



Scanalyzer 3-D High-throughput Plant Phenotyping

RANDOMISATION SCHEMES AND GREENHOUSE LAYOUTS
for
LemnaTec greenhouse management systems

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Introduction

The layout of conveyor belts in fully automatised greenhouses can have significant influence on the randomisation modes employed for exchanging plants during the growth phase in order to enable constant growth conditions. The modular and highly flexible LemnaTec conveyor concept can be adapted to a wide range of customer specific layouts and plant exchange schemes, which are determined by the layout of the greenhouse and attributes of the test objects. This paper will highlight the features and conditions of greenhouse conveyor layouts as well as the corresponding plant exchange schemes.

Conveyor layouts in the greenhouse

In general, the orientation and dimensions of a greenhouse are already in place or at least fixed before conveyor installation. If this is not the case, it is reasonable to take the specific requirements of the conveyor belts into consideration at a very early stage of planning, as pre-alignment of sizes and formats reduces costs significantly and also enables maximisation of the amount of plants to be put in a defined greenhouse area. As the optimisation depends on many factors, please contact LemnaTec as early as possible for a consulting service if you wish to equip a new or already existing greenhouse with conveyor belts.

The following outline only refers to some basic layout questions and largely ignores variables such as conveyor belt width (10–50 cm), plant sizes or pot formats.

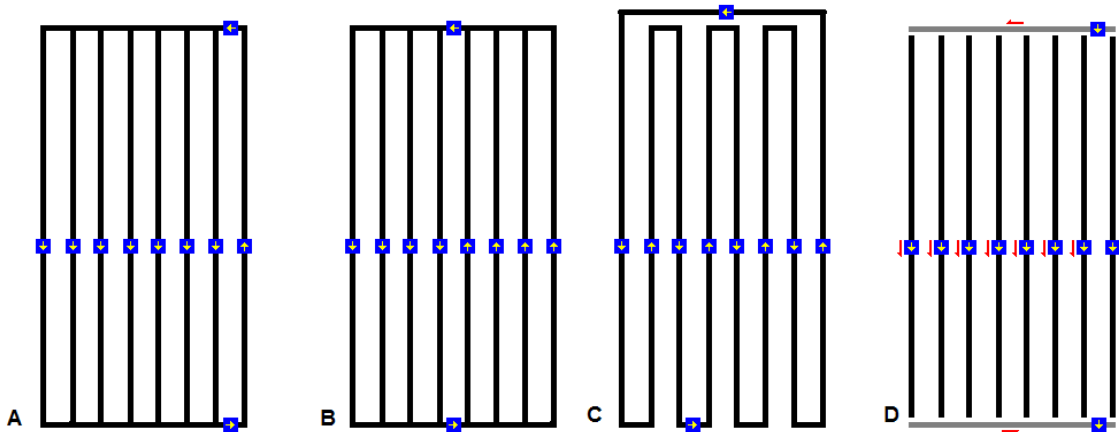


Fig. 1: A. Standard Layout 99:1; B. Standard Layout 50:50; C. Snake Movement Layout and D. Heavy-Duty Layout. Arrows on the blue symbolised pallets signify both transportation direction and plant orientation, except for D where plants always keep their orientation, and red arrows show how plants are transported on (black) conveyor lines or on a (grey) shuttle line.

One very basic layout question is if all storage belts should have the same orientation, with just one belt moving in the reverse direction for exchange (the so-called 99:1-scheme), or if half of the belts should run in one and the other half in the opposite

direction, without the need for specific reverse direction lanes (the so-called 50:50-scheme). For very small pots (with a maximum of 2 kg on 100 mm belts), a Snake Movement Design is also possible. All features and advantages of the specific solutions are described in the table below.

Table 1: Characteristics of different conveyor layouts

50:50	99:1	Snake Movement
Shortest time for exchange to a completely different position	Lane exchange needs transport over reverse lane (medium exchange time)	Slow, fixed, steady movement through all positions
Plants turn 180° from one parking lane to the next; on heavy-duty lines orientation is never changed	Plants keep orientation except for a short time on the reverse lane; on heavy-duty lines orientation is never changed	Plants turn 180° from one lane to the next; keeping term orientation to a minimum only possible when double lane steps are in use
Plants can pass two weighing/watering stations in one round	Plants can pass only one weighing/watering station in one round	Plants can pass any number of installed weighing/watering stations in one round
Additional line changes necessary to bring all plants to imaging stations	All lines have direct access to imaging stations, with minimum movement possible	All plants need to pass all positions to get access to imaging stations
Amount of position changes for randomisation is freely selectable, except for those changes that allow all plants to reach external watering or imaging points	Amount of position changes for randomisation is freely selectable (lowest required movement)	The highest frequency of movements for randomization is required
Randomisation modes: <ol style="list-style-type: none"> 1. Full random 2. Half line 3. Full line 4. First plant systematic 	Randomisation modes: <ol style="list-style-type: none"> 1. Full random 2. Half line 3. Full line 4. First plant systematic 	Randomisation modes: <ol style="list-style-type: none"> 1. Continuous Snake 2. Half line Snake 3. Full line Snake 4. Double line Snake

Moving Field Concept

The Moving Field is a special case of the 99:1- or 50:50-scheme, allowing to create high-density growth areas with plants overlapping in their clearance, but tolerating only minimal plant damage. With this option, only very specific randomisation schemes can be used (First Plant Systematic). The general layout for a 99:1-design is shown below, but a 50:50- or Heavy-Duty Design would not look significantly different.

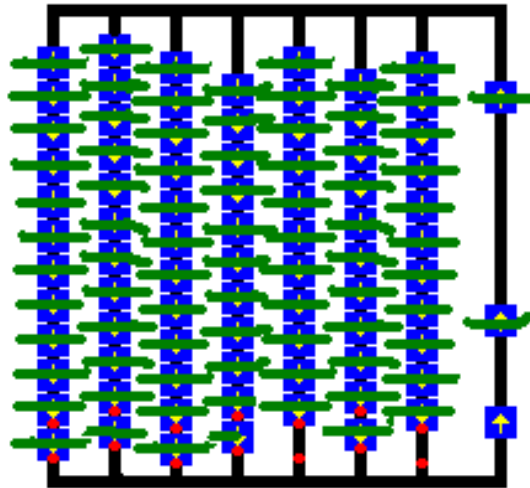


Figure 2: Moving Field Design for a 99:1-layout. Two stoppers (red dots) and an alternating positioning of the rows ensure minimum overlap, thus avoiding leaf damage. By always moving the first row out first (every 2nd plant) and then taking the alternating row somewhat behind, mechanical stress for the leaves is minimized. Filling of the lanes is done in the opposite way by always filling the more empty lanes first. The back-lane has a larger clearance to avoid any mechanical injuries. For more details, please consult the LemnaTec paper about the Moving Field concept.

To maximise the density of plants in greenhouses or growth chambers, LemnaTec can provide two options to fill an area almost completely with pots. As long as the plants do not jut out, all layouts are generally possible using protruding cars. For small, light plants like "Arabidopsis", the use of 100 mm belts in the Snake Movement layout is one choice, with a distance of 18 cm between the belts. This allows placement of trays with two or more plants. For 200 mm conveyors tray use (around 200 * 400 mm) is also possible to fill areas completely.

For big plants in pots with a diameter of 40 to 50 cm, high-density, heavy-duty belts for pot-weights of up to 30 kg can be installed. These belts use special cars and transfer systems which do not turn the plants around and are run preferably in the Moving Field mode (see there).

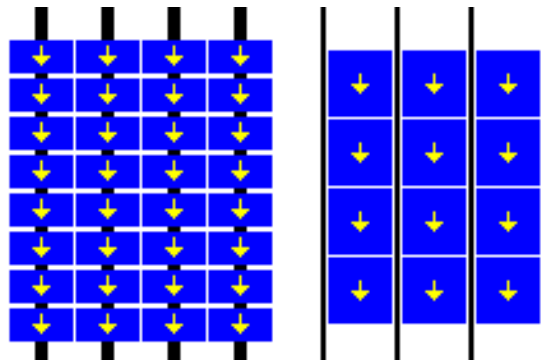


Figure 3: Protruding cars (left) are rather wide than long and may transport several plants per car. Cars on heavy-duty belts (right) are generally square. Both systems allow an almost complete filling of greenhouses or growth chambers.

Attachment of imaging units to greenhouse conveyor units

LemnaTec conveyor modules allow the attachment of the imaging units both in parallel or at right angles to the movement direction of the parking lanes. Depending on greenhouse dimensions and intended distances between the lanes, the various orientations may have different advantages and disadvantages concerning technical specifications (number of motors needed, length of connecting belts etc.) and biological issues.

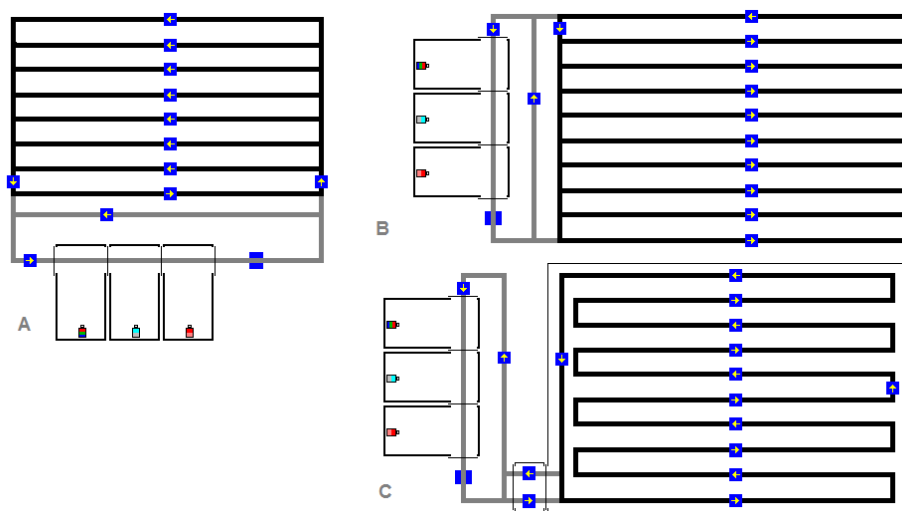


Figure 4: Imaging unit attachment options parallel to the storage belts (A) or rectangular (B), which is possible for both 99:1- and 50:50-schemes. The Snake scheme (C) is shown here for a growth-chamber layout including a climate sluice to separate the climatic conditions within the chamber from the imaging area outside the growth area. In all cases the imaging loop (grey) is designed as a stand-alone system for plants not handled on the greenhouse belts.

Orientation of belts relative to the sun

Belts in an almost north-southerly direction have a more equilibrated natural light from both sides, while shadowing through neighbouring plants is higher around midday. East-westerly oriented lanes have less shadowing from neighbouring plants – at least as long as no maximum density belt concept is used –, but plants tend to be illuminated rather from one side, especially with the 99:1-layouts.

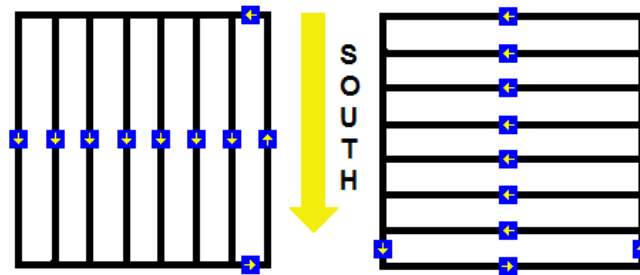


Figure 5: Belt orientation relative to the direction of the sun. Depending on the orientation and layout of the conveyor and the distance between lines, the shading and predominant light direction may change.

Randomisation modes

Full random + Continuous Snake

In the 50:50-scheme two plants will always be exchanged between two randomly selected lines. In the 99:1-scheme plants are randomly brought to the reverse lane and randomly sorted back again. To minimise running without time controlled procedures the number of plants on the connecting lanes is kept to a minimum. The corresponding mode for the Snake layout is the step-by-step movement of all plants. They are turned around and thus equally positioned on all positions, which is here called Continuous Snake.

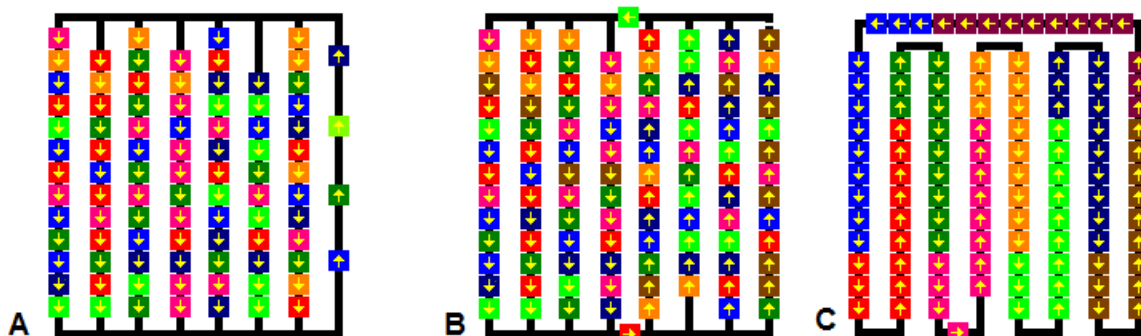


Figure 6: Random mode; A. 99:1: Plants are released randomly and sent back randomly creating completely undetermined mixtures; B. 50:50: Single plants are exchanged randomly between lines creating a completely undetermined mixture; C. Snake: Plants shift one by one to bring all plants to all positions for the same time span.

Half line + half line Snake

If an even number of cars is in one line, half of the cars per line can be exchanged in one step being handled like a train even if not fixed to each other, which is particularly useful to bring border cars to intermediate positions. Additionally, change lines to occupy all half-lines for the same time span.

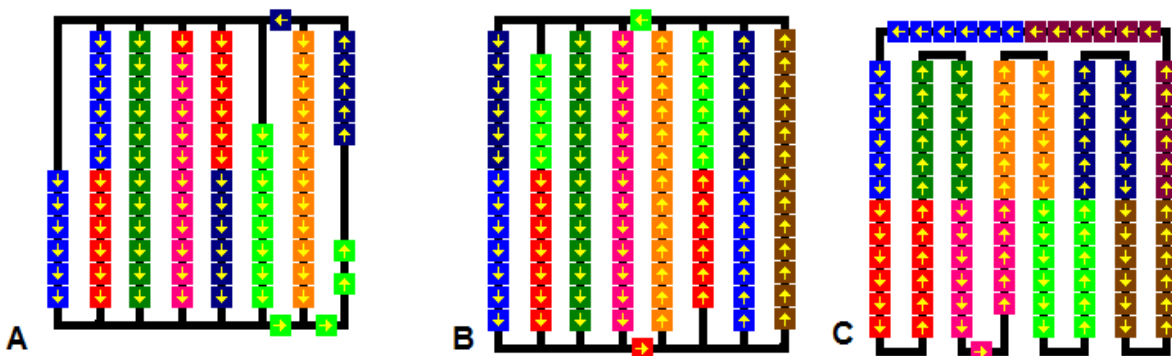


Figure 7: Half line mode; A. 99:1: Half line trains are released and parked again in a predetermined pattern between lines; B. 50:50: Half line trains are exchanged between two lines in a predetermined pattern; C. Snake: Half line trains are swiftly moved to the next line to park there for a predefined period before the next movement.

Full line + full line Snake

Invariably two trains covering each a full line exchange their positions in order to park on all lanes for an identical period. In the Snake layout all cars one of one full line train line are moved forward one full line.

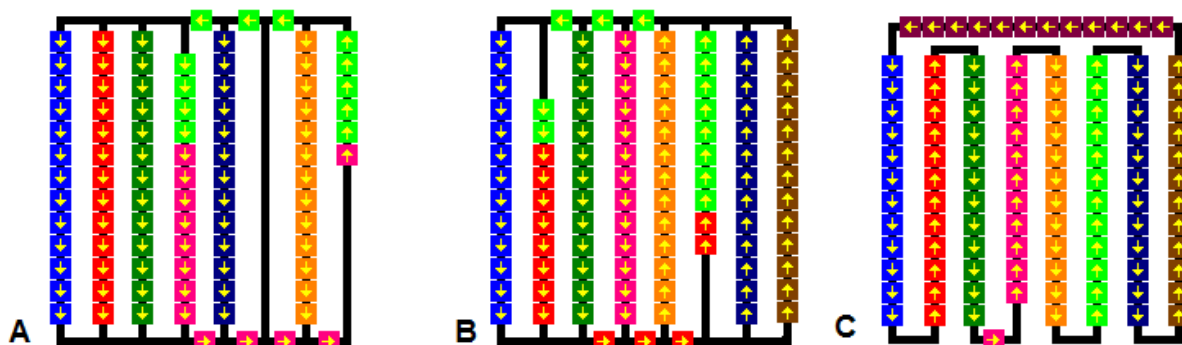


Figure 8: Full line mode; A. 99:1: Full line trains are released and parked again in a predetermined pattern between lines; B. 50:50: Full line trains are exchanged between two lines in a predetermined pattern; C. Snake: Full line trains are swiftly moved to the next line to park there for a predefined period before the next movement,

First plant systematic + double line Snake

The first car in every line is taken and returned back to the identical line or shifted by one line, in order to equilibrate the border lines. Nevertheless, the local environment of the

plants is kept almost constant. And the systematic transport allows the application of this scheme in Moving Fields units. For the Snake layout, the most systematic way to position plants is to always transfer them two line lengths to minimise orientation differences relative to the light (not relevant with growth chamber units). First plant systematic is necessarily be used with Moving Field concepts as this is the only way to move no single line faster than the others (except for back-lanes with larger clearance from the other lines).

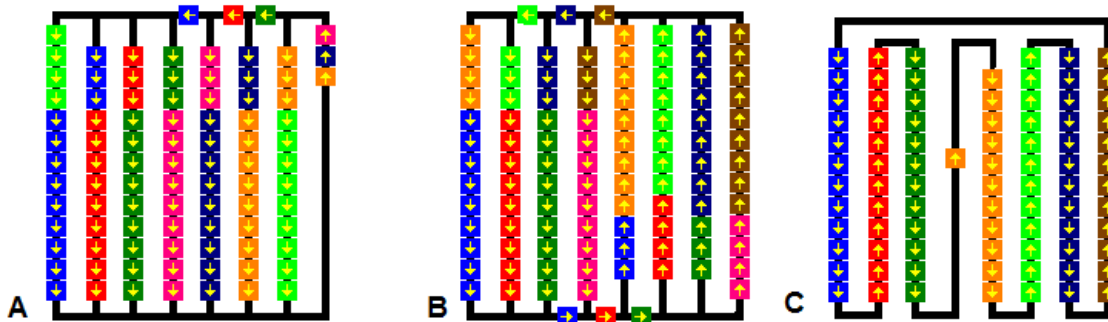


Figure 9: First plant systematic; A. 99:1: Always the first plant of each line is released and sorted back systematically, in this case with a one line shift; B. 50:50: Always the first plant of each line is released and sorted back systematically, in this case inverting center and outer lines; C. Snake: Half line trains are swiftly moved over an empty line to the next but one line to park there for a predefined period before the next movement in the same orientation as before.

Table 2: Features of randomisation schemes (+ fulfilled, - not fulfilled)

	Full random	Half line	Full line	First plant systematic
Exchange within lines in parking position	+ +	+	-	+
Analysis with plot design statistics possible, due to constant neighbouring plants	-	+	+ +	+ +
Long parking periods may alternate with short movement periods or shock stress due to cars bumping into each other	-	+	+ +	-
Line neighbours kept together	-	+	+ +	+
Row neighbours kept together	-	-	-	+(Snake -)
Moving Fields option applicable	-	-	-	+ +
Head and tail plants of lines change to inner positions	+ +	+	--	+ +
Watering/imaging always in constant order	-	+	+ +	+ +
Number of steps for all plants to have the same parking time on all different positions	Not available	-	+	+ +



Conclusion

LemnaTec can provide different basic conveyor belt layouts for various plant species and sizes, greenhouse requirements and scientific targets. Depending on the selected layout, different randomisation modes may be used alternatively, all with their different features mentioned in the table above. For different system sizes and research aims, the optimum conveyor layout and randomisation scheme will vary. LemnaTec offers a system with maximum flexibility to adapt to the specific needs of the experiments.

For a detailed analysis of your specific needs, please contact LemnaTec.

For any question or the development of customised solutions tailored to your particular needs, please contact LemnaTec.

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