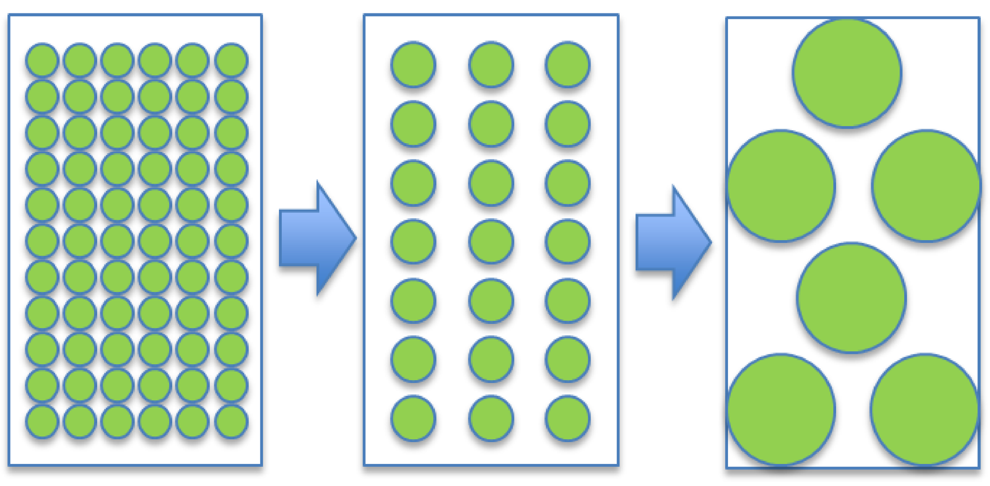
Quantitative Impact Evaluation of Respacing in Lettuce Production under Controlled Environment

COLLEGE OF AGRICULTURE AND LIFE SCIENCES
CONTROLLED ENVIRONMENT AGRICULTURE CENTER
ARIZONA

Chieri Kubota, School of Plant Sciences, Controlled Environment Agriculture Center, The University of Arizona, Tucson, AZ, U.S.A.

Why respacing?

- A classic strategy in hydroponic leafy crop production to increase the production capacity of limited growing space.
- Typically one (or two in some cases) respacing is applied manually in CEA (greenhouses and vertical farms).
  - To increase the production capacity
  - To reduce the wasteful use of electric lighting energy (light beam hitting the gaps between plants)
- However, the exact impact of respacing on productivity and the cost has not been quantified.



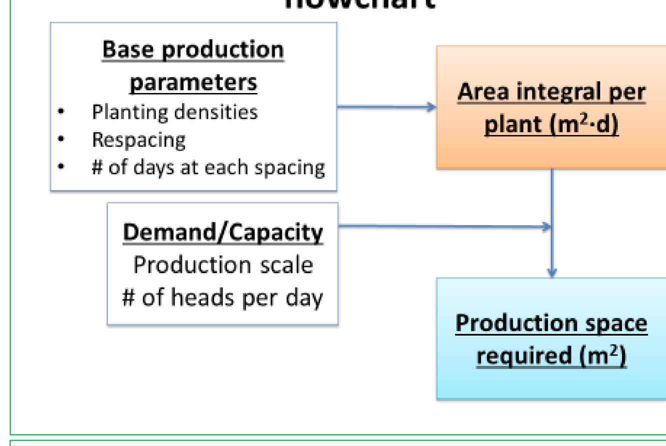
Study objectives:

- To theoretically evaluate the impact of respacing in hydroponic lettuce production under sole source lighting (i.e., vertical farms or plant factories)
  - Impact of number of respacing (once vs. twice after seedling stage)
  - Impact of respacing when other energy saving strategies are in place (e.g., incremental PPF settings; high lamp photon efficiency (μmol J⁻¹))
- To compare respacing with another strategy to reduce the production cost
  - Targeted lighting (Poulet et al., 2014) – Operating LEDs directly above the plant canopy only

Study approach:

Two papers reporting changes over time in single plant canopy size of lettuce crop under sole-source electric lighting was used for the analyses. We employed the following assumptions: 1) Effect of respacing and targeted lighting on plant growth is small enough to ignore; 2) Percentage of effective photons over the total photons emitted from the light source is a consistent (81%) regardless of lamp photon efficiency; 3) Re-heating is not needed in the HVAC system; 4) Total electricity consumption consists of the lamp electricity consumption and A/C unit (COP = 4) electricity consumption; 5) System is thermally insulated and no air exchange between inside and outside of the VF system; 6) Respacing labor cost was computed at 1680 plants/h and $10/h (S. Shimamura, personal comm.); 7) The remaining costs (materials, other labor) were estimated according to Ohyama (2015).

Production capacity estimation flowchart



Electricity cost estimation flowchart

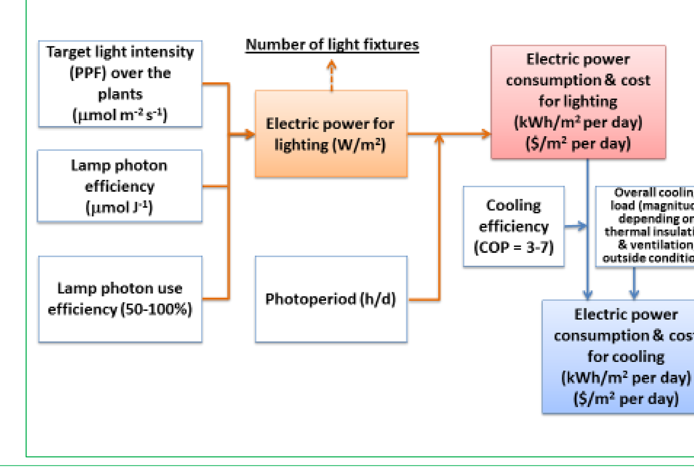
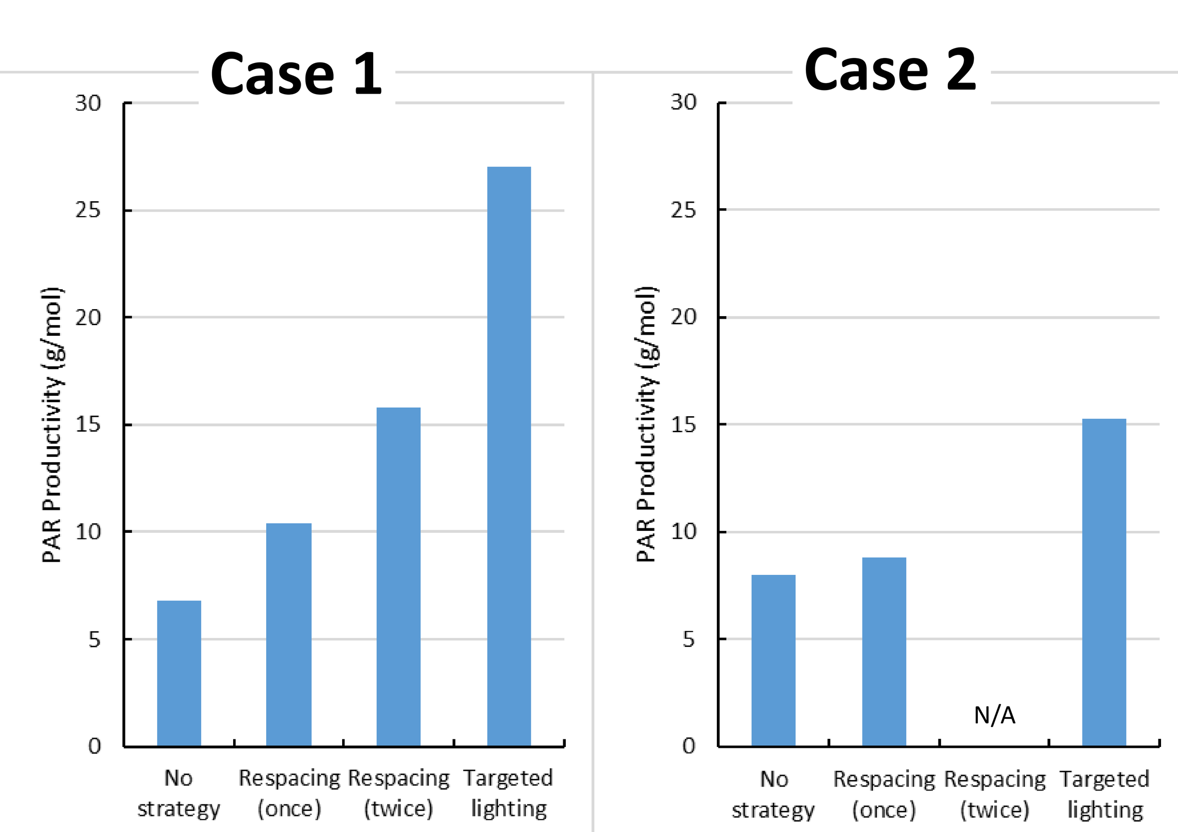


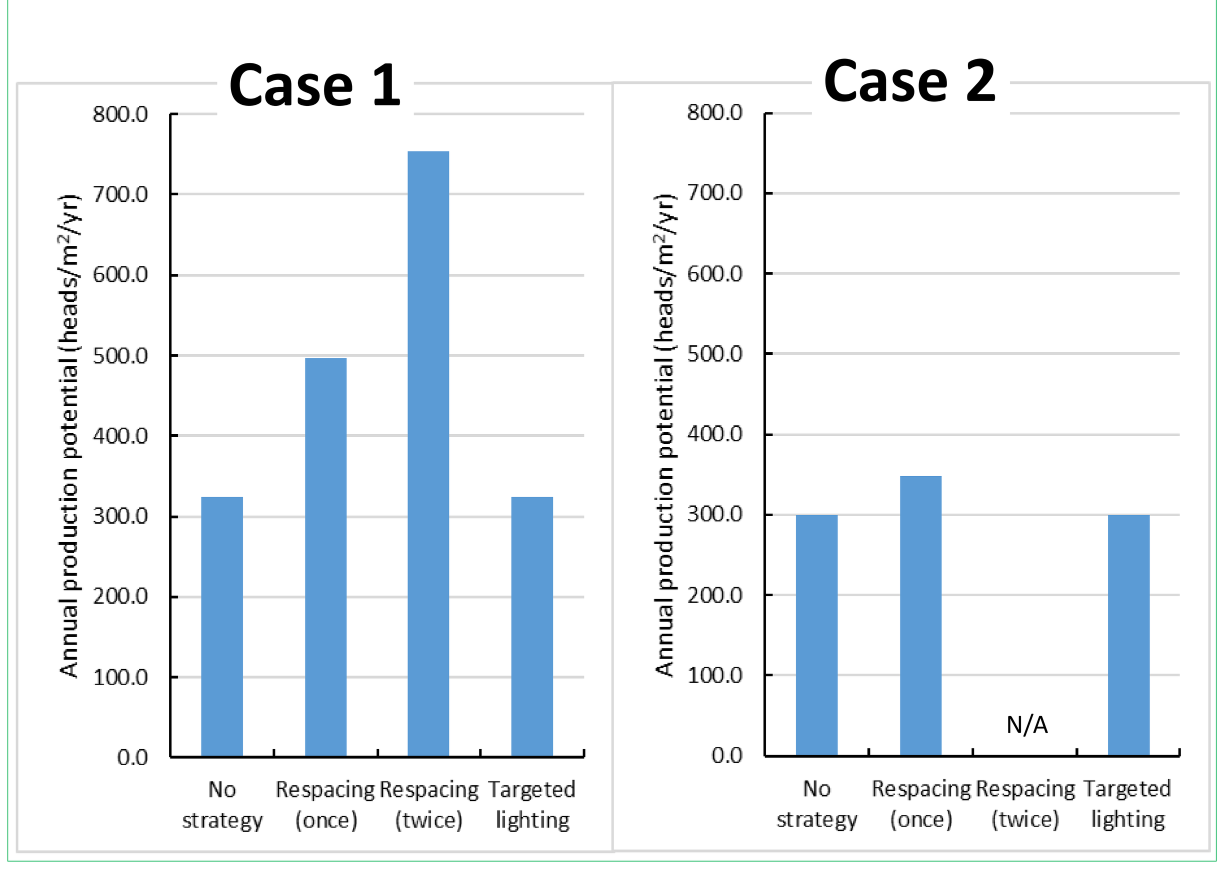
Table. Original conditions and additional 'what-if' scenarios examined in this study

	Case 1:	Case 2:
Source data	Wheeler et al. (1994)	Li et al. (2016)
Cultivar	'Waldmann's Green' lettuce	'Flandria RZ' lettuce
PPF	293 μmol m⁻² s⁻¹ for Days 1-27	50 μmol m⁻² s⁻¹ for Days 1-15; 70 μmol m⁻² s⁻¹ for Days 16-25; 120 μmol m⁻² s⁻¹ for Days 26-39
Photoperiod	16 h/d	16 h/d
CO_2 conc.; Air temperature	1,000 μmol mol⁻¹; 23°C/22°C	400 μmol mol⁻¹; 23°C/20°C
Final FW (g/head)	129 g	45 g
Planting density (original)	24 plants m⁻² for Days 1-27 (No respacing)	50 plants m⁻² for Days 1-15; 32 plants m⁻² for Days 16-39 (One respacing)
'What-if' scenarios evaluated	a) One respacing on Day 11 384 plants m⁻² for Days 1-10; 24 plants m⁻² for Days 11-27 b) Two respacing on Days 11 and 19 384 plants m⁻² for Days 1-10; 96 plants m⁻² for Days 11-18; 24 plants m⁻² for Days 19-27 c) Targeted lighting (Days 1-27)	a) No respacing was done at all (32 plants m⁻² for Days 1-39) b) Targeted lighting (Days 1-39)

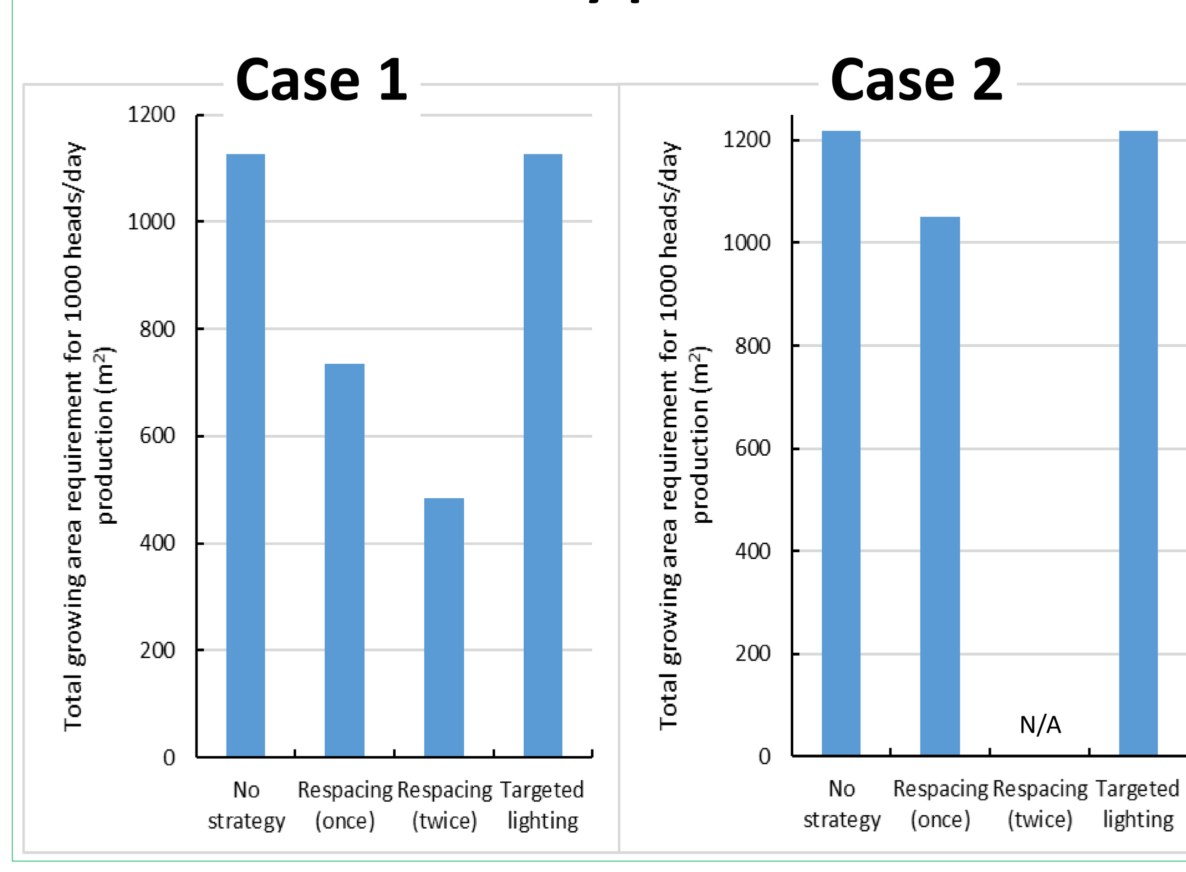
PAR based plant productivity (g FW mol⁻¹)



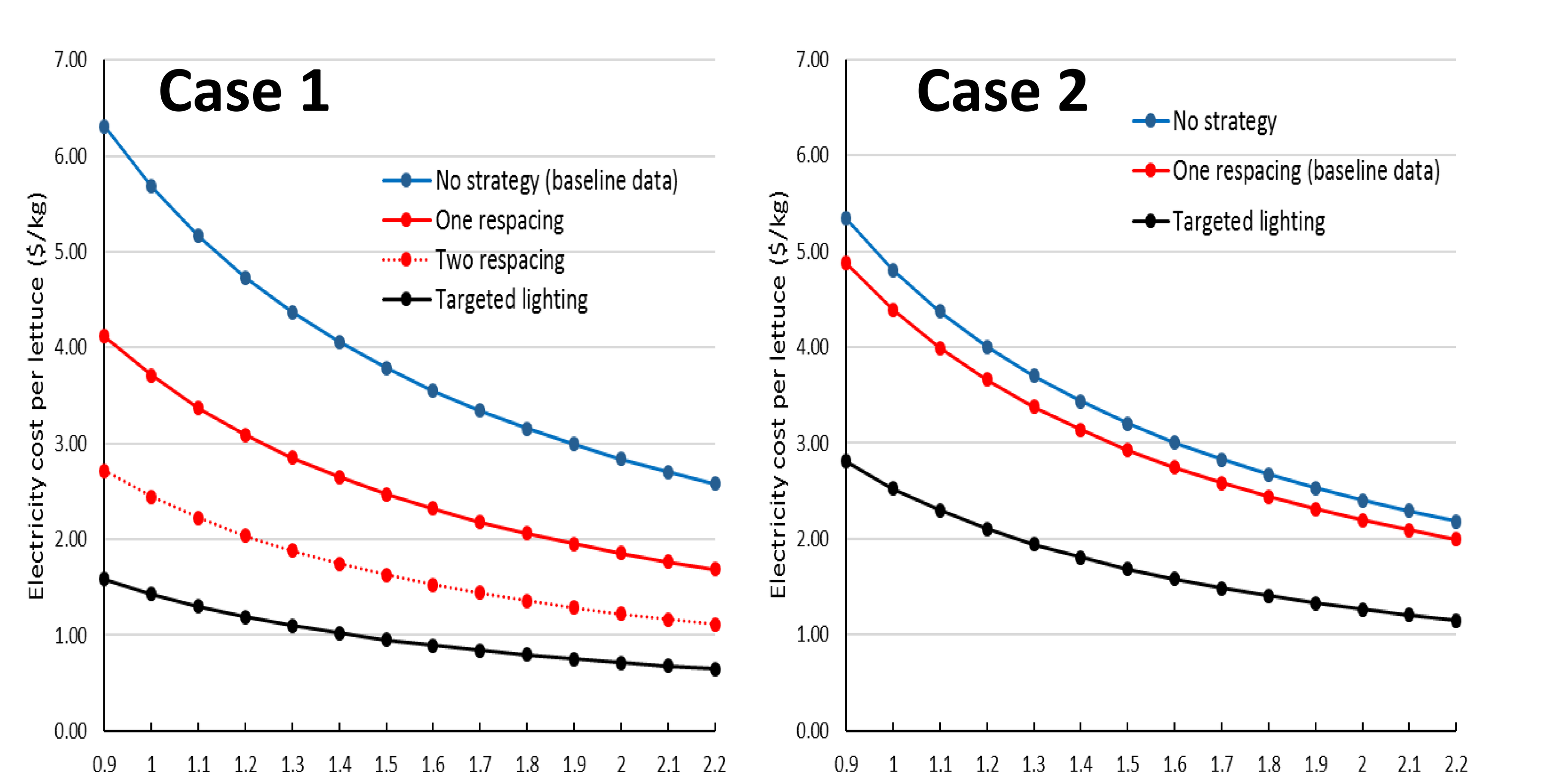
Annual production capacity (heads m⁻²)



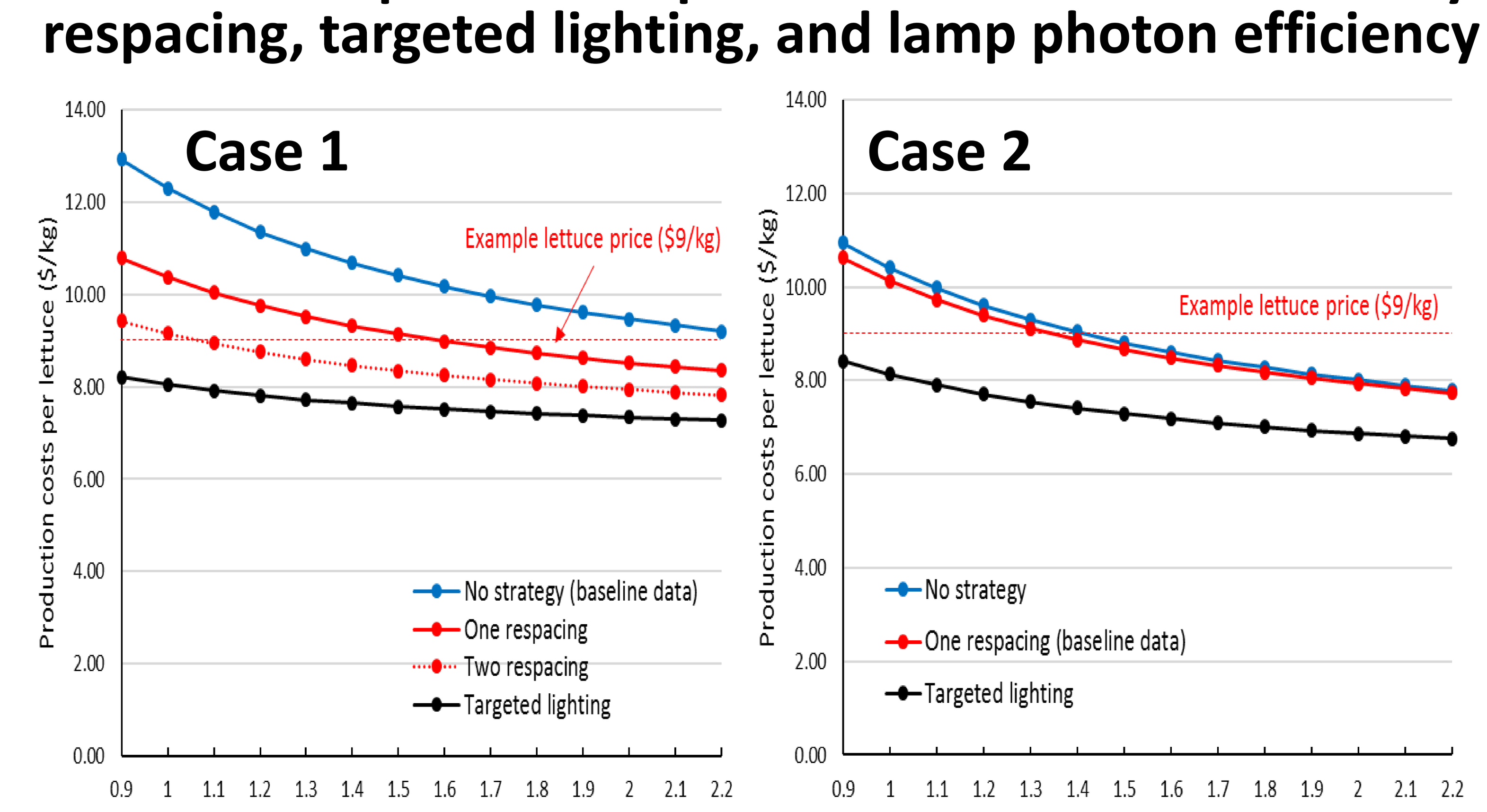
Production space (surface area) for 1,000-heads daily production



Electricity cost per lettuce head produced as affected by respacing, targeted lighting, and lamp photon efficiency



Total cost of production per lettuce head as affected by respacing, targeted lighting, and lamp photon efficiency



Summary of findings:

Respacing effectively reduced electricity consumption, especially when respacing was conducted twice in Case 1. In contrast, increase in labor cost with respacing was small (<1 cent per plant per respacing), compared with the large savings in electricity (>50% saved with two respacing). For both cases examined, electricity and total production costs (not including capital investment) were the lowest with targeted lighting. When targeted lighting was employed, the sensitivity of production costs to lamp photon efficiency was lesser than that in the reference cases without respacing. However, respacing also significantly increased the potential annual yield of a given size of production area. For example, annual lettuce yield was increased by 2.3 times by respacing twice over a production cycle (Case 1) in the present analysis. However, in Case 2, due to the small difference in density by the respacing employed as well as the incremental PPF setting over time, the impact of respacing on production capacity and production cost was smaller than those in Case 1, where respacing was conducted more aggressively at a constant high PPF setting. Depending on the production priority and market price, appropriate strategies need to be selected to maximize the profit.

References cited:

Li, K., Z. Li, and Q. Yang. 2016. Improving light distribution by zoom lens for electricity savings in a plant factory with light-emitting diodes. Front. Plant Sci. 7:92.
Ohyama, K. 2015. Management status of a large-scale commercial plant factory with artificial lighting JGHA Protected Horticulture. 168:330-33 (in Japanese).
Poulet, L., G.D. Massa, R.C. Morrow, C.M. Bourget, R.M. Wheeler, and C.A. Mitchell. 2014. Significant reduction in energy for plant-growth lighting in space using targeted LED lighting and spectral manipulation. Life Sci. in Space Res. 2:43-53.
Wheeler, R.M., C.L. Mackowiak, J.C. Sager, N.C. Yorio, W.M. Knott and W.L. Berry. 1994. Growth and gas exchange by lettuce stands in a closed, controlled environment. J. Amer. Soc. Hort. Sci. 119:610-615.