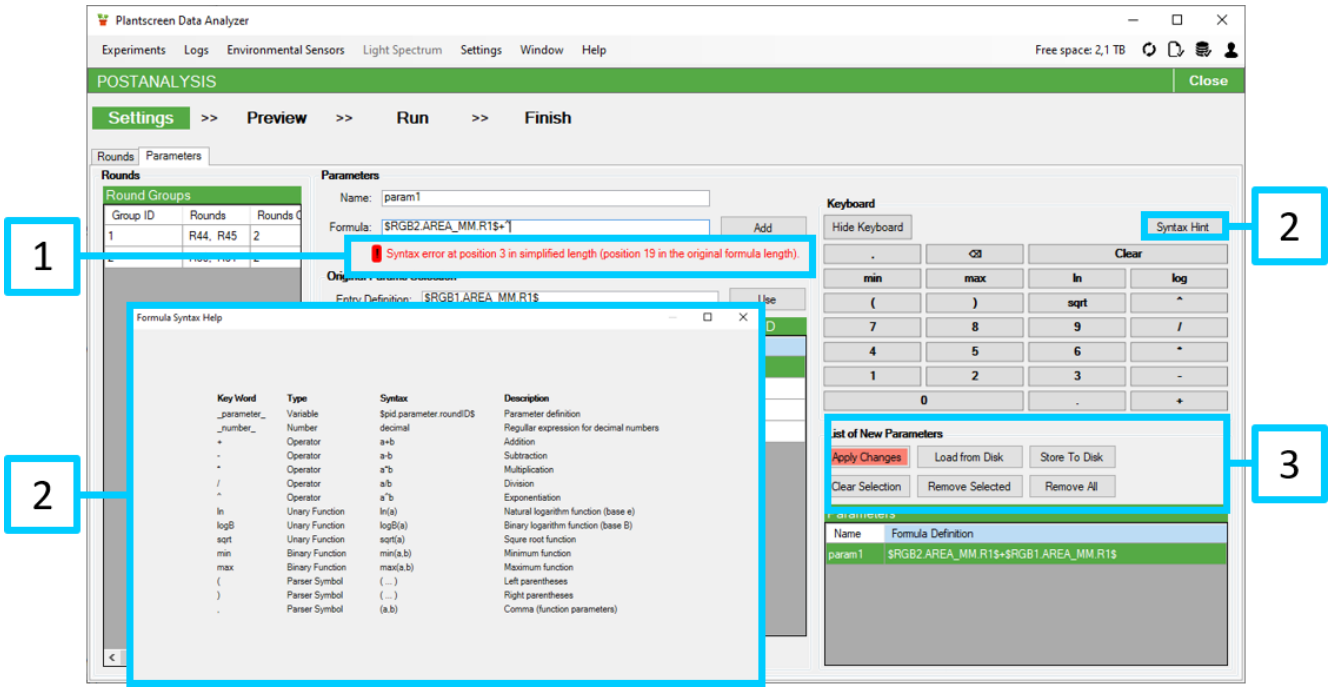


Fig. 133 List of new parameters

2.12.1.3 ADDITIONAL FEATURES AND FUNCTIONS

Process two or more Reanalysis files (or tar files containing raw data) in one Postanalysis run

Click **Open Local Files from Folder** button and select folder which contains reanalysed data (tar files) (Fig. 134-1). The tar files are then merged, opened and ready for postanalysis process.

	There are few importnat **conditions for successful** merging of the data: • local database contains only reanalysis files (obtained through local analysis and not postanalysis) • same version of DB must be used for all reanalysis • none of the rounds is present in more than one reanalysis file

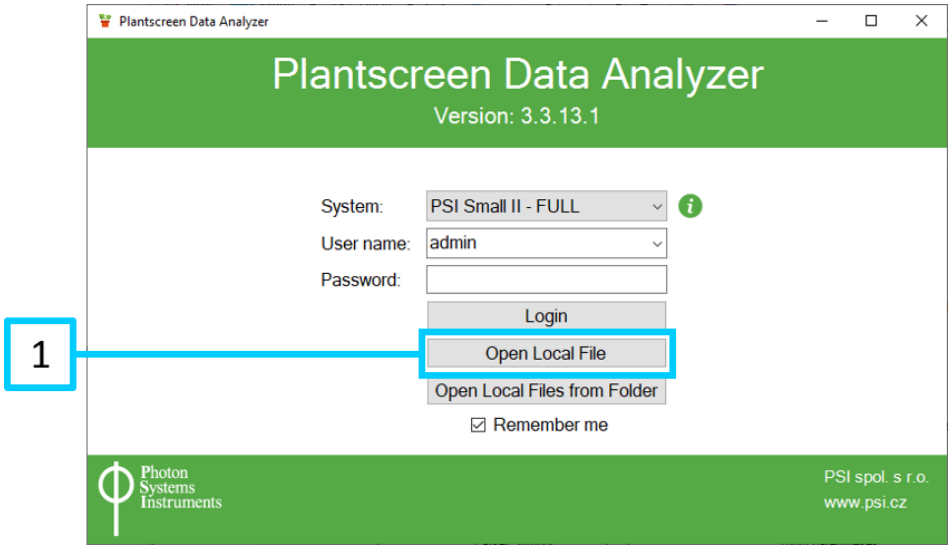


Fig. 134 More files used for postanalysis

Timediff function

Timediff function represents time difference between two measurements, expressed in seconds. Timediff function can be found in the list of parametres for all available measuring devices (Fig. 135) and can be used e.g. for growth rates calculation.

For **Single Rounds** option:

Timediff function (Fig. 135-1) calculates time difference between the measurements performed by two selected devices. The parameter format is: **$IR1.TImeDiffRGB2$** (time of IR measurement minus time of RGB measurement in given round). The absolute values of timediff calculations are provided – the measurement order does not matter.

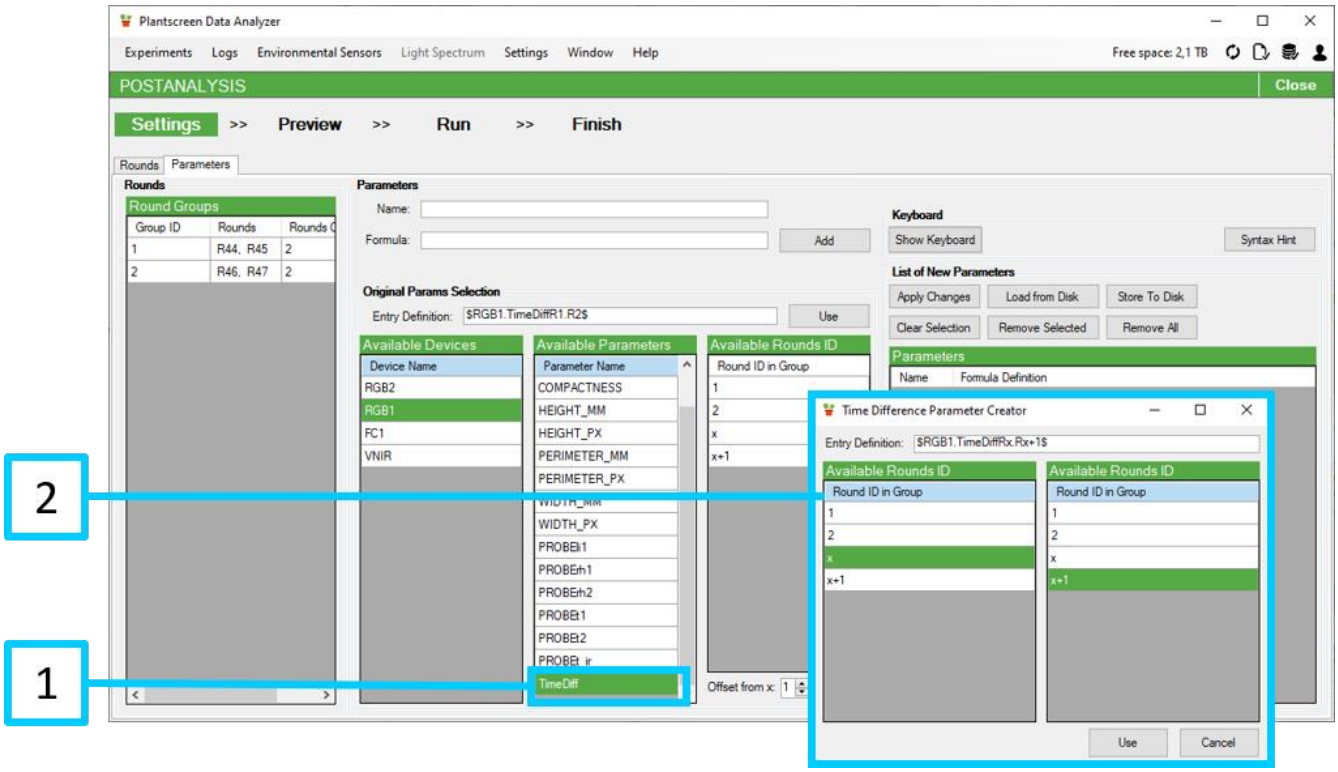


Fig. 135 Timediff function

For **Round Groups** option:

Timediff function calculates time difference between two rounds in a group for selected device (Fig. 135-1). The parameter format is: **$RGB1.TimeDiffRx+1.Rx$** (time of RGB1 measurement in round x+1 subtracted from the time of RGB1 measurement in the round x in a group) (Fig. 135 - 2). The absolute values of *timediff* calculations are provided – the round order does not matter.

	In the merged export file there are the time difference values (Fig. 136-1) as well as the original time values of measurements (Fig. 136-2).

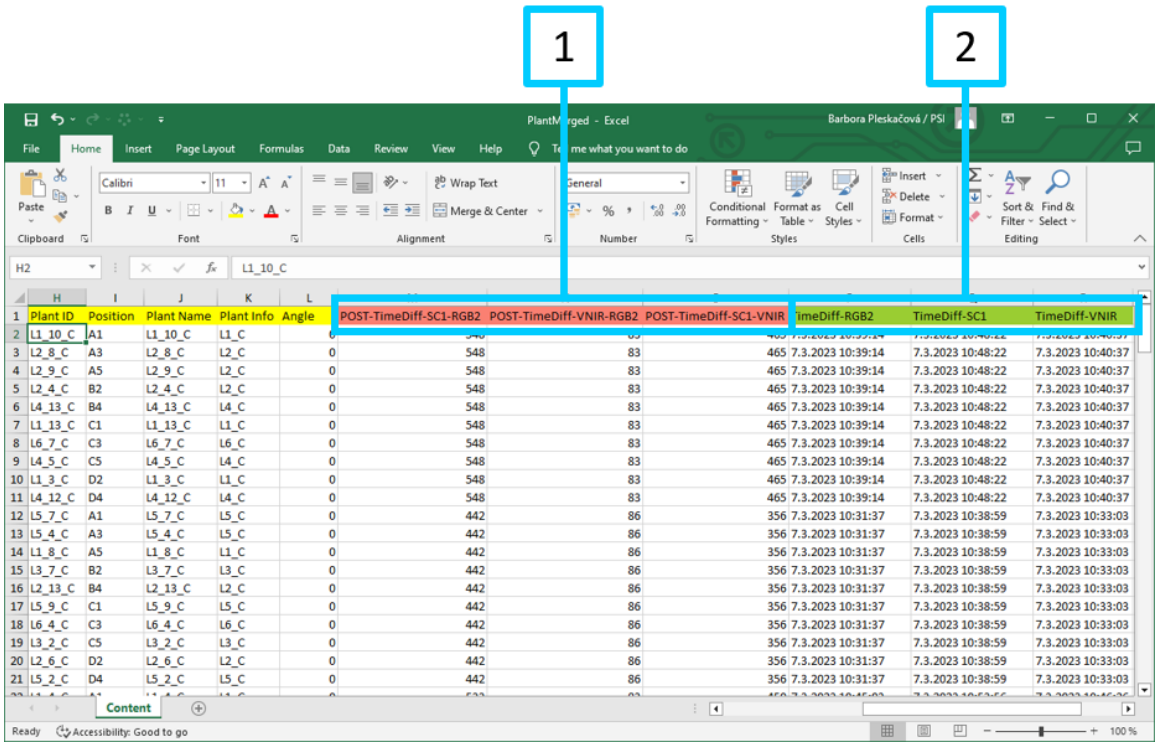


Fig. 136 Merged export files with Timediff values

Environmental data

In postanalysis process the values from environmental sensors can be also included in a formula (Fig. 137-1).

For each available device, it is possible to select the required sensor value in the list of parameters. The closest (in terms of the measurement time) value of the probe parameter to the given measurement is then used in calculation.

The parameter format is e.g.: **$IR1.Temp.Rx$/$IR1.PROBET1.Rx$** (normalisation of leaf temperature data (IR1) to ambient temperature and calculation of delta T parameter, Fig. 137-2).

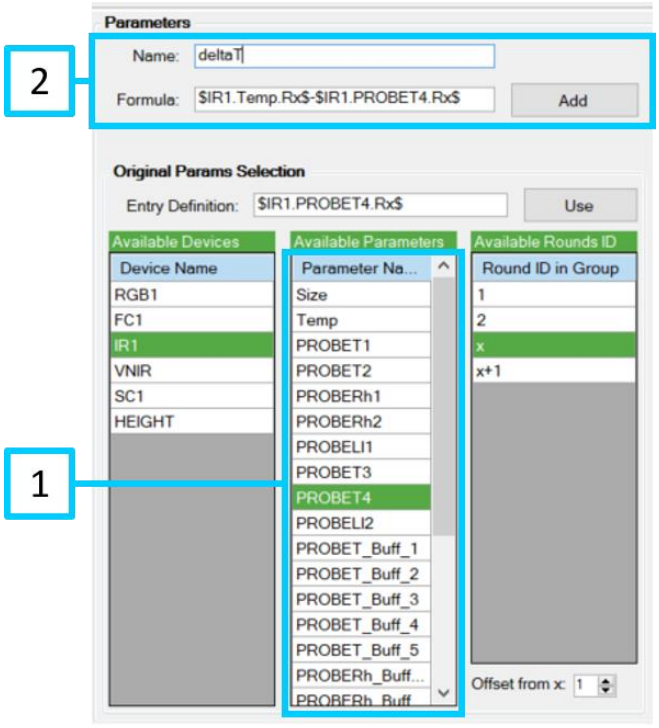


Fig. 137 Environmental data

2.12.2 PREVIEW

The preview window is empty in the current version of PlantScreen Data Analyzer. Calculation for the images will be completed later (Fig. 138).

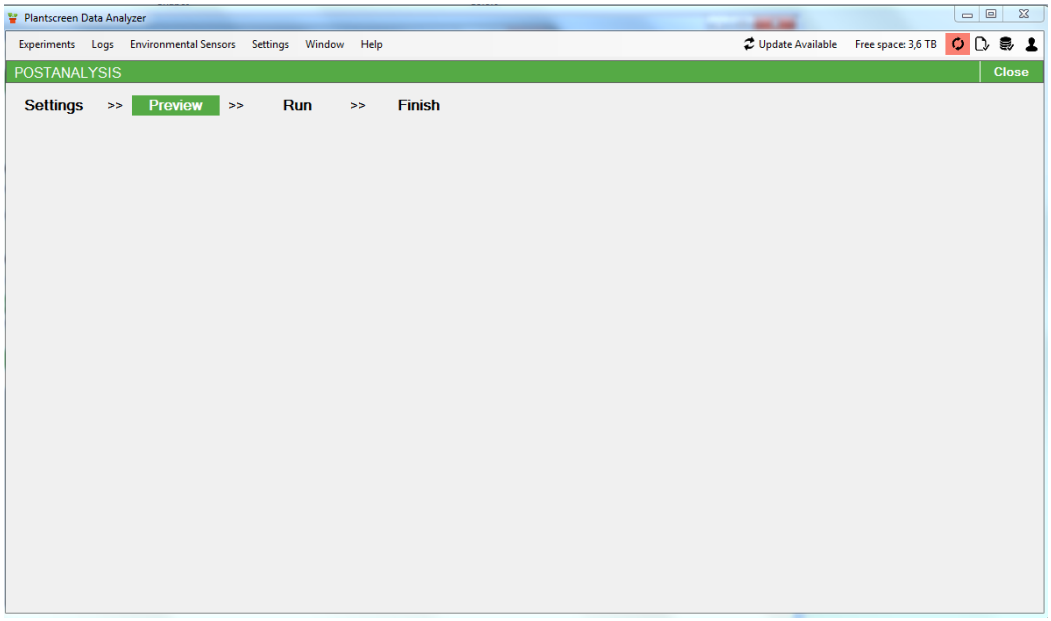


Fig. 138 Preview window

2.12.3 RUN

Run section contains controls to start postanalysis with the current settings on selected list of trays (Fig. 139). Trays for postanalysis are selected in the left part of the window (Fig. 139-1). The output path for storing the postanalysis results must be selected in order to activate the *Start Analysis* button (Fig. 139-2).

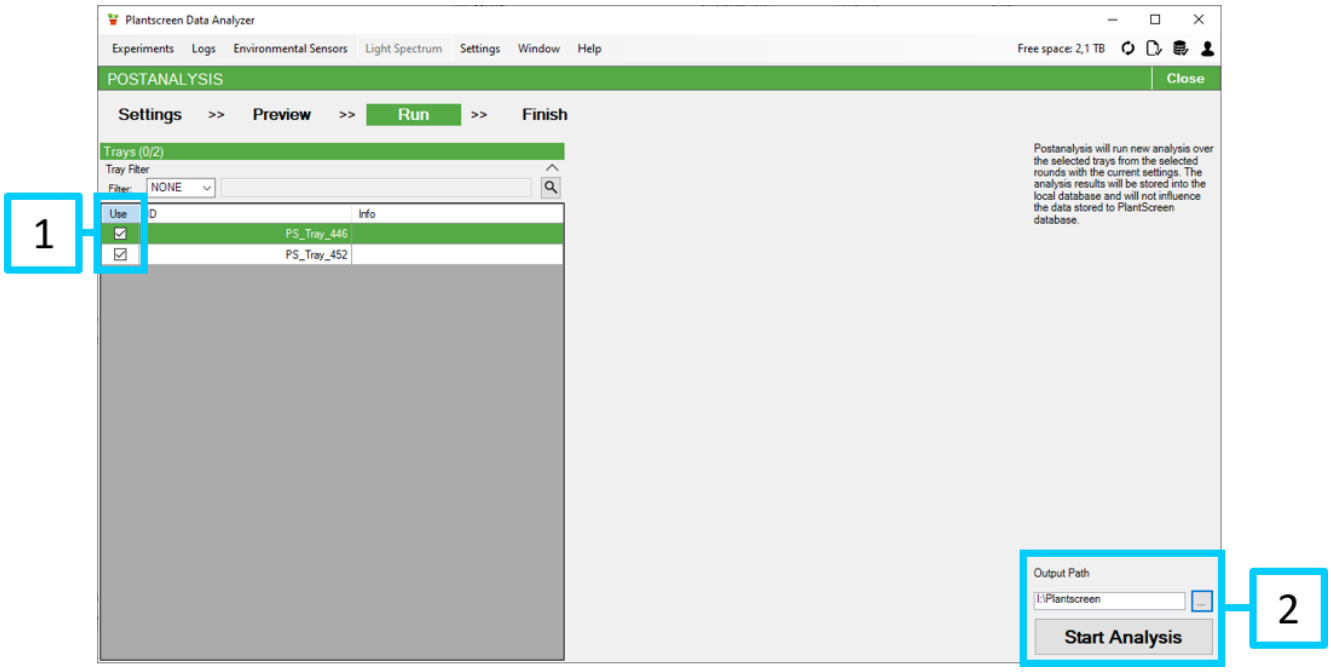


Fig. 139 Postanalysis run

The analysis results are stored in the local database as a tar file and do not influence the original data stored in the PlantScreen database.

⚠	When the postanalysis is running, it creates folder structure with temporary files. Do not open these files until the analysis is completed. If the file(s) are opened during the postanalysis process, the postanalysis may be corrupted or incomplete.

2.12.4 FINISH

Finish section contains postanalysis summary and shortcut to display postanalysed data. In the left part of the window the list of calculated parameters is displayed (Fig. 140-1). In the right part of the window, there is the *Trays Analyzed Overview* showing for which trays and in which rounds (groups) the given parameter was successfully calculated (green square notification) (Fig. 140-2). If the square is white, it means that the postanalysis was not performed because the original parameters for the given tray and the given round are missing.

Button *Switch Analyzer to Analyzed Data* (Fig. 123-2) switches application to the Local Analysis mode (Fig. 126) and opens Experiments window with the currently analyzed data.

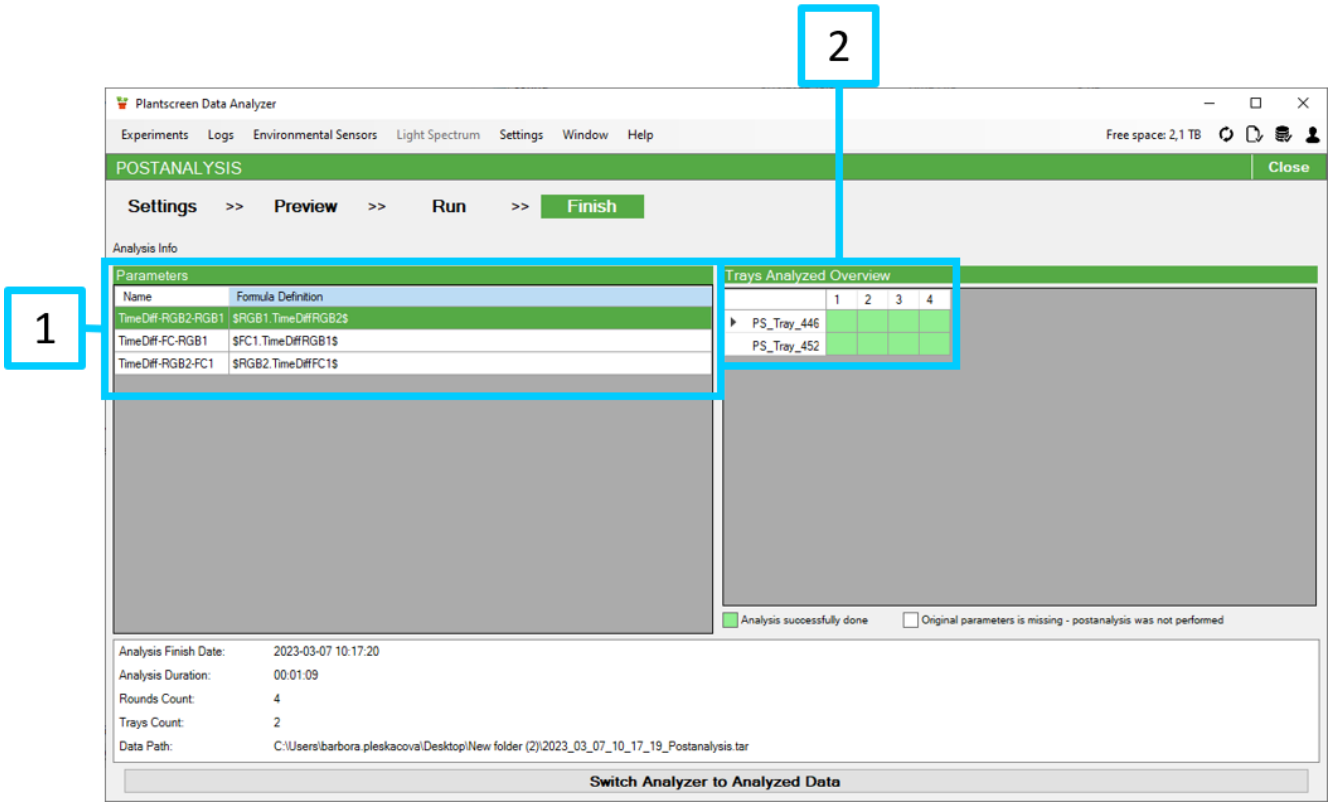


Fig. 140 Postanalysis Finish

In the *Experimental window* it is possible to either display calculated parameters in a graph (Fig. 141Fig. 15-1) by clicking *Selection place* window button or to export the calculated parameters in *Export window* (Fig. 141-2).

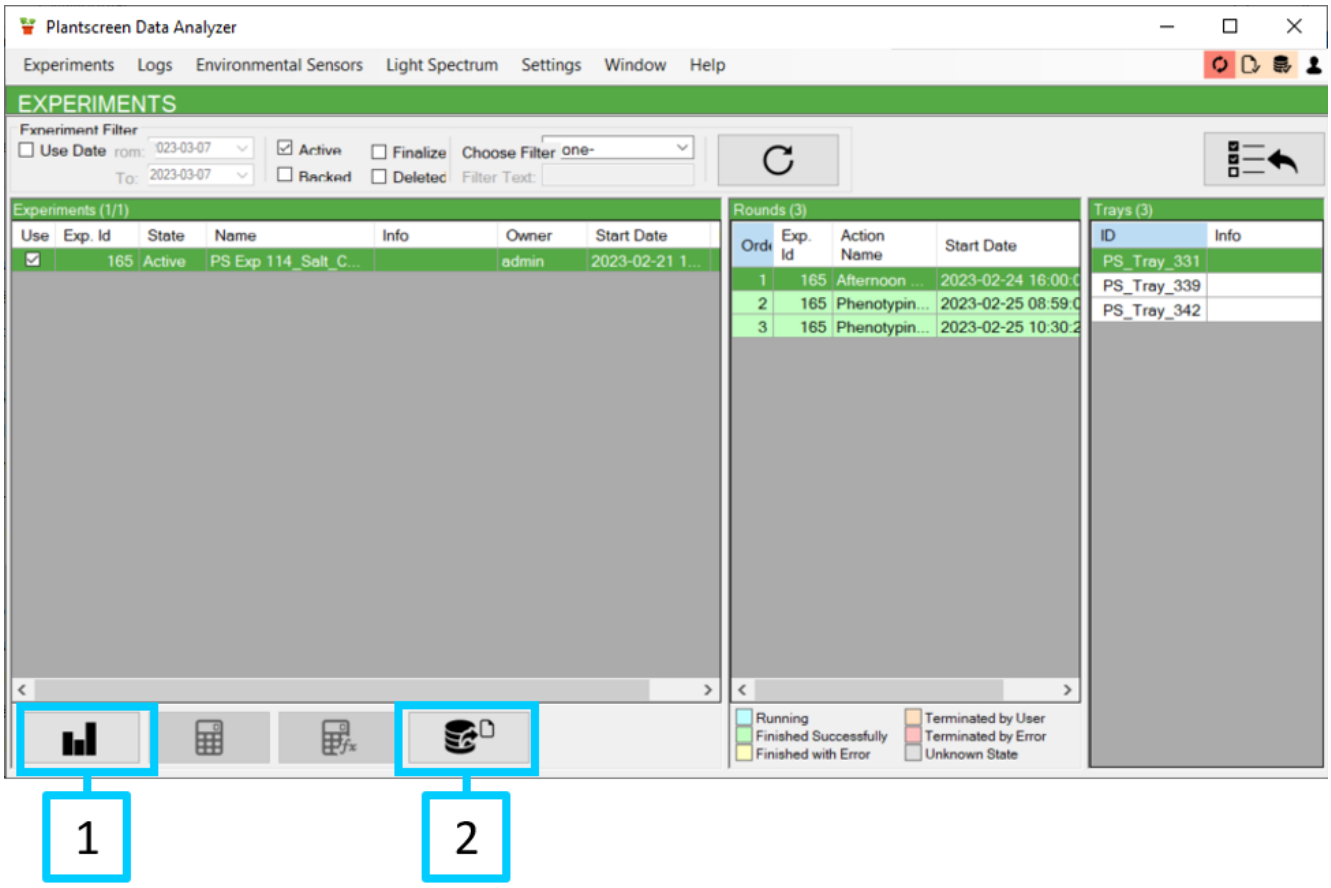


Fig. 141 Postanalysis Data Visualisation and Export

The list of calculated parameters can be displayed in Round Info - Protocol window - Postanalysis window.

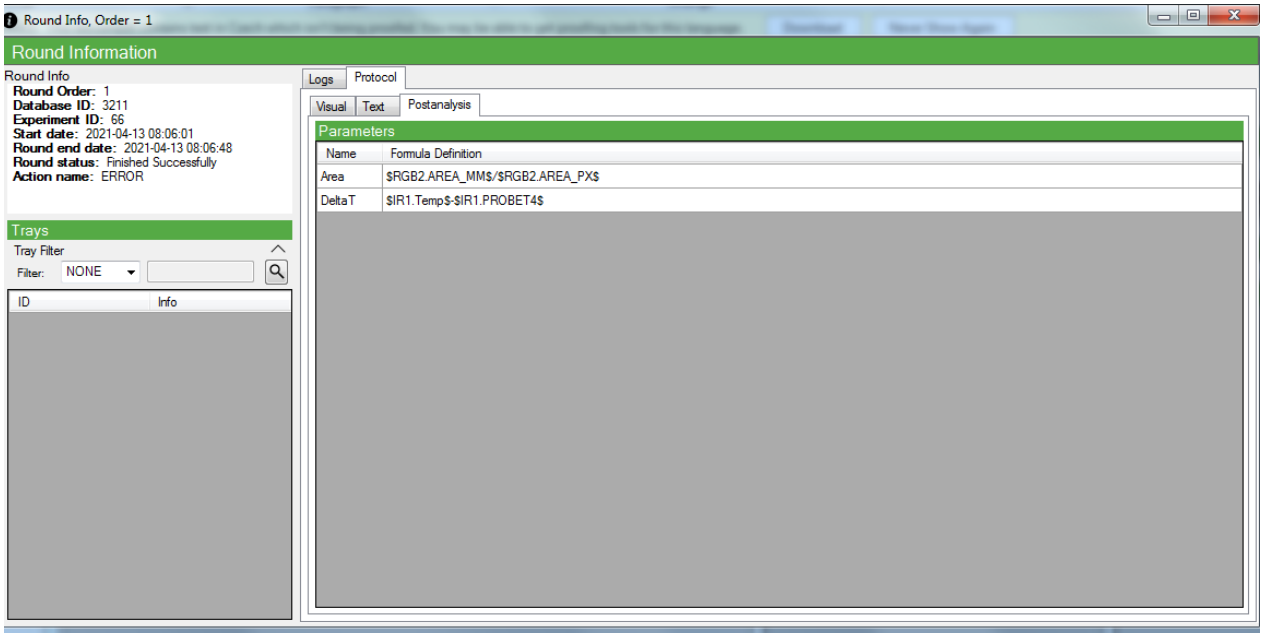


Fig. 142 Calculated parametres overview – Round Info

2.12.5 EXPORT

Export window enables the export of the original and postanalyzed data from the selected rounds/groups. *Round table* (Fig. 143-1) and *tray table* (Fig. 143-2) enable data selection. Select devices window (Fig. 143-3) contains only the devices which were selected in postanalysis process. This window and the postanalysis checkbox (Fig. 143-4) is in read-only mode so that the original parametres which were processed in postanalysis as well as newly created parametres are always exported. The Round Protocol Export and Sensor Values Export is optional.

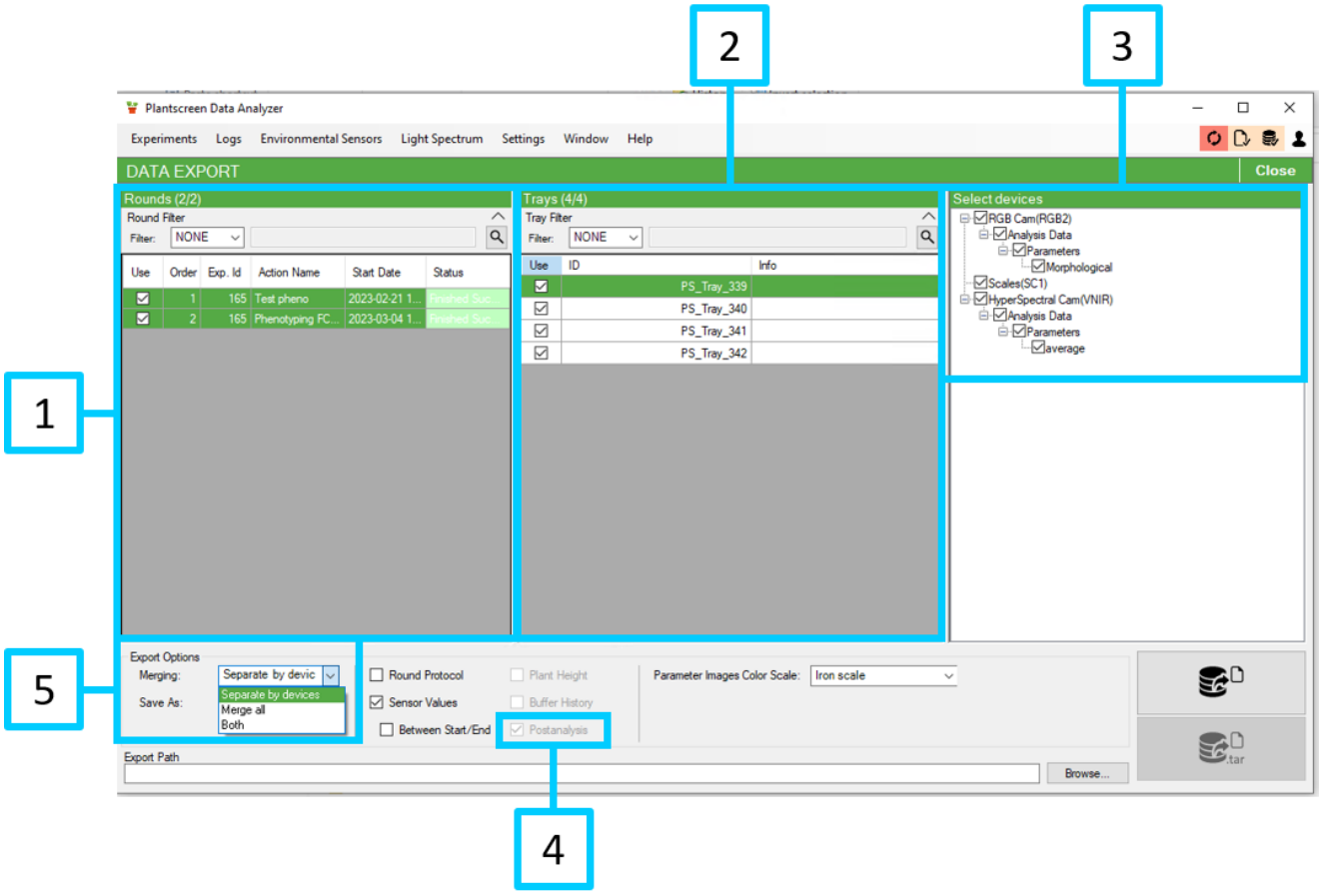


Fig. 143 Export

There are three options of exporting data:

- **Separate by device -** Separate by devices option exports data by measuring device (one file for each device)
- **Merge all -** Merge all exports all data to one file. In the merged table there are the Postanalyzed parameters listed followed by original parametres which were used in Postananlysis process (Fig. 144-1).
- **Both** - both types of exports are done

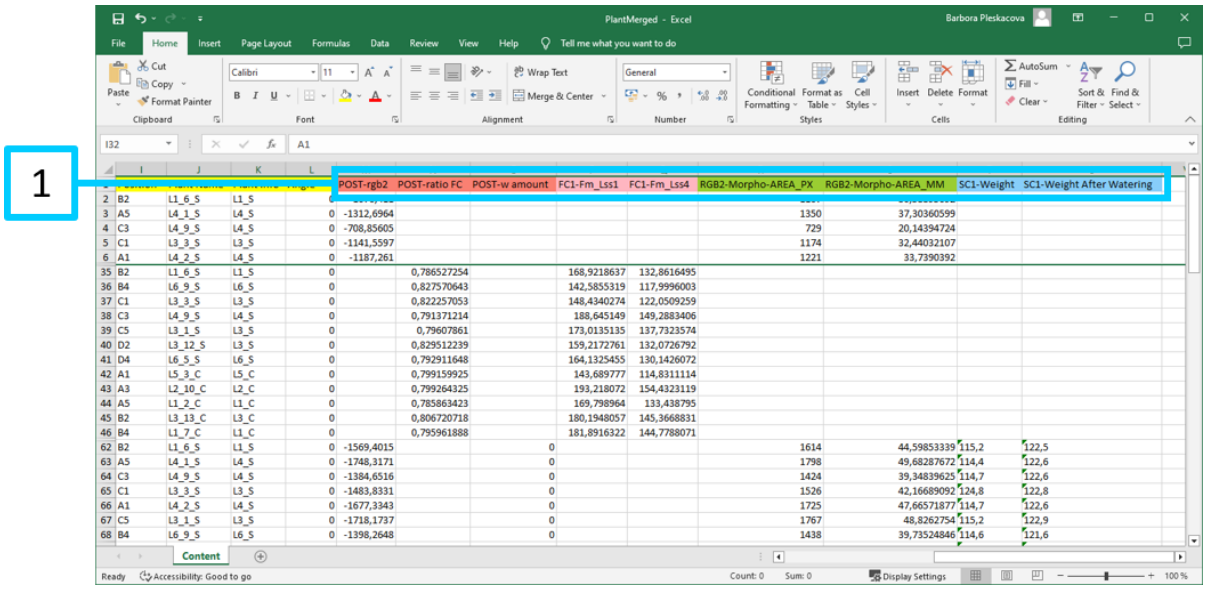


Fig. 144 Export options

Save As item enables selection of exported file type. It can be either comma separated values format (.csv), or Excel spreadsheet (.xlsx). If .csv option is selected, CSV Separator defines what character is used as separator. It can be one of the following: semicolon, backslash, dot, tab, space, forward slash.
Export Round Protocol includes round protocols into the export, **Export Sensor Values** includes ambient sensors readouts. If Between Start/End checkbox is checked, than all sensor values between the first and the last selected round are exported, otherwise the closest (in terms of the measurement time) value is found and exported for each round.
Export Plant Height includes measured plants heights (if supported by the system).
Parameter Images Color Scale – not functional since the values of images are currently not recalculated
Browse button shows dialog where the export path can be selected, **Export button** starts the export.

2.12.6 Example of postanalysis procedure

2.12.6.1 Single rounds option example

RGB top and RGB side images were measured in one round. Single round option can be used to calculate a volume from the RGB top and RGB side area parameters (Fig. 145).

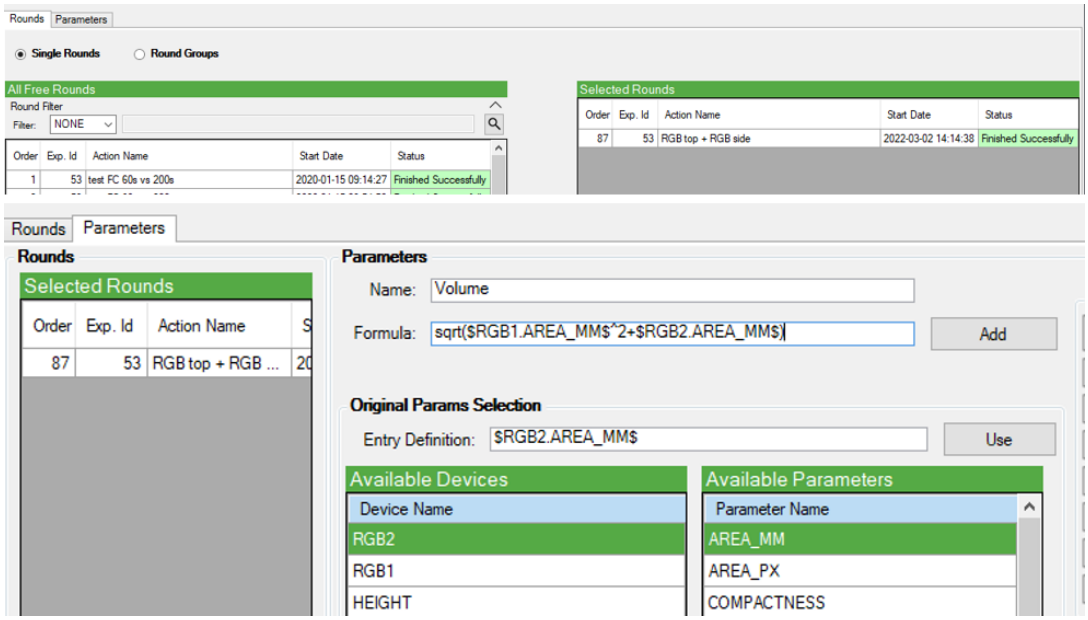


Fig. 145 Example of single rounds option analysis

2.12.6.2 Round groups option example

To combine parameters from sensors that were not measured in one round (or the same sensor but a different time of day), it is necessary to add these rounds to one group – use **round groups option**. E.g. If parameters from FC and RGB measurements should be combined, the given rounds must be added into one group (Fig. 146).

	When defining a parameter, it is important to realize which sensor was measured in which round. Otherwise, the calculation will not be possible due to missing data.

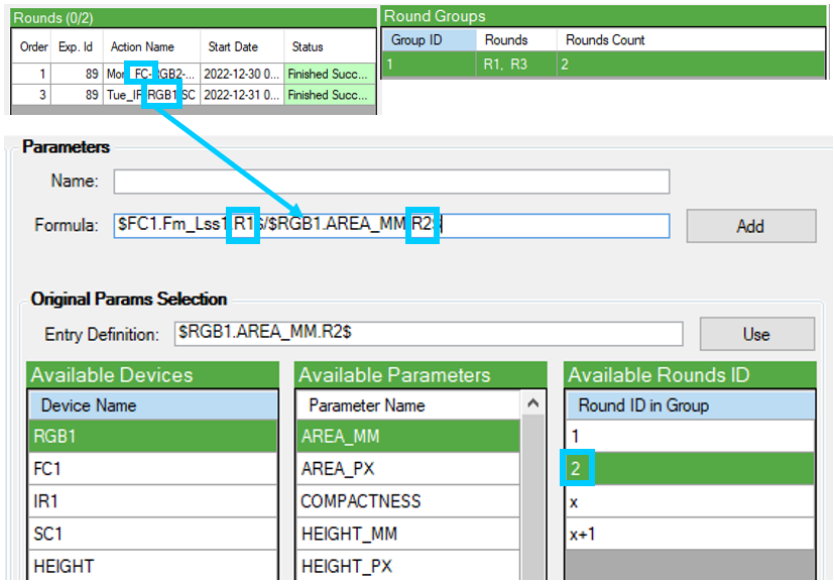


Fig. 146 Example of round groups option

2.13 Settings

Settings window provides access to the application settings.

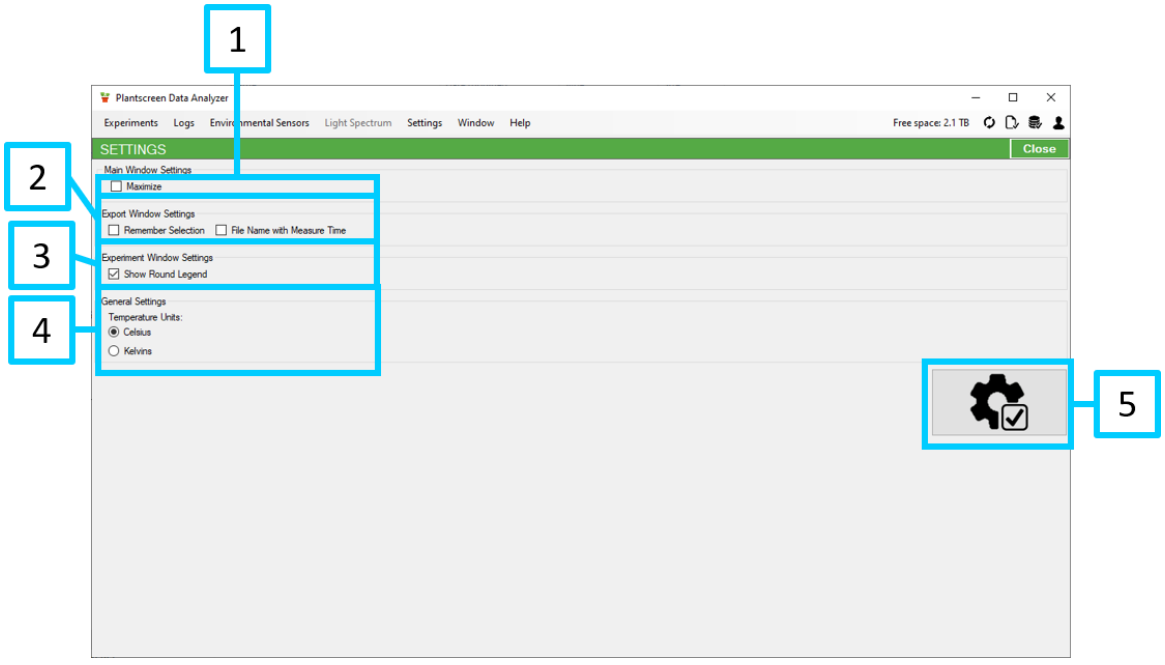


Fig. 147 PlantScreen Data Analyzer Settings

Maximize option (Fig. 147-1) maximizes the application window on startup.
Remember Selection (Fig. 147-2) remembers the last state of the export setup. Works only forexport options settings, does not store rounds, tray and dates selection. *File Name with Measure Time* triggers prefix based on the experiment time for all exported files.
Show Round Legend (Fig. 147-3) sets the default state of the round legend in the experiment window.
Temperature Units (Fig. 147-4) defines units for IR images in the imaging section of the application.
Changes are applied immediately by the *Apply* button (Fig. 147-5), application does not need to be restarted.

2.14 Logs

Logs menu item opens window with application logs. Each log item contains date, type, data identification and text message.

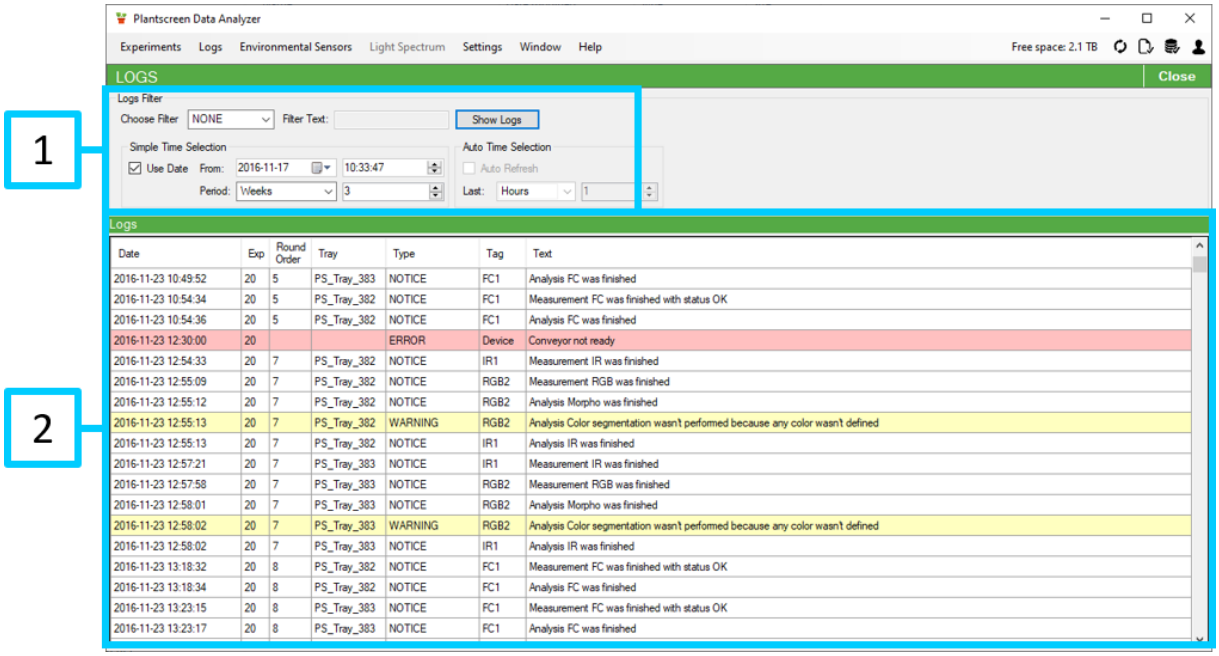


Fig. 148 System Logs

Top part of the window contains log filter (Fig. 148-1). Text filter (Fig. 149-1) enables filtering of the log items by text contained in the selected column. If the selected filter is NONE, text filter is not used.

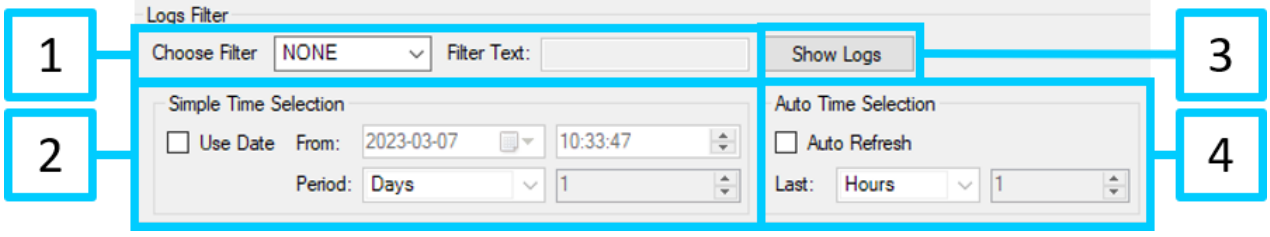


Fig. 149 Log Filter

Time filter (Fig. 149-2) enables filtering of the log items by date of the origin. If enabled, onlylogs written from the *From* field during the next *Period* are displayed.
Show Logs button (Fig. 149-3) displays the logs which meets the filtering criteria.

2.15 Environmental Sensors

Environmental Sensors window contains controls to visualize data from the systemenvironmental sensors.

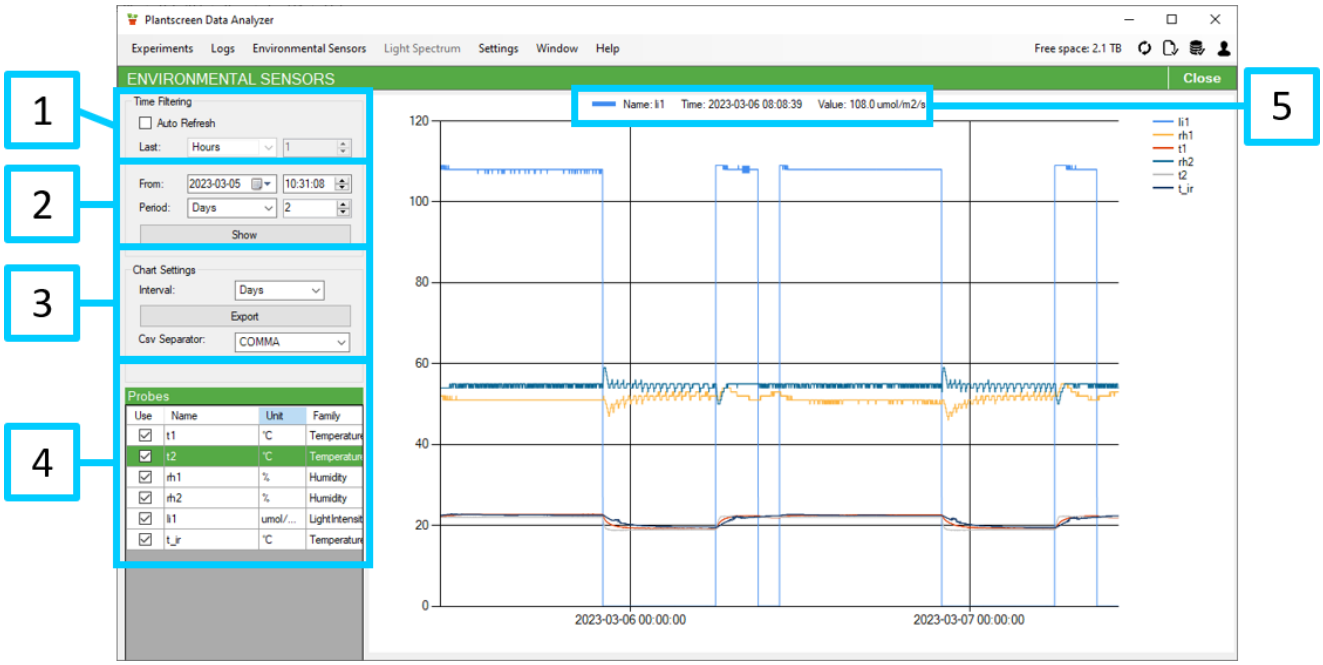


Fig. 150 Sensors

Chart Settings area (Fig. 150-3) allows setting X-axis interval.

Probes table (Fig. 150-4) contains list of probes installed in the system and basic informationabout them. *Use* checkbox shows/hides probe in the chart.
Information about the currently selected point is displayed in the top part of the chart(Fig. 150-5).

2.16 Help

Help window shows basic information about the application version and Photon Systems Instruments company.

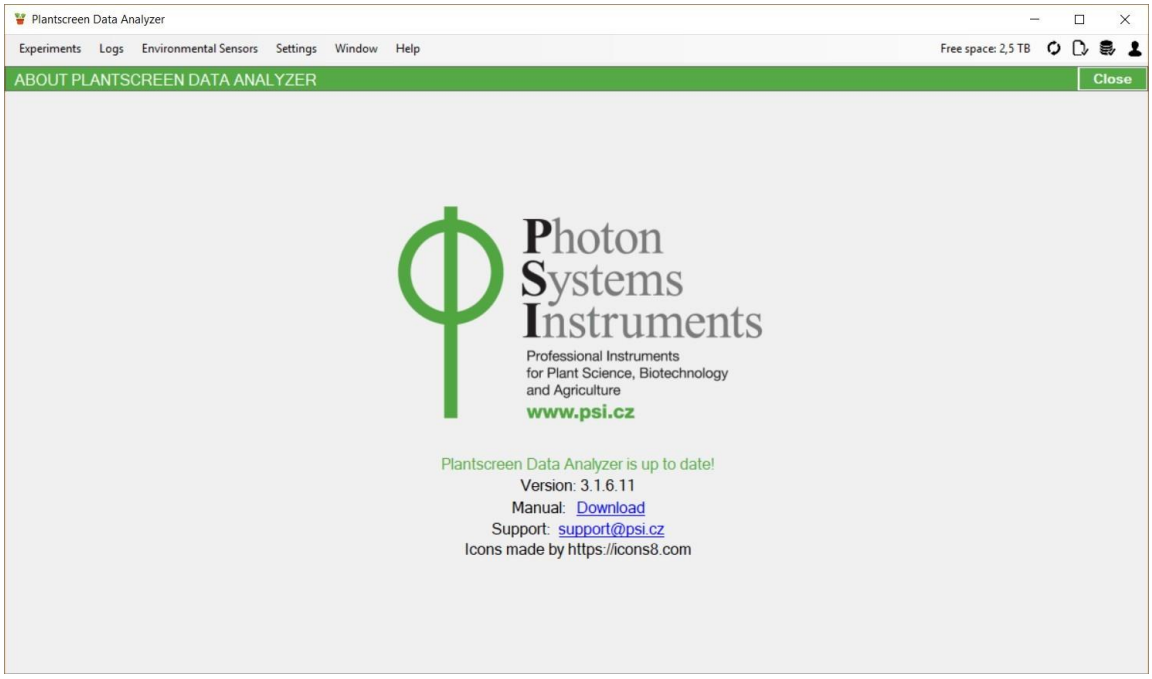


Fig. 151 Help,

2.17 PARAMETERS DESCRIPTION

Parameters Description window contains treeview with description of the basic analysisparameters for all possible measurement stations.

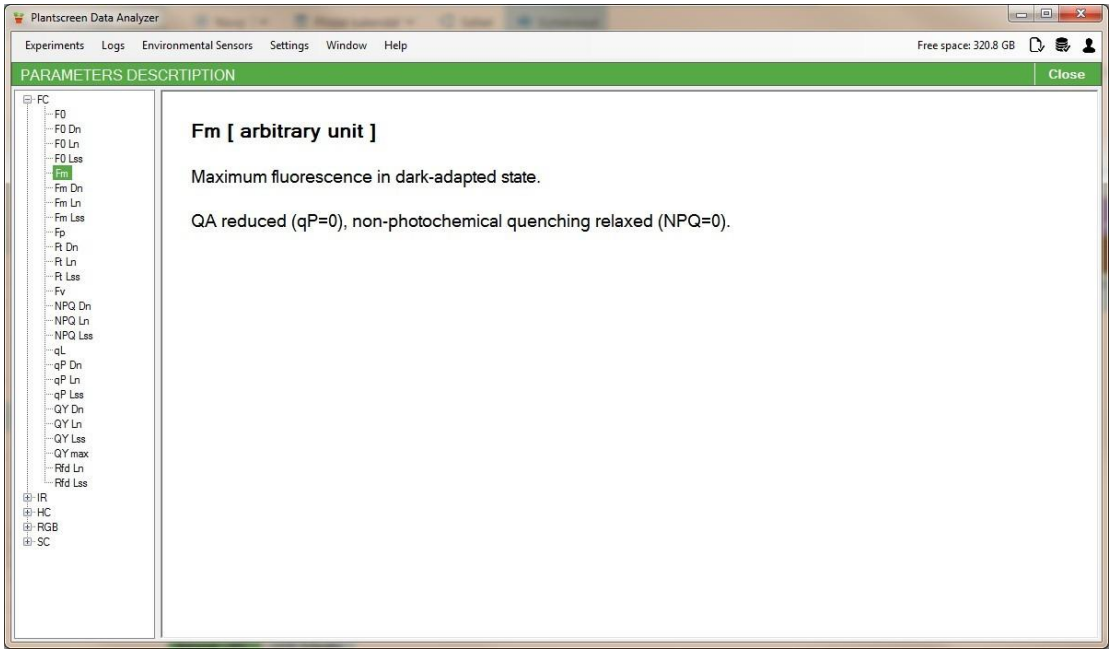


Fig. 152 Parameters Description Window

2.17.1 SYSTEM CONFIGURATION

System configuration file is used to configure data source connections, which are displayedat the login screen.

```
<?xml version="1.0" encoding="utf-8"?>
<AppConfig>
  <!-- preselected system at the login screen -->
  <DataSources preselected="PSI">
    <!-- name, db version and profile id -->
    <DataSource name="PSI" type="mysql-1.0" profileID ="profile_id">
      <MySql>
        <ip value="ip address" />
        <port value="port" />
        <db value="database name" />
        <user value="user name" />
        <password value="password" />
      </MySql>
      <CloudStorage>
        <address value="cloud storage address" />
      </CloudStorage>
    </DataSource>
  </DataSources>
</AppConfig>
```

Ex.1 System Configuration File

Node <DataSources>is the top node of systems configuration. Each child node of the <DataSources>node contains description of a system which Planscreent Data Analyzer canconnect to.

Node <DataSource>must contain <MySql>and <CloudStorage>elements, to connect the systemdatabase and Cloud Storage service.

2.17.2 USER CONFIGURATION FILE

User configuration file defines users displayed in the login screen user name control item. Each child node of the <RememberedUsers>node defines one user.

```
<AppConfig>
  <RememberedUsers preselected="JohnDoe">
    <admin value="" />
    <JohnDoe value="" />
  </RememberedUsers>
</AppConfig>
```

Ex.2 User Configuration File

3 BUG REPORT

Even though we are extensively testing each released version of the software, some bugs still may pass our testing process. Please consider reporting bugs to make this software better. If you encounter a bug or application crash, first make sure that application is up to date (2.5 Update) and if positive, please send a mail with “PlantScreenData Analyzer bug” text in the subject to support@psi.cz. In the message body, describe the sequence of the steps leading to the error and attach current logfile. It is named:

PlantDataAnalyzer-<year>-<month>.log

and it is located on the following path:

C:\Users\<user_name>\AppData\Roaming\PSI\PlantDataAnalyzer\<current_ version>.

4 LIST OF FIGURES

5 List of Tables

6 List of Examples

7 List of Appendices

8 Alphabetical Index

D

E

F

H

I

L

M

O

P

R

S

T

W

9 TERMS AND ABBREVIATIONS

3D - Raw Model	The output of 3D scanning represented by a point cloud model, with a number of vertices.
3D - Texture Image Tab	Panel that contains controls for selection of the source data and of the texture image and for definition of the parameter displayed over the 3D model.
3D Analysis Data - Parameters	Computed parameters as numeric values in .csv or .xls format.
3D Analysis Data - Plant Model	Colored segmented 3D model in .ply format
3D Analysis Data - Segmented model	The output of 3D analysis represented by triangulated models, sorted according to belonging to the mask area, with number of vertices and faces.
3D Analysis Data - Textured “x-x-x”	Output of texture mapping represented by triangulated models, sorted according to belonging to the mask, with number of vertices and faces. Different source data can be overlapped to the 3D model.
3D Raw Data - Dot Model	3D model in the .pcd format
Buffer history	If a growing buffer with multiple rows is part of the system, it is possible to store tray positions in the buffer after each round.
Color Segmentation Chart	It is a 100% stacked area charts that shows the distribution of the plant area between the different color hues throghout multiple measuring rounds. Items shown can be leaves, plants or plant groups, depending on the chart type.
Common Chart	It is designed to enable comparison of trends in data series of different parameters or even different measurement stations.
Common Table Controls	If the table contains selectable items, right click displays context menu, which among other options contains items to select/deselect all items and to show brief information about the current item.
Environmental Sensors window	It contains controls to visualize data collected by the system environmental sensors.
Experiment	Collection of all the measuring rounds belonging to a specific trial. An experiment has to be created in PlantScreen Scheduler before any measurement can be performed.
Backup Experiment	Option that allows to save the data of a selected experiment to local disk or another available storage. It makes space like deleting of an experiment, but allows the restoring of the data back to the database in the future.
Copy Experiment	Option that allows to save the data of a selected experiment to local disk or another available storage. The data is not deleted from the database as in the case of backup. The created file can then be used in the future to restore the backed up experiment.
Delete Experiment	Option that allows to erase the data of a selected experiment from the database to make space for future experiments. This action is irreversible.
Experiment ID	Unique ID of an experiment. It consists of consecutive numeric values assigned to each experiment in the database.
Show Experiment Info	It shows information related to the selected experiment: ID of the experiment in the database, owner, number and list of rounds, date of creation, list of logs.
Experiment Owner (Responsible)	Owner and creator of the experiment.
Experiment Restore	Option that allows to restore a backuped experiment.
Experiment State	Every experiment stored in database is in one of the following states: Active, Finalized, Backed up and Deleted. Experiment state can be changed by context menu, exclusively by the owner of the experiment or an user with permissions to modify others' experiments.
Export Button	It enables export of the raw and analyzed data and measurement protocol from the selected experiments.
Export user selection to file	Possibility to export user's selection to tar file. The tar file contains local database and all data files, therefore can be used as data source in any Plantscreen Data Analyzer

	software (Open local file). Useful when sharing data to external user who does not have access to the PlantScreen system.
FluorCam Kinetic	FluorCam kinetics dispayed as numeric values in .csv or .xls format.
FluorCam Parameters	FluorCam parameters obtained from image analysis and dispayed as numeric values in .csv or .xls format.
FluorCam Parameters Images	FluorCam parameters displayed as images (FloatFrame format), where each pixel contains a specific parameter value.
FluorCam protocol	FluorCam measurement protocol, It can be locally stored as a .txt file.
FluorCam Raw Data - Tar File	FluorCam data in the native tar format. They can be opened using FluorCam software.
Help window	It shows basic information about the application version and Photon Systems Instruments company. The user can also find here a brief description of the analysed parameters.
Hyperspectral - Raw Data	Raw data in .hdr and .bil format. They can be opened with the bilReader software.
HyperSpectral Analysis Data - Parameter	Calculated parameters and results of basic statistical functions over areas as numerical values, in .csv or .xls format.
HyperSpectral Analysis Data - Parameter Images	Images of each measured parameter, whose value is displayed in a false color scale, in .fimg or .png format.
HyperSpectral Analysis Data - RGB Image	RGB image reconstructed from the corresponding wavelengths (if possible) in .png format.
IR Frame	Raw IR data in the .raw format
IR Frame Auto Scale Bitmap	Raw IR data converted in automatic (from minimal value to maximal value of the raw image) false color scale images in .png format.
IR Frame Masked	IR data after background subtraction by plant mask overlay, converted in false color scale images in .png format.
IR Parameters	Measured and calculated parameters and results of basic statistical functions dispayed as numeric values in .csv or .xls format.
Leaf Tracking	Analysis mode that focuses on single leaves of a plant (Note: This is valid only for top view image analysis).
Load selection	Button that allows to open a file dialog, where the previously saved selection file can be chosen.
Local Analysis	Module that allows to repeatedly analyze raw data saved in the system database. Results of the Local Analysis are not stored in the database, but can be stored locally as .tar files.
Logs	Recording of each action performed by the system. Each log item contains date, type, data, identification and text message.
Main Menu	Main display shown after successful login into PS Data Analyser. It shows the list of active experiments.
Mask Builder	Graphical tool available in Local Analysis. It allows to draw new top and side tray mask and to save them locally as Tray Type or as .xsel files.
Open Local File	Button used for opening archive tar file previously created in local analysis and locally stored.
Open Local Files from folder	Button used for opening more archive tar files previously created in local analysis and locally stored. To successfully merge multiple tar files, the data in the files must not overlap.
Parameters Selection	It displays parameters, which were measured at least once for the selected rounds.

Parameters	Result of the image analysis, obtained through different methods, according to the sensor that originally collected the image.
Plant Chart	Chart with data for individual plants. Plants contained in any of the plant groups are also included, their color matches the color of the originating plant group and their name is preceded by the name of the originating plant group.
Plant Group Chart	It shows data for selected plant groups. Series points are computed from the series of the plants in the group, using the selected function.
Plant Groups	Grouping of the trays and/or plants subjected to phenotyping in a specific round. Plant Groups can be created in the Group Manager window. The grouping allows to visualize the parameter of interest as an average in charts.
Plant Info	Optional information (treatment, genotype, etc.) to be added for each plant in the Tray Registration file. It can be useful for grouping.
Plant ID	Unique ID of the plant (number or text with maximum length of 200 characters)
Plant Mask	Plant area, automatically identified by the algorithm according to the plant's color hues/signal strength. It is located inside of the Tray Mask.
Plant Name	Name given to each plant in a tray at the moment of the Tray Registration. It doesn't have to be unique.
Plant height	File including measured plants heights can be obtained in export part (if supported by system)
PlantScreen™ Data Analyzer	Experiment result browser with re-analysis module.
PlantScreen™ Database	Relational SQL database and file storage service.
PlantScreen™ Scheduler	Application for tray registration and experiment planning.
Postanalysis	Module that allows to combine outputs of individual analysis. Postanalysis tool can process either the raw data saved in system database or results from the local analysis, which are stored locally as .tar files.
Probes	Environmental values recorded by the environmental sensors installed in the system.
(Round) Protocol	Designed by the user, it consists of a sequence of actions to be executed by the system. Protocol steps to be selected includes Measure and Analysis. The available steps can differ according to the system. Can be exported as a text
Raw Data	Data obtained from the different sensors, before undergoing any kind of analysis.
Round groups	Part of postanalysis process. Option to combine parameters obtained from measurements that were performed in different measuring rounds.
RGB Color Segmentation Image	Color-segmented image (hues are defined in the measurement protocol) with fisheye correction and plant mask overlay in .png format.
RGB Fish Eye Corrected	Non-segmented raw image after fisheye correction in .png format.
RGB Fish Eye Masked	Segmented raw image after fisheye correction in .png format.
RGB Original Image	Non-segmented raw image in .png format.
RGB Parameters - Color Segmentation	Number of plant pixels assigned to each hue (defined in the measurement protocol) in .csv or xls format.
RGB Parameters - Morphological	Morphological parameters as numeric values in .csv or .xls format.
RootCam Analysis Data - Morphological Parameters	Morphological parameters as numeric values in .csv or .xls format.
RootCam Raw Data - Bitmap Image	Raw image in .png format
RootCam Raw Data - Fish Eye Corrected	Raw image after fisheye correction in .tiff and .png format
RootCam Raw Data - Fish Eye Masked	Raw image after fisheye correction with plant mask overlay in .png format.
RootCam Raw Data - Original Image	Raw data in .tiff format

Round	One time-point executed measurement, which corresponds to one measurement step.
Round Information window	It shows information related to the selected round: ID of the experiment in the database, owner, number and list of rounds, date of creation, list of logs.
Round table	It displays information about a round for a selected experiment.
Scales	Weights of the pots before and after watering, recorded by the Weighing and Watering system(s). The vaalues can be stored locally in .csv or .xls format.
Settings window	Settings window provides access to the application settings (Maximize option, Remember selection, Show Round Legend and Temperature Units).
Single rounds	Part of postanalysis process. Option to combine parameters obtained from measurements that were performed in one measuring round.
Tray	Holder for one or more plants registered with unique ID and specified by given type.
Tray Info	Optional information (treatment, genotype, etc.) to be assigned to the entire tray in the Tray Registration file. It can be useful for grouping.
Tray Information window	It shows details about the selected tray (plants positions, date of registration, mapping of the tray position to the scales position). It can also show information related to previous registrations of the selected tray.
Tray Mask	User-defined area in which the algorithm will look for the plant according its color hues/signal strength. It has to be defined at the moment of the tray registration.
Tray Type	User-defined area of interest, where plant features are extracted and analysed. Tray type contains size, number and place of the areas on the tray. A list of standard tray types are already present in the system, but customised tray types can be created by the user. Once a Tray Type is assigned to a specific Tray ID, it cannot be modified.
Account	Credentials (username and password) and information (personal and contact information) associated with a specific user. Each User account can be assigned a specific role.
Working Container	Top level window, generated after selection of rounds, trays and plants in the Parameter Selection Window, and containing smaller windows with data (graphs and raw/analysed images) controls.

10 Appendix 1 Export Formats Description

10.1 Format .fimg(Float Image)

Format is used for FluorCam and Hyperspectral parameter images.
Format structure:

Width(int32)	4 bytes
Height(int32)	4 bytes
Data (float)	Width * Height *4 bytes

Tab. 23 Format .fimg Structure

10.2 Format.raw

Format is used for IR camera raw data.
Format structure:

Width(int32)	4 bytes
Height(int32)	4 bytes
PixelIndexes (uint16)	Width * Height
DataLength (int32)	4 bytes
DataValues [in Kelvin] (float)	Data Length

Tab. 24 Format .raw Structure

Format .usraw

Format is used for Multispectral camera raw data.
Format structure:

Width(int32)	4 bytes
Height(int32)	4 bytes
Frames count(int32)	4 bytes
Bit depth (byte)	1 byte
Data (uint16)	Width * Height * Frames count *2 bytes

Tab. 25 Format .usraw Structure

Format.bil (Band Interleaved by Line)

Format is used to save hyperspectral data – commonly referred as hypercube. Data have three dimensions – image width, height and light spectral band. One .bill record has two files:

- data file (.bil) with raw data in binary form
- header file (.hdr) with data format description

Structure of the .hdr file
File contains description of the hypercube data. It can be opened by any text editor.File content description:

BYTEORDER	I	*byte order, I = Intel byte order (least significant bytefirst))*
LAYOUT	BIL	*band interleaved by line*
NROWS	420	*number of rows*

NCOLS	500	*number of columns*
NBANDS	408	*number of spectral bands*
NBITS	12	*bit depth*
BANDROWBYTES	1000	*number of bytes for one row for one spectral band*
TOTALROWBYTES	408000	*number of bytes for onerow for all spectral band*
BANDGAPBYTES	0	*number of padding bytesbetween spectral bands*
STARTWAVELENGTH	399.8	*start wavelength [nm]*
ENDWAVELENGTH	999.5	*end wavelength [nm]*
INTEGRATIONTIME	90000	*measurement integrationtime [us]*

Following parameters are optional and only some of the cameras use them:

WAVELENGTHS		*start of the wavelengthbytes flag*
VALUES	349.79 350.95 . . .	*pixel wavelength values*
WAVELENGTHS_END		*end of the wavelengthbytes flag*

Tab. 26 Header File Structure

Structure of the .bil file

File contains uint16 binary values.

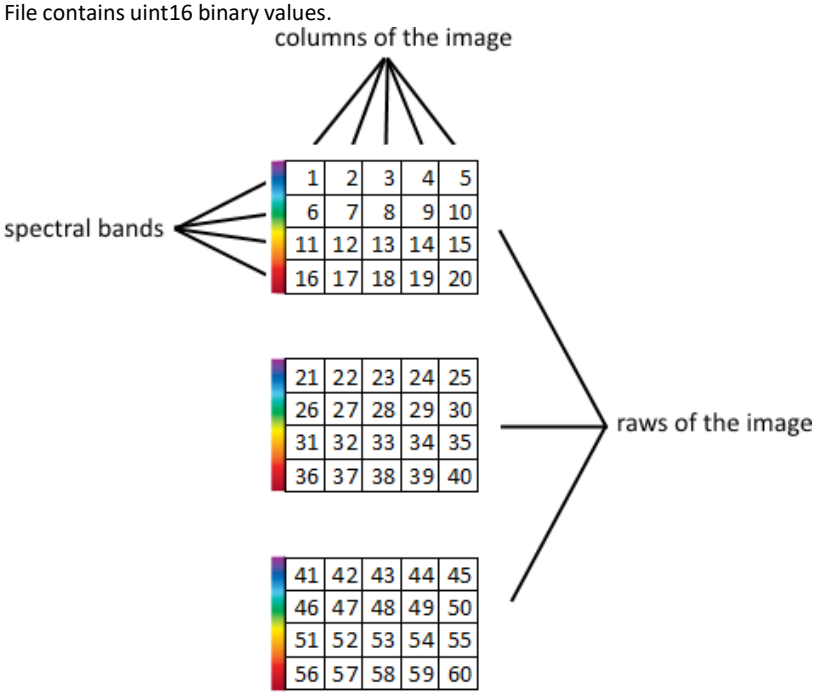


Fig. 153 Values Order

Images shows uint16 values order in the .bil file. Number in the table shows value order inthe file. Hypercube in the image is5px wide, 4px high and has 4 spectral bands.

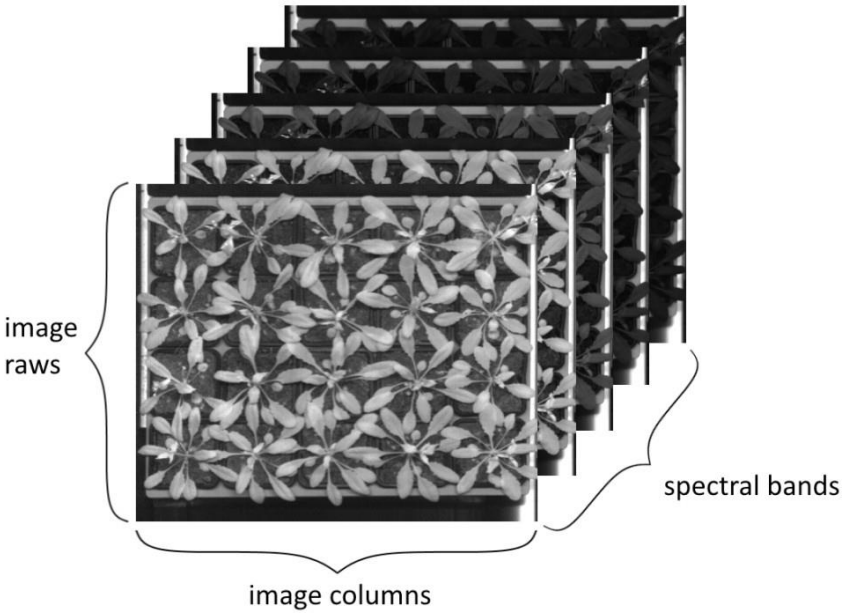


Fig. 154 Hypercube Visualization

11 Appendix 2 Automated Image Processing Pipeline

To produce images while maintaining a relatively short distance between camera and object,a fisheye lens is used. Consequently, the first step in the automated image pre-processing is a simple correction of the barrel distortion caused by the lens. The next step involvesbackground subtraction, in which the images of the plants within pots or trays are isolated from their background, so that further analysis is done only on plant tissue. The same barrel correction and background subtraction is done for both top view and side view images.
In the following sections individual steps of the data analyses are described. Individual parameters and their influence on the image processing are described in chapter **2.11.1 Settings.**

RGB Data analysis

Morphological and color-segmented analyses are performed on the binary and RGB images respectively. The binary image represents the surface of the actual plant. The color- segmented image provides information about the condition of leaves, such as the presence of infections and degree of chlorosis. The user may define numerous color groupings indicative of plant condition (e.g. healthy green, dark green, pale green, chlorotic yellow etc. etc.) and the software will calculate the percentage of the plant that falls into each category,and track changes over time. Raw images are stored in the file storage for further processingand data archiving.

- Input: Original undistorted RGB image
- Output: RGB and binary image of the plant surface with removed background, “Plant Mask” in .xsel format representing the individual plants, list of computed morphological traits

RGB MORPHOLOGY AND BACKGROUND SUBTRACTION

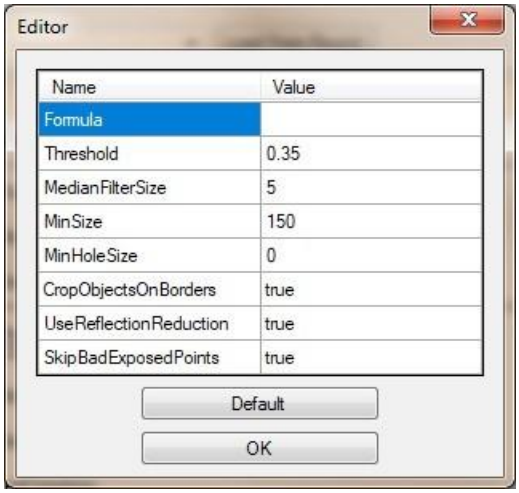


Fig. 155 RGB Plant Mask

PARAMETERS AND THEIR INFLUENCE

- Formula: definition for object mask generation. Formula can contain constants (1, 2, 3, …), operators (+, -, *, /, min, max, ln, log, sqrt, ^) and variables (R, G, B), which de- fine color component used (Red component, Green component, Blue component). When not filled the standard formula will be used: 4*G-3*B-R. Pixel values computed by this formula must be divided by the Threshold value to recognize wanted and un- wanted pixels. Wanted pixels have formula result greater than the Threshold value.
- Threshold: This threshold is applied for conversion of grayscale image with enhanced green channel to binary image – determining surface covered by plant
  - Lower N – better sensitivity, increasing Type 1 (false positive) error
  - Higher N – better specificity, increasing Type 2 (false negative) error
- MedianFilterSize: 2D median filter of size [NxN], reducing salt and pepper noise, re- moving invalid pixels and filling missing ones. Each output pixel contains median value of NxN neighborhood.
  - Lower N – more accurate shape and edges, lower filtering performance whenbackground x plant difference is not clearly visible
  - Higher N - better performance in noisy images,
- MinSize: Minimal size of object in pixels to be included in analysis, typically hundredsof pixels

- MinHoleSize: Minimal size of holes in the mask objects in pixels, typically tens of pixels. The holes smaller than this value are closed and taken into the object pixels. Zerovalue means the most detailed mask but in some cases it can lead to slow analysis computations.
- CropObjectsOnBorders: Option deleting object on the border area (e.g. overlappingleaves from neighboring pot). Particularly useful for top view with multiple plants close to each other.
- UseReflectionReduction: Option normalizing RGB values in each pixel (ratio betweenchannels is then considered for thresholding rather than absolute pixel values). Useful for harsh imaging conditions – e.g. light reflection from petri dishes.
- SkipBadExposedPoints: Crops over/under exposed pixels from the plant mask. Usedfor pixels where the color components ratio is not correct because of some of the color component exceeded the minimal or maximal value. Typically for omission the surface reflections or the dark pixels where the noise is larger than the signal.

PROCESSING PIPELINE

- Distortion correction: Removing barrel distortion caused by short focal distance us- ing simplified Brown's polynomials.
- Tray mask application: cropping image to certain regions of interest defined by tray mask. Position of the tray is detected automatically.
- Background subtraction: based on chlorophyll presence in majority of plant tissues, background subtraction utilizes the thresholding of a grayscale image with enhanced green channel.
- Subsequent filtration: artifact suppression based on median filtering and morphological features.
- Statistical parameters computation
- Color segmentation
- Plant segmentation / leaf tracking

COLOR SEGMENTATION

- Input: Processed RGB image (removed background), color map – list of hues for specific analysis
- Output: Color-segmented images a table with pixel sums for each hue

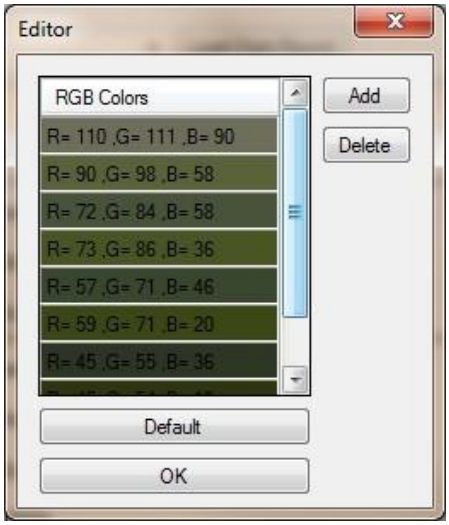


Fig. 156 RGB Color Segmentation

HUES DEFINITION

- Hues are defined by their position in RGB color space, ranging from 0-255 for each channel.
- Color of these hues as well as their total number can be modified to meet experimental requirements

HUES SELECTION – DESCRIPTION OF POST HOC COLOR ANALYSIS

- Selection of hues is performed using "training" dataset, usually 5-10 images from on- going experiment, different stages of development and conditions to get unbiased results
- Analysis saves R,G and B values of each pixel of each image from this training dataset.
- This Nx3 matrix (row for each pixel, columns for R,G,B values) serves as an input fork-means clustering.
- K-means clustering assigns input data, according to their Euclidean distance in RGBcolor space, to predefined number of clusters (usually 5-15), whose centroids are used as an input hues for greenness analysis.

- Processed RGB images with subtracted background are analyzed, pixel by pixel, andRGB values of each pixel are approximated with the nearest values from used colormap.
- Sum for each hue is computed and the image is stored.

Hyperspectral data analysis

- Input: Hyperspectral data cube with header, reference hyperspectral images
- Output: Defined vegetation indices for each pixel, pseudo RGB image for mask generation

PARAMETERS AND THEIR INFLUENCE

- MinValidPixelsPercentage: Minimal percent of the valid pixels for computation. In- valid pixel is defined as pixel, for which the equation gives invalid result (division by zero, …). These pixels are discarded from the parameter computation. If the valid pixel percentage is lower than the threshold, whole computation of the correspond- ing parameter is flagged as failed. If 0 is set, any number of invalid pixels is accepted. If 100 is set, all pixels have to be valid.
- Formula definition for object mask generation. Formula can contain constants (1, 2, 3, …), operators (+, -, *, /, min, max, ln, log, sqrt, ^) and variables (R740, R672, ...), which define wavelength used. Variables wavelengths must be from valid range de- fined by the camera.
  - Formula for computation of the object mask utilizes spectral features, e.g. ab-sorption bands of chlorophyll, to determine regions of interest
- Threshold: results in binary image, mask, where pixels with subliminal values com- puted by aforementioned formula are excluded as a background
- MedianFilterSize: Defining window for median filtration
  - Lower value: more precise object borders, more sensitive to salt and peppernoise
  - Higher value: increased filtering performance, worse identification of edges
- ErosionLevel: parameter defining number of iterations for morphological operation – erosion. This step removes N pixels from outside of the objects / regions of interest. This is useful considering relatively low spatial resolution of hyperspectral camera, where border pixels (plant tissue and soil transition) can influence the parameter sta- tistics and bring ambiguity in resulting spectra.
  - Low or none: preserves object shape
  - Higher: Better performance in terms of average vegetation indices computation

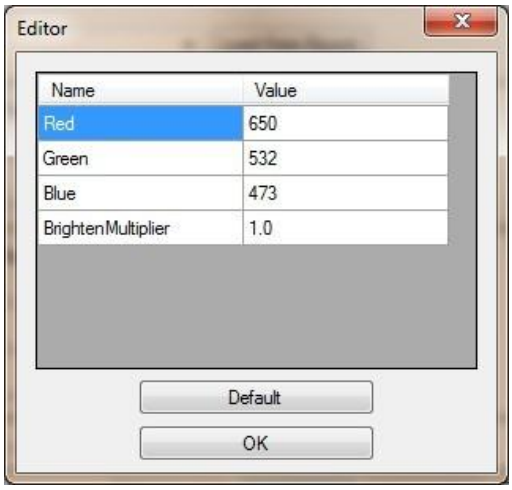


Fig. 157 VNIR RGB

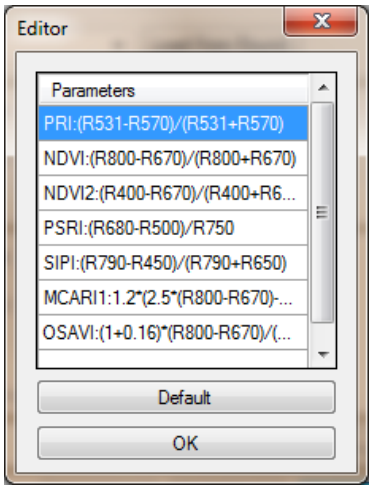


Fig. 158 VNIR Parameters

- Red: Wavelength used as red color for RGB image
- Green: Wavelength used as green color for RGB image
- Blue: Wavelength used as blue color for RGB image
- BrightenMultiplier: RGB value multiplier. If greater than 1, image is brighter, if lower, image is darker.
- VNIR and SWIR parameters: User defined parameters. Name of the parameter is be- fore the colon, equation for its computation after the colon. Equation can contain constants (1, 2, 3, …), operators (+, -, *, /, min, max, ln, log, sqrt, ^) and variables (R740, R672, ...), which define wavelength used. Variables wavelengths must be from valid range defined by the camera.
- WISurrounding: Parameter for camera noise reduction. Defines number of neighboring pixels (both in spectral and spatial dimensions), which are averaged and resulting value is used for the parameter computation. If set to 0, the original pixel value is taken.,

ANALYSIS PIPELINE

- Software reads the header and BIL file of the actual hyperspectral image as well as the supplementary calibration images
- Data are calibrated to get the accurate spectral response which is highly influenced by camera Quantum efficiency, light source spectra and other variables
  - Calibration is performed using so called white image – target with 99% reflectivity reference standard and dark image – image captured with no light, re- moving the artifacts caused by dark noise
- Generation of pseudo-RGB image of acquired scene for visual examination of the dataset with user defined wavelengths for red, green and blue channel
- Background subtraction utilizing defined formula and thresholding of the results
- Computation of vegetation indices using predefined set of equations, this can be per- formed
- for regions of interest or whole dataset. Results are visualized for pixel-by- pixel inspection and can be exported with means for each area of interest defined by mask and basic statistics
- (min, max, standard deviation).

3D Scan analysis

- Input: Point cloud model obtained by fusion of 3D scans taken from different angles of view of the plant.
- Output: Triangulated model segmented to individual leaves, set of morphological parameters describing leaves and whole plant

ANALYSIS SETTINGS

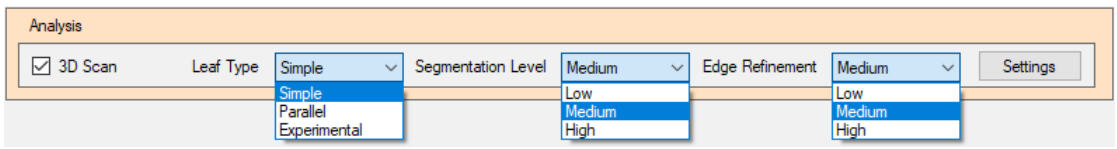


Fig. 159 3D Scan Analysis Settings

- Leaf Type: Selection of settings affects model triangulation approach. The Leaf Type is primarily defined by the shape, arrangement, and margins of plant leaves. Two leaf types are predefined and the Experimental choice is possible:
  - *Simple* – entire shape with smooth, toothed or undulate margin, mostly pinnate veins
  - *Parallel* – entire, linear, long and narrow sword-shaped leaves, with smooth margin, mostly parallel veins
  - *Experimental* - is used to set experimental triangulation rules. See below.
- Segmentation Level: allows influence the level of plant segmentation to the leaves.
  - *Low* – Parts of the point cloud models are merged into larger units. When merging multiple leaves together, it is advantageous to increase this level.This level is suitable for small or uneven leaves.
  - *Medium* – stands somewhere between low and high levels.
  - *High* - The individual parts of the point cloud model are more separated. Ifone leaf is divided into several parts, it is advisable to lower this level. Thislevel is more suitable for straight leaves.
- Edge Refinement: allows improve the curvature of the leaves edges in the triangulated model
  - *Low* – Achieves better results on oval leaves with a smooth margin. The edges of the toothed and undulate leaves are considerably simplified.
  - *Medium* – stands somewhere between low and high levels.
  - *High* - Achieves better results for undulate leaves. This level leads to in- creased computational difficulty and analysis may take longer, especially when combined with a large number of points in the model.

EXPERIMENTAL SETTINGS

Experimental Leaf Type option provides advanced triangulation settings if predefined *Leaf Types* do not achieve satisfactory results. The *Segmentation Level* and *Edge Refinement* op- tions described above are not available for this choice. These settings are replaced by new parameters in the analysis settings. The parameter *Editor* opens with the *Settings* button andcontains other parameters:

- SegmentationAngle supplants the Segmentation Level of the previous setting. Param- eter represents the threshold for the angle between the normals of the model points. Values can be entered between 0 – 180°. At smaller angles, segmentation is higher, at larger angles lower. Higher values lead to increased computational difficulty and analysis may take longer, especially when combined with a large number of points in the model.
- ControlPointsCount supplants the leaf Edge Refinement from the previous setting. Parameter represents the number of model points to be tested during triangulation for smoothing the edges of the leaves. Values can be entered between 10 – 200. Increasing the value can lead to better results for the undulate or toothed edges of the leaves. Higher values lead to increased computational difficulty and analysis may take longer, especially when combined with a large number of points in the model.

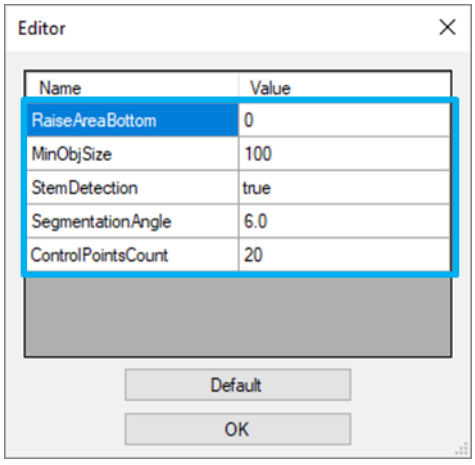


Fig. 160 3D Scan Settings

MORPHOLOGY PARAMETERS

The following leaf parameters are calculated during the analysis:

Parameter	Description
AREA	Object area [mm^2]
PROJECTED_AREA	Area of the object after projection onto XY plane [mm^2]
LEAF_INCLINATION	Ratio between area and projected area [-]
LEAF_AREA_INDEX	Ratio between area and area of XY plane of the bounding box enveloping anobject [-]
COMPACTNESS	Ratio between leaf area index and leaf area inclination [-]
R, G, B	Red, green and blue subcomponent of the false color of object in the analyzedtriangulated model, range <0,255>

The following plant parameters are calculated during the analysis:

Parameter	Description
AREA	Object area [mm^2]
PROJECTED_AREA	Area of the object after projection onto XY plane [mm^2]
LEAF_INCLINATION	Average leaf inclination for all leaves[-]
LEAF_AREA_INDEX	Ratio between area and area of XY plane of the bounding box enveloping anobject [-]
COMPACTNESS	Ratio between leaf area index and leaf area inclination [-]
PLANT_HEIGHT *	Height of the bounding box enveloping an object [mm]
DIGITAL_BIOMASS	The product of the plant height and area of the object [mm^3]
STEM_HEIGHT	Height of the bounding box enveloping an object detected as stem [mm]
STEM_LENGTH	Sum of the length of the cylindrical units forming the object found as a stem[mm]
BRANCHES_COUNT	The number of branches of an object found as a stem [-]

* The value of the analyzed object. In the case of poor identification of the highest parts of the plant as whole leaves, the value may differ from the height of the plant obtained by analysis from other measuring sensors.

ROOT

Morphological analysis is performed on the binary images. The binary image represents the surface of the actual root. Raw images are stored in the file storage for further processing and data archiving.

ROOT MORPHOLOGY AND BACKGROUND SUBTRACTION

- Input: Original undistorted RGB image
- Output: Binary image of the root surface with removed background, “Plant Mask” in .xsel format representing the individual roots, list of computed morphological traits

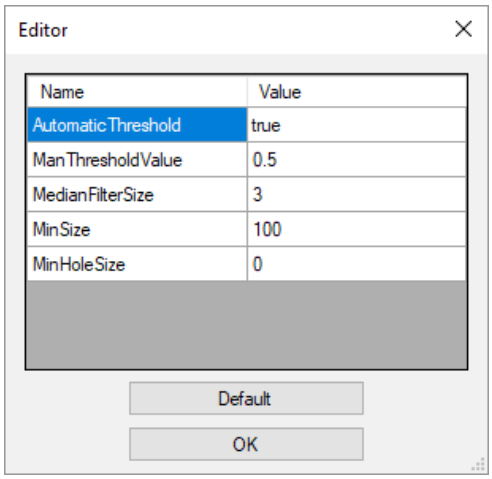


Fig. 161 ROOT Plant Mask

PARAMETERS AND THEIR INFLUENCE

- AutomaticThreshold: Option to choose automatic or manual determination of threshold to convert image to binary – determining surface covered by root.
- ManThresholdValue: This threshold is applied for conversion of grayscale image to binary image, unless automatic threshold determination is selected.
  - Lower N – better sensitivity, increasing Type 1 (false positive) error
  - Higher N – better specificity, increasing Type 2 (false negative) error
- MedianFilterSize: 2D median filter of size [NxN], reducing salt and pepper noise, re- moving invalid pixels and filling missing ones. Each output pixel contains median value of NxN neighborhood.
  - Lower N – more accurate shape and edges, lower filtering performance whenbackground x root difference is not clearly visible
  - Higher N - better performance in noisy images
- MinSize: Minimal size of object in pixels to be included in analysis, typically hundreds of pixels
- MinHoleSize: Minimal size of holes in analyzed object. Holes smaller than the indicated value, are filled.

PROCESSING PIPELINE

- Distortion correction: Removing barrel distortion caused by short focal distance us- ing simplified Brown's polynomials.
- Tray mask application: cropping image to certain regions of interest defined by tray mask. Position of the tray is detected automatically.
- Background subtraction: based on the brightness difference between roots and soil in the image, background subtraction utilizes the thresholding of a grayscale image.
- Subsequent filtration: artifact suppression based on median filtering and morphological features.
- Statistical parameters computation.

12 Appendix 3 PlantDataAnalyzer Parameters

Measuring device	Parameter	Unit	Description	Formula
FC	Size	mm^2	Total area covered with plant.	Measured
	F0	arbitrary unit	Minimum fluorescence in dark-adapted state.	Measured
	F0_Ln	arbitrary unit	Minimum fluorescence during light adaptation.	(F0/((Fv/Fm) + (F0/Fm_Ln)))
	F0_Lss	arbitrary unit	Steady-state minimum fluorescence in light.	F0/((Fv/Fm)+(F0/Fm_Lss))
	F0_Dn	arbitrary unit	Minimum fluorescence during dark relaxation.	F0/(Fv/Fm+F0/Fm_Dn)
	Fm	arbitrary unit	Maximum fluorescence in dark-adapted state.	Measured
	Fm_Ln	arbitrary unit	Maximum fluorescence during light adaptation.	Measured
	Fm_Lss	arbitrary unit	Steady-state maximum fluorescence in light.	Measured
	Fm_Dn	arbitrary unit	Instantaneous maximum fluorescence during dark relaxation.	Measured
	Fp	arbitrary unit	Peak fluorescence during the initial phase of the Kautsky effect.	Measured
	Ft_Ln	arbitrary unit	Instantaneous fluorescence during light adaptation.	Measured
	Ft_Lss	arbitrary unit	Steady-state fluorescence in light.	Measured
	Ft_Dn	arbitrary unit	Instantaneous fluorescence during dark relaxation.	Measured
	Fq_Ln	arbitrary unit	Difference in fluorescence between Fm_Ln and Ft_Ln in light.	Fm_Ln – Ft_Ln
	Fq_Lss	arbitrary unit	Fluorescence quenching capacity under actinic light.	Fm_Lss – Ft_Lss
	Fq_Dn	arbitrary unit	Difference in fluorescence between Fm_Dn and Ft_Dn during dark relaxation	Fm_Dn – Ft_Dn
	Fv	arbitrary unit	Variable fluorescence in dark-adapted state.	Fm – F0
	Fv Ln	arbitrary unit	Variable fluorescence in light.	Fm_Ln - F0_Ln
	Fv Lss	arbitrary unit	Variable fluorescence in light-adapted state.	Fm_Lss – F0 _Lss
	Fv Dn	arbitrary unit	Variable fluorescence during dark relaxation.	Fm_Dn - F0_Dn
	Fv/Fm (QY_max)	arbitrary unit	Maximum quantum efficiency of PSII photochemistry in dark-adapted state.	Fv/Fm
	Fv/Fm_Ln	arbitrary unit	PSII maximum efficiency of light adapted sample.	Fv_Ln/Fm_Ln
	Fv/Fm_Lss	arbitrary unit	PSII maximum efficiency of light adapted sample in steady-state.	Fv_Lss/Fm_Lss

	Fv/Fm_Dn	arbitrary unit	PSII maximum efficiency during dark relaxation.	Fv_Dn/Fm_Dn
	NPQ Ln	arbitrary unit	Instantaneous non-photochemical quenching during light adaptation.	(Fm-Fm_Ln)/ Fm_Ln
	NPQ Lss	arbitrary unit	Steady-state non-photochemical quenching.	(Fm - Fm_Lss)/Fm_Lss
	NPQ Dn	arbitrary unit	Instantaneous non-photochemical quenching during dark relaxation.	(Fm-Fm_Dn)/ Fm_Dn
	qL	arbitrary unit	Parameter used for estimation of the fraction of PSII open centers.	(Fm–F0)/Fm
	qL_Ln	arbitrary unit	Fraction of PSII centers that are 'open' during light adaptation.	(Fq_Ln/Fv_Ln) *(F0/Ft_Ln)
	qL_Lss	arbitrary unit	Fraction of PSII centers that are 'open' in steady state.	(Fq_Lss/Fv_Lss)* (F0/Ft_Lss)
	qL_Dn	arbitrary unit	Fraction of PSII centers that are 'open' during dark relaxation.	(Fq_Dn/Fv_Dn) / (F0_Dn/Ft_Dn)
	qN_Ln	arbitrary unit	Coefficient of non-photochemical quenching during light adaptation.	(Fm-Fm_Ln)/ (Fm- F0_Ln)
	qN_Lss	arbitrary unit	Coefficient of non-photochemical quenching in steady state.	(Fm-Fm_Lss)/ (Fm- F0_Lss)
	qN_Dn	arbitrary unit	Coefficient of non-photochemical quenching during dark relaxation.	(Fm-Fm_Dn)/ (Fm- F0_Dn)
	qP Ln	arbitrary unit	Coefficient of photochemical quenching during light adaptation.	Fq_Ln/Fv_Ln
	qP Lss	arbitrary unit	Coefficient of photochemical quenching in steady-state.	Fq_Lss/Fv_Lss
	qP Dn	arbitrary unit	Coefficient of photochemical quenching during dark relaxation.	Fq_Dn/Fv_Dn
	QY Ln	arbitrary unit	Instantaneous PSII quantum yield during light adaptation.	Fq_Ln/FM_Ln
	QY Lss	arbitrary unit	Steady-state PSII quantum yield in light.	Fq_Lss/ FM_Lss
	QY Dn	arbitrary unit	Instantaneous PSII quantum yield during dark relaxation.	Fq_Dn/FM_Dn
	Rfd Ln	arbitrary unit	Instantaneous fluorescence decline ratio in light.	(Fp-Ft_Ln) / Ft_Ln
	Rfd Lss	arbitrary unit	Fluorescence decline ratio in steady-state.	(Fp - Ft_Lss) /Ft_Lss
	PAR	nm	Photosynthetically active radiation calculated from light calibration curves.	LightA * LightIntesity + LightB
	ETR	arbitrary unit	Calculated electron transport rate.	0.8 * 0.5 * QY_Lss * PAR
	ETR_Lss	arbitrary unit	Electron transport rate in steady-state.	Measured

Measuring device	Parameter	Unit	Description	Formula
IR	Temp	°C	Temperature of plant surface.	Measured
	User Defined	arbitrary unit	User defined parameters.	

Measuring device	Parameter	Unit	Description	Formula
HC	MCARI1	arbitrary unit	Modified Chlorophyll Absorption in Reflectance Index.	1.2 * [2.5 * (R800 - R670) - 1.3 * (R800 - R550)]
	NDVI	arbitrary unit	Normalized Difference Vegetation Index.	(R800 - R670) / (R800 + R670)
	OSAVI	arbitrary unit	Optimized Soil-Adjusted Vegetation Index.	(1 + 0.16) * (R800 - R670) / (R800 - R670 + 0.16)
	PRI	arbitrary unit	Photochemical Reflectance Index.	(R531 - R570) / (R531 + R570)
	PSRI	arbitrary unit	Plant Senescence Reflectance Index.	(R680 - R500) / R750
	SIPI	arbitrary unit	Structure Insensitive Pigment Index.	(R790 - R450) / (R790 + R650)
	User Defined	arbitrary unit	User defined parameters.	

Measuring device	Parameter	Unit	Description	Formula
RGB	Area PX	pixels	Total area covered with plant.	Measured
	Area MM	mm^2	Total area covered with plant.	Measured
	Perimeter PX	pixels	Length of the plant perimeter, usually used for further computations.	Measured
	Perimeter MM	mm	Length of the plant perimeter, usually used for further computations.	Measured
	Compactness	arbitrary unit	Ratio between area and surface of convex hull enveloping particular plant	Area / Convex_Hull_Area
	Roundness	arbitrary unit	Ratio between area and perimeter of plant surface.	$4 * PI * Area / Perimeter^2$
	Roundness2	arbitrary unit	Ratio between area and perimeter of plant convex hull.	$4 * PI * Convex\_Hull\_Area / Convex\_Hull\_Perimeter^2$
	Eccentricity	arbitrary unit	Parameter describing the degree of difference between convex hull area and circle, which has center in plant centroid	{Area(circle only) + Area(Convex hull only)} / Area(intersection)
	RMS	arbitrary unit	Rotational Mass Symmetry.	$2 * \{sqrt((1/2 * Major\_Axis\_Length)^2 - (1/2 * Minor\_Axis\_Length)^2)\} / Major\_Axis\_Length$
	SOL	arbitrary unit	Index, which is calculated as a ratio between square of leaf lengths (sum of distances from plant center to the end of a leaf blade) and Area.	$Skeleton\ Perimeter^2$ / Area
	Isotropy	arbitrary unit	Crerates polygon from leaf tops and computes its roundness - analogical to plant roundness, more robust.	$4 * PI * Polygon\_Area / Polygon\_Perimeter^2$
	Height PX	pixels	Heigth of bounding box enveloping plant.	Measured
	Height MM	mm	Heigth of bounding box enveloping plant.	Measured

	Width PX	pixels	Width of bounding box enveloping plant.	Measured
	Leaf colors	%	Represents pre-selected colors of leaves. Value of each color in the charts reports percentage of the color on plant surface. Exported values are number of pixels.	Measured

Measuring device	Parameter	Unit	Description	Formula
ROOT	Height PX	pixels	Height of bounding box enveloping root.	Measured
	Height MM	mm	Height of bounding box enveloping root.	Measured
	Width PX	pixels	Width of bounding box enveloping root.	Measured
	Width MM	mm	Width of bounding box enveloping root.	Measured
	Aspect Ratio	arbitrary unit	Ratio between the width of the root surface and the height of the root surface.	Width / Height
	Area PX	pixels	Total area covered with root. It is also used, especially with perimeter and convex hull area as input for computing more complex parameters.	Measured
	Area MM	mm	Total area covered with root. It is also used, especially with perimeter and convex hull area as input for computing more complex parameters.	Measured
	Compactness	arbitrary unit	Ratio between area and surface of convex hull enveloping particular root.	Area / Convex_Hull_Area
	Perimeter PX	pixels	Length of the root perimeter, usually used for further computations.	Measured
	Perimeter MM	mm	Length of the root perimeter, usually used for further computations.	Measured
	Total Length PX	pixels	The number of pixels in the skeleton of the root (width roots reduced to one pixel).	Measured
	Total Length MM	mm	The number of pixels in the skeleton of the root (width roots reduced to one pixel) converted to millimeters.	Measured
	RMS	arbitrary unit	Rotational Mass Symmetry.	$2 * \{\text{sqrt}((1/2 * \text{Major\_Axis\_Length})^2 - (1/2 * \text{Minor\_Axis\_Length})^2)\} / \text{Major\_Axis\_Length}$
	Distribution Median	arbitrary unit	The median number of root pixels in each row of the image.	Measured
	Endpoint	arbitrary unit	The number of root pixels that adjoins only one pixel.	Measured
	Nodes	arbitrary unit	The number of root pixels that have more than 2 neighbors.	Measured

Measuring device	Parameter	Unit	Description	Formula
S3D	Area	mm2	Leaf - Area of all triangles forming the leaf in the triangulated model.	Measured
			Plant - Sum of the Area parameter for all leaves.	Measured
	Projected Area	mm3	Leaf - Area of the projection of all triangles forming the leaf in the triangulated model into an XY plane.	Measured
			Plant - Area of the projection of all triangles forming the whole plant in the triangulated model into an XY plane.	Measured
	Leaf Inclination	arbitrary unit	Leaf - Ratio between the Area parameter of the leaf and the Projected Area parameter of the leaf.	Area_Leaf / Projected_Area_Leaf
			Plant - The average of the Leaf Inclination parameter for all leaves.	avg(Leaf_Inclination)
	Leaf Area Index	arbitrary unit	Leaf - Ratio between the Area parameter of the leaf and the area of an XY plane of the bounding box enveloping leaf.	Area_Leaf / Area_Bounding_Box
			Plant - Ratio between the Area parameter of whole plant and the area of an XY plane of the bounding box enveloping the whole plant.	Area_Plant / Area_Bounding_Box
	Compactness	arbitrary unit	Leaf - Ratio between the Leaf Area Index parameter of the leaf and the Leaf Inclination parameter of the leaf.	Leaf_Area_Index / Leaf_Inclination
			Plant - Ratio between the Leaf Area Index parameter of the whole plant and the Leaf Inclination parameter of the whole plant.	Leaf_Area_Index_Plant / Leaf_Inclination_Plant
	Plant Height	mm	Height of the bounding box enveloping the whole plant in the triangulated model.	Measured
	Digital Biomass	mm3	The product of the Plant Height parameter and the Area parameter of the whole plant	Plant_Height * Area_Plant
	Stem Height	mm	Height of the bounding box enveloping the plant stem.	Measured
	Stem Length	mm	Length of the plant stem.	Measured
	Branches Count	arbitrary unit	Number of the stem branches.	Measured
	RGB values	arbitrary unit	The R, G, B values in exported documents represent the leaf color in the analyzed triangulated model.	Measured

Measuring device	Parameter	Unit	Description	Formula
SC	Weight	g	Weight of pot with plant.	Measured
	Weight after watering	g	Weight of pot with plant after watering.	Measured