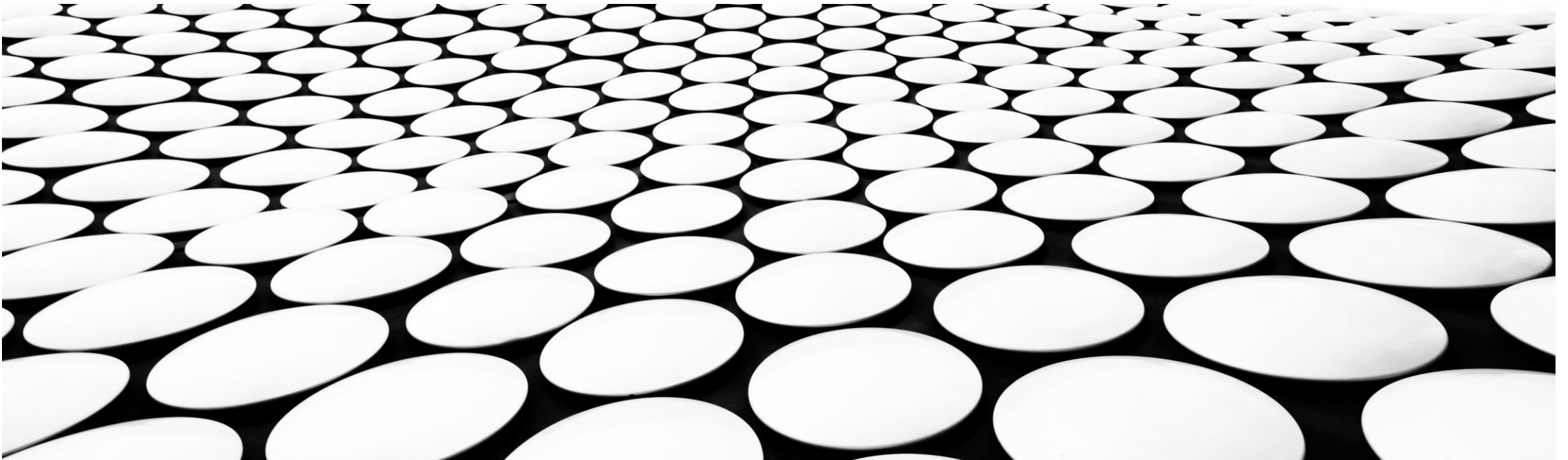


DEFINING PHOTOSYNTHETIC PHOTON FLUX DENSITY (PPFD)

OPTIMIZED LED LIGHTING ARRAY FOR HORTICULTURAL APPLICATIONS

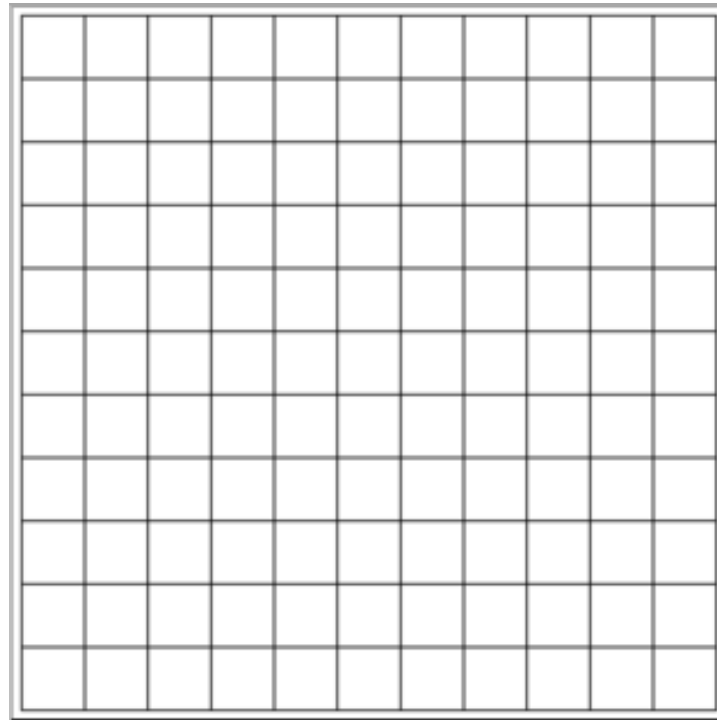


ALGORITHM FOR MEASURING THE EFFICACY OF LIGHTING ARRAYS

We have developed a patented variance measurement algorithm which generates 2D and 3D illustrations that enable you to clearly see the significant improvement our lighting arrays offer over competitors in uniformly saturating a given area with photosynthetically active radiation (PAR).

TESTING MAT

An 5-foot by 5-foot, 11 x 11 grid testing mat is screen printed and a measurement of photosynthetically active radiation (PAR) is collected at each of the 121 points on the mat. These measurements serve to represent “PAR Spikes”.



EQUATIONS FOR GENERATING NEW METRICS

■ Generating **APSV** Values

- (1) Average PAR Spikes to produce Averaged PAR Spikes (**APS**).
- (2) Deduct each PAR Spike from the **APS** value and use the absolute value of each of those results to generate Deducted PAR Spikes (**|DPS|**), then average these values to generate the Averaged PAR Spike Variance (**APSV**) metric.

- Equation example for experiment in which 121 points are tested.

$$\text{APSV} = \frac{1}{121} * \sum_{i=1}^{121} |DPS_i| \rightarrow$$

Elite **APSV** = 185.419985

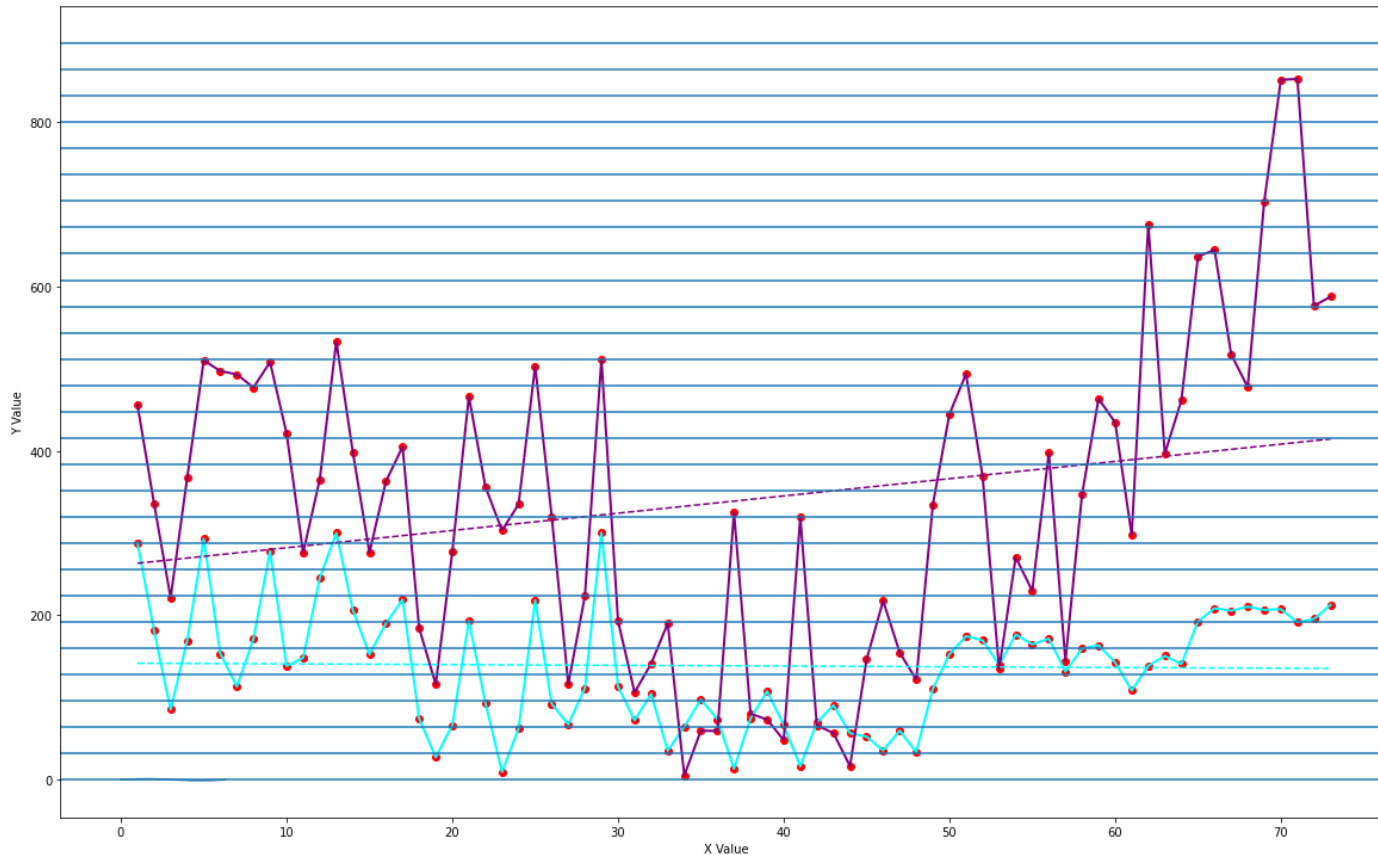
HPS **APSV** = 241.867632

Average PAR Spike Variance (**APSV**) Improvement of: 26.4214%

PRODUCING 2-DIMENSIONAL ILLUSTRATIONS USING THE GENERATED METRICS

- We use the |DPS| metric generated by our algorithm to generate our 2-Dimensional illustrations. These illustrations allow us to visualize the difference in radiometric uniformity between our arrays and LED competitors / traditional high-pressure sodium (HPS) lighting systems on a line graph.
- The first plot point for each line on the graph corresponds to the uppermost left point of the 5' x 5' square testing mat. The next plot point in each line corresponds to the next point (e.g., to the right of the first point) and the subsequent points follow the outside of the five foot by five-foot square, and then the four foot by four-foot square, and so on, spiraling inward to the center point of the three foot by three-foot square, for a total of 121 plotted points.
- You want to see as stable a line as possible, as well as a line sitting as low on the graph as possible. We can see on the next slide that the differences are clear.
- Note that the 1000w HPS' trend line (purple) crosses 7 lines on the graph, and our trend line (blue) does not deviate from its starting line. This is very difficult to achieve in a lighting system.

1000w **HID:HPS** vs. 957w **Elite**
24" Mounting Distance
No Reflective Walls



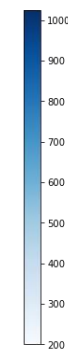
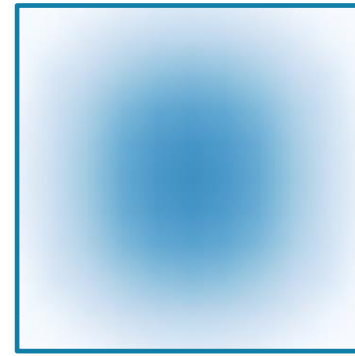
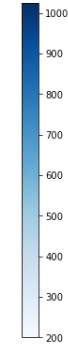
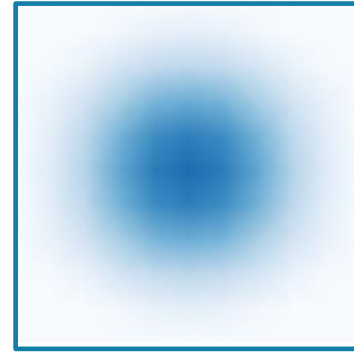
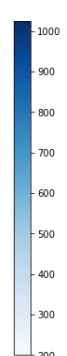
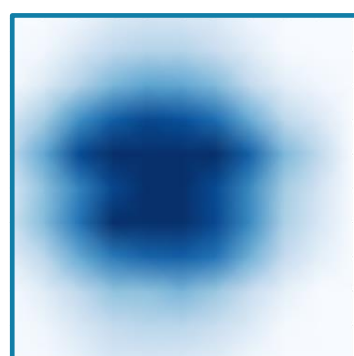
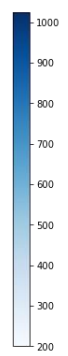
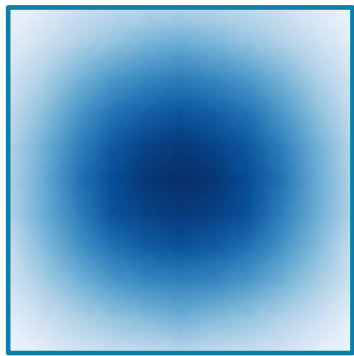
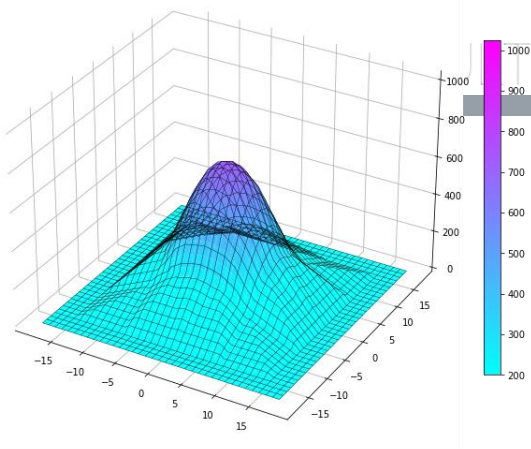
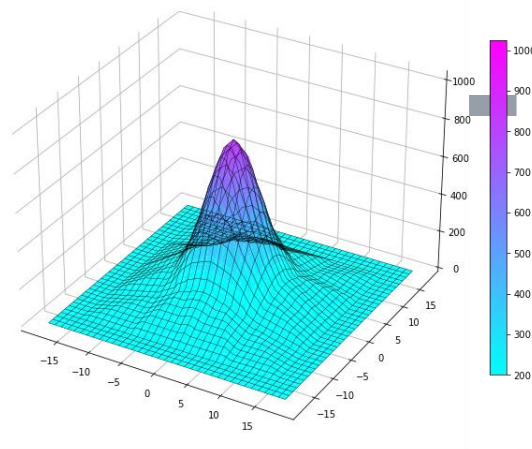
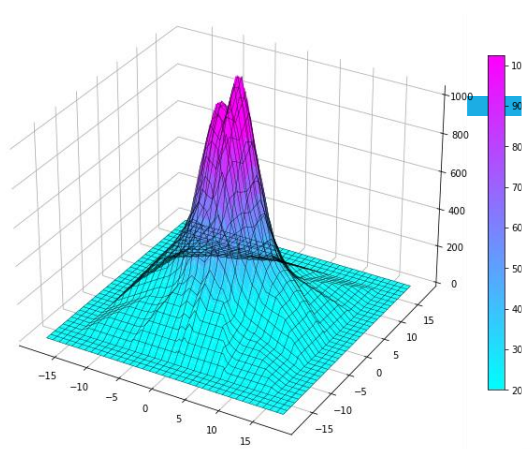
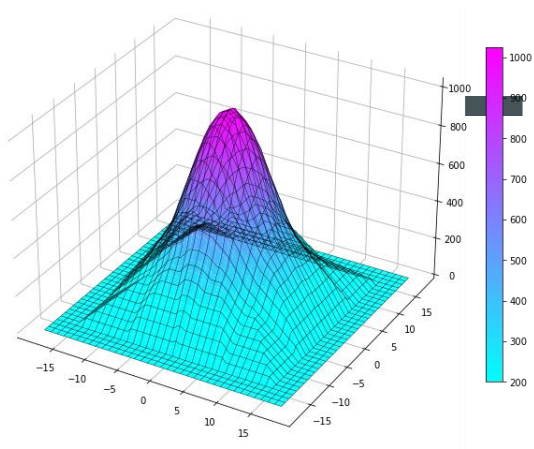
1000w **HPS** Averaged PAR Spike Variance
(**APSV**): 241.867632

957w **Elite** Averaged PAR Spike Variance
(**APSV**): 185.419985

Elite vs. **HPS** = **26.4214% APSv**
Improvement

PRODUCING 3-DIMENSIONAL ILLUSTRATIONS USING THE GENERATED METRICS

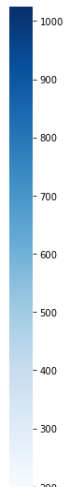
- To generate 3-Dimensional illustrations, we wrote a script in Python that draws 3-Dimensional photosynthetic photon flux density (PPFD) surface graphs. These enable you to truly visualize how the PAR is behaving in the testing environment.
- The script simulates our 5-foot by 5-foot, 11 x 11 grid testing mat and raises each PAR spike along the Z-axis relative to the amount of PAR collected at each point.
- Imagine your canopy is in the middle of the plot; you want that area to be *encapsulated* with light. As you can see in the next slides, there are some significant differences in how well the photons produced by different lighting systems behave.
- Also included in the following slide are PAR heat maps for our LED solution versus HID:HPS and LED competitors.



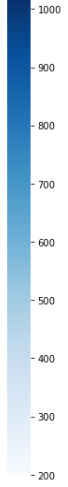
230	280	355	392	457	459	447	397	346	283	234
283	385	486	563	611	619	600	541	463	375	296
345	462	591	701	769	804	764	682	582	457	370
387	533	683	814	915	930	891	800	674	526	414
410	572	741	878	970	1002	958	866	737	578	430
438	607	763	911	991	1023	989	902	770	610	445
412	573	740	876	966	999	960	862	736	580	433
388	534	681	810	914	930	888	798	677	528	415
346	464	589	700	767	808	762	683	580	459	373
285	386	482	560	613	610	597	543	462	372	299
231	282	352	389	454	460	445	400	350	280	233



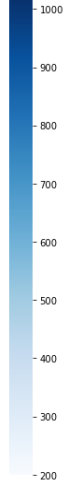
85	97	105	138	155	155	195	167	130	107	109
127	156	192	280	333	352	426	321	229	167	137
168	216	272	407	471	493	576	426	282	207	174
228	312	392	602	735	737	867	619	412	298	229
299	394	517	808	944	940	1103	828	568	393	303
328	437	586	873	1090	1054	1239	923	638	453	331
335	439	544	859	1099	1058	1268	949	649	456	341
337	411	537	790	1018	953	1163	873	582	422	312
262	331	420	625	802	757	938	717	460	331	235
211	241	299	432	564	546	637	493	310	226	187
160	170	204	286	349	317	410	327	202	156	129



64.55	91.68	122.85	152.95	176.2	185.15	176.2	152.95	122.85	91.68	64.55
89.28	130.38	209.23	259.3	281.5	298	281.5	259.3	209.23	130.38	89.28
115.05	178.78	260.83	352.75	428.5	455.5	428.5	352.75	260.83	178.78	115.05
141.05	226.98	343.5	481.25	595.5	638	595.5	481.25	343.5	226.98	141.05
160.93	263.23	410.5	583.5	729.5	783.5	729.5	583.5	410.5	263.23	160.93
169.5	277	432.25	616.5	774.75	833	774.75	616.5	432.25	277	169.5
160.93	263.23	410.5	583.5	729.5	783.5	729.5	583.5	410.5	263.23	160.93
141.05	226.98	343.5	481.25	595.5	638	595.5	481.25	343.5	226.98	141
115.05	178.78	260.83	352.75	428.5	455.5	428.5	352.75	260.83	178.78	115.05
89.28	130.38	209.23	259.3	281.5	298	281.5	259.3	209.23	130.38	89.28
64.55	91.68	122.85	152.95	176.2	185.15	176.2	152.95	122.85	91.68	64.55



122.48	165.45	205.65	235.3	252.7	259.9	252.7	235.3	205.65	165.45	122.48
173.43	236.1	320	358.75	371.5	380.5	371.5	358.75	320	236.1	173.43
223.5	313.5	397	462.25	499.25	510	499.25	462.25	397	313.5	223.5
267.08	378.75	482.75	566	609.5	623.5	609.5	566	482.75	378.75	267.08
294.5	420.25	537.25	627	678.75	694.5	678.75	627	537.25	420.25	294.5
308.5	434	556.25	648.5	702.5	719.5	702.5	648.5	556.25	434	308.5
294.5	420.25	537.25	627	678.75	694.5	678.75	627	537.25	420.25	294.5
267.08	378.75	482.75	566	609.5	623.5	609.5	566	482.75	378.75	267.08
223.5	313.5	397	462.25	499.25	510	499.25	462.25	397	313.5	223.5
173.43	236.1	320	358.75	371.5	380.5	371.5	358.75	320	236.1	173.43
122.48	165.45	205.65	235.3	252.7	259.9	252.7	235.3	205.65	165.45	122.48



LED Cultivation "Elite"

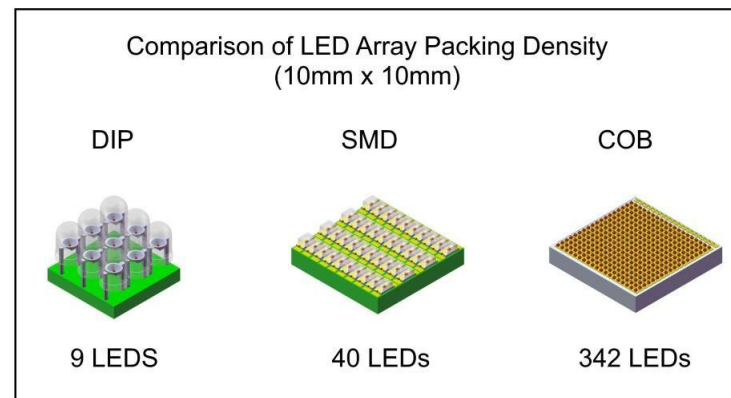
1000w HID:HPS

HLG 550 V2 R-Spec

Gavita Pro 1700e

WHAT ARE SOME DIFFERENCES BETWEEN US AND OTHER LED COMPETITORS?

- The principal issue we have solved is in uniformly saturating a given area with photosynthetically active radiation (PAR). This results in the highest yield per square foot on the market.
- Our lighting arrays' photon output is primarily sourced from Chip On Board (COB) technology and supplemented with Surface Mount Technology (SMT), whereas competing technologies' photon output is sourced solely from SMT. COBs are the most cutting-edge LED technology available on the market. Improvements over SMT include a higher chip packing density, resulting in a higher quality beam of light; higher photon production efficiency, resulting in less heat produced / more usable light per watt; and 360-degree multi-directional photon emission, which enables more areas of your canopy to receive PAR.
- With 25 separate LED modules consisting of precisely 5,000 LEDs, our arrays are comprised of more LED modules and LED chips than anything else on the market.



CONCLUSION

If the PPFD is spatially uniform at an appropriate level in a plant canopy regardless of the canopy's depth, the net photosynthetic rate of the whole plant canopy increases significantly, and the decrease in net photosynthetic capacity of lower leaves due to their senescence is prevented. (Zhang et al., 2015; Joshi et al., 2017)

Even distributions of photosynthetic photons and air currents to all parts of all leaves maximize photosynthesis and thus plant growth. A uniform light environment in a plant canopy has the following effects:

(1) Geometrical relationships between the source (photosynthesizing parts) and sink (accumulating parts of translocated carbohydrates) of plants are changed; (2) All leaves of a plant canopy relatively equally act as producers of carbohydrates; (3) Senescence of lower leaves due to low PPFD is suppressed; and (4) Phytohormone balances in individual plants are changed.

References:

Joshi, J., Zhang, G., Shen, S., Supaibulwatana, K., Watanabe, C., Yamori, W., 2017. A combination of downward lighting and supplemental upward lighting improves plant growth in a closed plant factory with artificial lighting.

Hortscience 52 (6), 831-835. <https://doi.org/10.21273/HORTSCI11822-17>