Conclusion: Economic and Operational Feasibility

The economic viability of autonomous photonic insecticides is grounded in an intercept strategy that targets pests at the field perimeter, where beetles typically migrate from previous year's potato fields and congregate for several days to feed and regenerate within a specific ingress depth D. For a standard 100-hectare square field (1000m × 1000m) with a 4,000-meter perimeter, this approach divides the defense into 4,000 individual 1-meter wide slices. At a high-impact field pressure B of 1,600 adults per hectare per day, the resulting population translates to exactly 40 individual targets ($N(B) = 40$) that must be neutralized within each perimeter slice. To clear these pests, a micro-UAV must perform repeated acceleration and deceleration "hops" at a limit a of 5 m/s^2 combined with a specific action time t_{act} of 1.0 second per beetle, an energy-intensive process dominated by battery depreciation. By determining the unit cost of energy based on a battery replacement price C_{batt} of $\$50.00$, a cycle life L of 1,000, and a capacity E_{cap} of 17.3 Wh, we can calculate the financial cost to defend a single perimeter slice using the following integrated formula:

$$Cost_{slice} = \left(2\sqrt{\frac{N(B) \cdot D}{a}} + N(B) \cdot t_{act}\right) \cdot P \cdot \frac{C_{batt}}{L \cdot E_{cap}}$$

Assuming a constant power consumption P of 90 W to account for aggressive maneuvering, a seasonal cost per hectare can be calculated—projected at approximately \$10.68 per hectare for 100-ha fields—which significantly undercuts the roughly $\$54.00$ price of conventional chemical methods. Like the 'Million Mile' battery (Harlow et al., 2019), solid-state advancements may render depreciation costs negligible in the future. In the meanwhile, a traveling salesman visitation pattern, based on precise insect location pest pressure maps, for which commercially available solutions exist today, can further optimize the efficiency. Event cameras are promising to enable faster field scanning required to build these pest maps, as they reveal distinct insect silhouettes, when shot at 500 FSP on EVK4-IMX636 by Prophesee:

Besides their theoretical lower cost per hectare, autonomous photonic insecticides have four identified pathways to commercial introduction. Firstly, via True Potato Seed (TPS) systems: while TPS offers a genetic solution to *Phytophthora infestans* (Haynes et al., 2022), the seedlings remain highly vulnerable to the Colorado Potato Beetle (Martin, 1988). By protecting these fragile seedlings, the technology unlocks the massive value of blight resistance—estimated at

€1,000–€1,500/ha in NW Europe (Europatat Action Plan, 2024; NEPG, 2024). Secondly, by replacing chemical inputs with physical alternatives, a combined value of up to €650 per hectare could be generated through Eco-scheme subsidies (EU CAP, 2023) and Biodiversity Insetting premiums (McCain, 2024), aligning directly with the European Green Deal's mandate to reduce chemical pesticide use by 50% by 2030 (European Commission, 2020). Thirdly, neonicotinoid exemptions currently hinge on a 'lack of viable alternatives,' as biologicals like *Bt* and nematodes suffer from weather instability and an inability to control adult pests (EASAC, 2023). Autonomous photonic insecticides would invalidate this regulatory defense, positioning them to outcompete biological programs that cost up to €200 per hectare (Alyokhin et al., 2012). Finally, the technology is highly scalable to other major pests, with immediate potential to target the Brown Marmorated Stink Bug and the stationary egg masses of the Yellow Stem Borer. In addition to these economic impacts, autonomous photonic insecticides offer vast ecological advantages by providing species-specific control that preserves local biodiversity and pollinators, unlike broad-spectrum chemicals that contaminate soil and waterways. Furthermore, because this physical method functions effectively in wet soil and bypasses the biological mechanisms of pesticide resistance, it provides a resilient, zero-residue solution for long-term environmental health. By offering the system through a subscription-based service model, the operational learning burden for growers is minimized. Large-scale field trials can therefore be conducted with limited downside risk, as the system operates in parallel with conventional pest management and allows immediate fallback to standard spraying if pest thresholds are exceeded. During early deployment phases, service fees may be waived if target suppression performance is not achieved, further reducing adoption barriers.

The common assumption that drone instability ruins precision aiming can debunked by current gimbal performance. The DJI Zenmuse H20 demonstrates an angular jitter of only 0.01 degrees, which translates to a lateral deviation of a mere 0.17 mm at a 1 meter range, proving that modern stabilization hardware effectively isolates the "aim" from the "airframe." (see: https://www.youtube.com/watch?v=TBgBUask3Is&t=61s)

1. Regarding the vulnerability to Colorado Potato Beetle due to seedling size:

- ***Martin (1988):*** *This reference explicitly notes that direct-seeded TPS plants are "extremely sensitive" to Colorado potato beetle (CPB) feeding. It explains that because "TPS seedlings are small and slow-growing, a few Colorado potato beetles can soon eat all seedlings in long stretches of row," causing severe damage or elimination of the crop.*

2. Regarding TPS as a solution to Late Blight (Phytophthora infestans):

- *Haynes et al. (2022): This study describes the successful "development and release of a diploid TPS population explicitly selected for late blight resistance," confirming that TPS populations can be bred with robust resistance to the disease*

3. (EU CAP, 2023)

- **Reference:** European Commission. (2023). *Approved CAP Strategic Plans 2023-2027: Summary of Eco-schemes and Pesticide Reduction Targets.* Directorate-General for Agriculture and Rural Development.
- **Relevance:** This policy framework establishes the "Eco-schemes" (allocated 25% of direct payments), specifically listing "pesticide-free cultivation" and "organic farming" as eligible practices for per-hectare subsidies ranging from €60 to over €540 depending on the Member State.

4. (McCain, 2024)

- **Reference:** McCain Foods. (2024). *Global Sustainability Report 2023-2024: Regenerative Agriculture Framework.*
- **Relevance:** This industry report details the company's "Regenerative Agriculture Framework," which includes specific financial mechanisms (grants, premium contracts, and interest-free loans) to compensate growers for reaching "Advanced" or "Leading" status by reducing synthetic inputs and enhancing biodiversity.

5. Alyokhin, A., et al. (2012). *Colorado Potato Beetle Management on Potatoes: Options, Thresholds, and Economics.*American Journal of Potato Research.

- **Context:** This key paper establishes that while neonicotinoids are relatively cheap, losing them forces farmers to rely on spinosyns or diamides (like *Rynaxypyr*). These alternatives often require multiple applications to achieve the same control, which can triple the cost per hectare compared to the standard baseline.

6. European Academies Science Advisory Council (EASAC). (2023). *Neonicotinoids and their substitutes in sustainable pest control.* EASAC Policy Report 44. German National Academy of Sciences Leopoldina. ISBN: 978-3-8047-4394-6.
Relevance to your claim: This report explicitly criticizes the continued use of "emergency authorizations" (Article 53 of Regulation 1107/2009) to bypass bans, noting that these are often justified by a claimed "lack of alternatives," a justification your solution would directly invalidate.