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Sent: 9/3/2015 4:58:01 PM

To: TTAB EFiling

CC:

Subject: U.S. TRADEMARK APPLICATION NO. 85361278 - FLORASUN - GLA 3004 - Request for Reconsideration Denied - Return to TTAB - Message 2 of 7

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Attachment Information:

Count: 7

Files: thesweet-08.jpg, thesweet-09.jpg, thesweet-10.jpg, thesweet-11.jpg, thesweet-12.jpg, thesweet-13.jpg, thesweet-14.jpg

reasonable prices." Be warned, though, that your interior decorator vampire friends will *love* the color of the Grow Max light bars, which tint everything a sort of bloody pink. If you'd like a little more green in your life, opt for BML Light Bar View-Max Spectrum lights instead. Choose a 90° beam angle for more even light distribution across your seedlings.

## The budget options

If all you want to do is get your seedlings up to around ½-inch (1 cm) high, I can tell you from personal experience that a fixture with two T8s will do an adequate job. However, they'll only give you a maximum DLI of 3 if you keep them on 16 hours a day; for a DLI of 4, you'll need to run them at least 23 hours a day. Your seedlings will be a bit pale and leggy compared to plants grown under better lights, and they'll benefit from getting outside as soon as possible. If you're starting small with a single seedling flat, you don't have that many options for shop lights with a reflecting hood that will direct slightly more light downwards and make viewing your plants slightly more pleasurable.

The 2' Hydrofarm 2' Fluorescent Grow Light Fixture FLV22 ($31) and the Lights of America Fluorescent Grow Light System with 2 T8 Grow Bulbs – 2 Foot ($44) appear to be exactly the same light and are the cheapest available options for a 2-foot shop light. The Lights of America fixture comes with two T8 bulbs; you'll have to buy them separately for the Hydrofarm Fixture. Run them for five years for eight weeks a year, and your total cost including electricity will be around $60-83. Just don't come running to me when your Radiator Charlie's Mortgage Lifter tomatoes don't fruit in time for the state fair.

Also Great

A budget-minded light

Hydrofarm FLV22

For getting your seedlings up to around ½-inch (1 cm) high on a budget, the FLV22 is your best option.

$32* from Amazon

*At the time of publishing, the price was $31

## How we calculated output vs. cost

Giacomelli was unequivocal: "Are you trying to grow seedlings? Go to Home Depot and buy fluorescent tubes." Other experts had slightly more nuanced views. Harwood and

Mattson observed that although LEDs have improved over the years and now put out as many µmoles/watt of photons as fluorescents, they're still expensive. "For the average person using lights for a couple of months in the spring, it's probably not worth it [to buy LEDs]" said Mattson. As Jacob A. Nelson and Bruce Bugbee wrote: "In large greenhouses with small aisles and uniformly spaced plants, the broad, even output pattern typically emitted from HPS fixtures provides uniform light distribution and good capture of photosynthetic photons. In smaller greenhouses with spaced benches, the more focused pattern typically found in LED fixtures can maximize radiation transfer to plant leaves."

Although these opinions were useful, I wanted to confirm them. If you're starting a commercial greenhouse, you can calculate the cost of lighting with this calculator spreadsheet created by Bruce Bugbee, Ph.D., director of the Utah State University Crop Physiology Lab. For home use, I put together a spreadsheet for different types of bulbs including

- Initial purchase cost (bulb plus fixture)
- Cost of electricity to operate
- Replacement cost (bulb only)

I assumed that you, gentle reader, intend to grow thoroughly legal seedlings, herbs, and table-top lettuce, and that seedlings require approximately 4 moles/m²/day of photons, while lettuce needs least 12 moles/m²/day. I also assumed that you're going to start small, with either one or two standard 21-by-11-inch black seedling flats that look like this. That's 231 square inches, or .14903 m². Four feet is the standard length for grow lights used in the nursery trade, but companies that cater to home growers, aquarium hobbyists, and orchid growers commonly offer 2-foot bulbs and fixtures. Based on their guidance, including Jacob Nelson and Dr. Bugbee's analysis of plant lighting, I made up a spreadsheet calculating the cost of using the lights for five years, using the daily light integral (DLI), the minimum total number of photons necessary each day that researchers recommend for growing seedlings (4 mol/m²/d) and lettuce and herbs (12 mol/m²/d). I analyzed lights suitable for a single seedling flat (approximately 11 by 20 inches or 28 by 51 cm) in a small space—say, hung on a bookshelf. I also read reviews on Amazon, Home Depot, and various aquarium hobby sites to see what users thought of the lights.

I made two sets of calculations for seedlings and lettuce. For average usage, I assumed that growers would have the light on for 16 hours a day for eight weeks every spring for five years, or 3,480 hours. For tabletop lettuce, I assumed that, like AeroFarms' clients, growers would leave the light on for 24 hours a day for five years straight, for 43,800

hours. To calculate the electricity cost of growing seedlings and lettuce, I made two sets of calculations assuming low-cost energy (10 cents per kilowatt hour) and high-cost electricity (30 cents per kilowatt hour). For more miserly users, I also calculated the cost of electricity for just getting plants the minimum daily light integral (DLI). I excluded lights that couldn't provide the minimum DLI for seedlings in 24 hours. I did calculations for the top-rated T5 High Output fluorescent fixtures, standard shop-light T8 fluorescent bulbs, LED, and high pressure sodium (HPS) lights on Amazon and Home Depot, as well as the top three energy-efficient fixtures (in terms of cost per micromole of photos) in each category as evaluated by Jacob Nelson and Bruce Bugbee at the USU Crop Physiology Laboratory. I eliminated lights that were clearly overpowered for home seedlings (such as 1,000-watt HPS lights designed to light a 10' by 10' greenhouse, which would generate enough heat to cook seedlings if they were 1 foot away), but if there were lower-powered lights available from the same manufacturer in the same model line, I included them. I looked at photosynthetic photon flux density data (PPFD) for the lights, which refers to how many photons fall on a square meter of surface in a second, measured in µmoles/m²/sec. In cases where reliable PPFD data was not available, I made separate calculations for the highest and lowest values for photon production per joule for that type of light from the Nelson and Bugbee analysis, multiplied it by the wattage given for that light, and assumed that a narrow surface area underneath the light would be illuminated (an area the length of the fixture with a width equal to 1.3 times the fixture's height above the seedling flat).

## What about LEDs?

LEDs are a fascinating technology, but they're still far more expensive than other types of plant lights, and they don't produce enough photons per unit cost to justify their use by most home gardeners. One day, LEDs will produce enough photons per watt of wall-plug electricity to make them economically competitive with fluorescent lights. But as of today, you'll pay a premium to get enough LEDs to grow plants indoors. One expert who chose to speak off the record said to me, "With LEDs, you're paying for future research." Horticulturists and lighting scientists expect that LED lights will become much more efficient over the next decade and start to become competitive with high-pressure sodium and metal halide lights for supplemental greenhouse lighting and indoor growers, but they're not there yet. Still, there's hope for a cooler, more efficient light. As Giacomelli said, "LEDs will improve in the years to come, but HPS [lights] won't." Mattson observed, "It's eight times the [carbon] footprint to grow plants completely indoors vs. in a greenhouse." If you use photovoltaic cells to power your indoor plant lights, you need to cover an area 25 times the size of your plants to power the lights. If you want to try to save

Cover an area 25 times the size of your plants to power the lights. If you want to try to save the earth by growing your own lettuce, wait.

## The competition

I looked high pressure sodium (HPS) lamps as well. Warburg said, "Most applications in commercial greenhouse use HPS [lights]," and according to Giacomelli, they are still the most practical lights for growing plants indoors. For small-scale home seedling and lettuce growers, though, HPS lamps are expensive and take up too much space. Thanks to their heat output, high-watt HPS need to be kept up to several feet away from young seedlings to prevent the lights from scorching their leaves—and all those watts make for expensive electric bills. I calculated the expected cost of starting seedlings and growing lettuce under a variety of High Pressure Sodium (HPS) lamps rated highly by Amazon users and cited as being most efficient in Dr. Bruce Bugbee's paper. In cases where I did not have PPFD measurements available, I made separate estimates for both high-PPFD and low-PPFD scenarios, based on Bugbee's HPS data.

The lamps higher than 200 watts were obviously overkill. They're designed to light a 3' by 3' area, produce a DLI of 4 in three hours, and need to be suspended at least 24 inches over seedlings according to this Sunlight Supply Information Sheet. I eliminated the G8LED 240 Watt LED Grow Light with Optimal 8-Band plus Infrared (IR) and Ultraviolet (UV) – 3 Watt Chips – All in One for Veg and Flower, the Horizon Grow Light Kit (250 W), and the ViaVolt 250 Watt HPS Grow Light Fixture. That left three low-wattage HPS fixtures: Horizon Grow Light Kit (150 W) Hydrofarm SRM150S 150-Watt Mini Sunburst with HPS Lamp, and the Sun System 150 Watt HPS Reflector, Ballast and Bulb.

They need to be suspended about 12 to 24 inches above plants, depending on your setup's ventilation. All three of these HPS systems are a bit overpowered for seed-starting as well. They'll produce a DLI of 4 in four hours for seedlings, and a DLI of 12 for lettuce in just 16 hours. If you run them for just the amount of time needed to produce the minimum DLI, they're economical. The total cost for five years of seedlings will run from $90-200 for four hours per day of light, depending on your electricity cost, while lettuce will run you somewhere between $450-1000 for 16 hours per day. Heck, as long as you're pumping out that many photons, you might as well keep it on for 20 hours and try out some tomatoes (DLI 15, in the "good" range for lycopersicon).

That said, I am not recommending HPS lights per se because their heat output means that they require more attention. If your plants grow too close to these bulbs, they will be damaged—and if you spill water on the bulb while it's on, the bulb could explode. If you

feel like you'd like to experiment with HPS lights, both the Hydrofarm SBM150S 150-Watt Mini Sunburst with HPS Lamp ($78) and the Sun System 150 Watt HPS Reflector, Ballast and Bulb ($85) received enthusiastic user reviews like, "I LOVE THIS LIGHT!"

Some T8 fluorescent fixtures are a little different from our main picks, but they aren't any better. The 2-foot Flora Hydroponics Fluorescent Grow Light System ($50) has the same features as the Lights of America T8 fixture, but comes with bulbs that have a light temperature of 5000 K, not 41000 K like Lights of Americabout That means that light will look slightly bluer. If that matters to you, go ahead and spend $6 more on this light, but don't expect your plants to notice the difference. If you still haven't spent enough money on T8 bulbs, you could choose spend $20 apiece on "full spectrum" T12 grow bulbs, which will fit into the same fixture, such as the Agrosun T12 or an Agrobrite 24-inch 20-watt T12 bulb. I'm sure they're charming, but they'll only get you to a maximum DLI of 2 if you leave a two-bulb fixture on for 24 hours a day less than a foot away from little leaves. That's enough light to raise ferns, African violets, and orchids, but seedlings of other species won't live up to their full potential. If you have $40 to spend on bulbs and another $40 for a fixture, you should just give up lattes for the week, save up, and buy the $92 Hydrofarm FLT24 2-Ft/4-Tube T5 Commercial System with Bulbs instead.

## Types of lights

Grow light catalogs confront you with five different types of lights: fluorescent, compact fluorescent, metal halide, high-pressure sodium, and LEDs. Unfortunately, it can be hard for consumers to directly compare their performance. For the complete story, read The light plants need below.

Incandescent bulbs, the type that Thomas Edison invented and that appear over cartoon characters' heads when they have a brilliant idea, aren't generally used for growing plants because they give out so much heat for the amount of photons they produce. I excluded incandescent bulbs from the list.

Fluorescent bulbs are those tubes that you remember hissing and flickering from school or the library. They're glass tubes filled with mercury glass and coated inside with material that fluoresces—that is, lights up when it's excited by ultraviolet light. When you turn a fluorescent light on, the electrical current makes the mercury atoms emit ultraviolet light, which makes the coating fluoresce. (Canon has a good animation of how this process works on their Science Lab pages.) Fluorescent bulbs can have different colors depending on what substance exactly you use for that coating. Older fluorescent fixtures

flicker because they're not putting enough electrical current through the bulb to get the mercury atoms going.

The reason people use fluorescent bulbs for lighting is that they convert a larger proportion of their electricity to light than incandescent bulbs, so they don't require as much power to illuminate a spot. Since they're using less power, they also generate less heat than incandescents. Lighting companies equivocate about exactly how hot their bulbs get, saying that it all depends on the environment around them, the fixture they're in, etc. I took a laser thermometer to fluorescent bulbs in my house, measuring their temperature after running for two hours at 65ºF (we're cheap with heating oil around here). The surface temperature of a T5 grow-light bulb was around 100ºF; the ancient T12 bulb in the laundry room was around 140ºF. Neither of them will burn the house down, but your tender seedlings wouldn't appreciate it having the T12 bulb too close; water at 140ºF is hot enough to cause a third-degree burn in five seconds, according to the Burn Foundation.

Fluorescent tubes also last longer than incandescent bulbs, running for up to 20,000 hours, about ten times as long as incandescents. You'll see references to T12, T8, and T5 fluorescent bulbs; the T just tells you that you're measuring the diameter of the bulb in eighths of an inch. T12 bulbs are 1.5 inches in diameter, T8 bulbs are 1 inch, and T5 bulbs are ⅝ of an inch and are built a little differently. You can generally plug T8 and T12 tubes into the same fixtures, but not T5 tubes. The smaller-diameter fluorescent tubes put out more light per watt than the larger tubes.

Some T5 bulbs are T5HO, where HO stands for "high output." The T5HO tubes do put out more light than the T5 bulbs, but they also use more energy to do so. You'll get less light per watt from these bulbs, according to this chart put together by the Rensselaer Polytechnic Institute Lighting Research Center. Even more confusing, fluorescent bulbs' light output varies with the room temperature. T8s give out more light at 77ºF, T5s at 95ºF. T5 performance falls off rapidly between 86-68º F (30-20ºC) from 95 percent to 75 percent of their maximum light output. At 59ºF (15ºC), you'll only get 60 percent of the light out of a T5 as you would at 95ºF, while T8s are still putting out 90 percent of their maximum light.

The moral: Keep your seedlings warm. Fluorescents do eventually wear out. As the glass on the tube gradually absorbs mercury, there's less mercury vapor in the tube to create ultraviolet light. Both T8 and T5 bulbs continue to put out about 90 percent of their maximum lumens over the course of their 20,000-hour lives, while T12 output falls to 75

percent by 5,000 hours. For that reason, and the sheer bulk of T12 lights, I excluded those bulbs from my sample.

Compact fluorescent bulbs are also available as grow lights, but they use more energy to create light than the tubes (more watts per lumen). They last about 10,000 hours, or half as long as the fluorescent tubes. The only real advantages to CFLs are that they can be plugged into conventional light sockets and that they contain less mercury than the tubes—but they do contain mercury and need to be disposed of carefully. Because of their inefficiency and relatively short useful life, I excluded them from the grow light sample.

Metal halide (MH) and high pressure sodium (HPS) lamps are both types of high intensity discharge (HID) lamps. HID lamps contain tungsten electrodes inside a tube filled with gas and metal salts. When electricity flows through the lamp, electricity arcs between the electrodes through the gas, melting and heating the metal salts until they form a glowing plasma. They put out a lot of light, but they use of energy (250 to 1000 watts per bulb) and consequently they give off a lot of heat. You can't put a 600ºC HID bulb on top of your seedlings, or your laptop, or pretty much anything except another HID bulb. You need plenty of space and air circulation.

Metal halide lamps are filled with vaporized mercury and metal halides (compounds of bromine and/or iodide). HPS lights contain—surprise!—sodium instead. MH lights put out somewhat more light in the blue part of the spectrum than the HPS lights, which produce more yellow-to-red light. But, as Giacomelli said, most commercial applications use HPS because plants can do reasonably well without the additional blue light.

If you want to see what an HPS light looks like, go to a parking lot at night and look up. HPS lights are frequently used for outdoor lighting, giving everything that special orange glow. Many people find this particular hue aesthetically unpleasing. If you're going to be looking at your plants under lights, consider what color you'd like to see. That said, HPS bulbs are much more popular for horticulture, in part because the MH bulbs last just 10,000 hours on average, compared to about 10,000 hours for the HPS, and their light output decreases fairly rapidly with use. According to this chart, MH bulbs' light output will deteriorate by about 25-51 percent before they're halfway through their expected use. HPS lights will still put out 70 percent of their initial lumens at the end of their useful life. I eliminated MH bulbs from the sample.

LEDs, or light-emitting diodes, are the hot new light. Well, really, they're the cool new light, because they

LEDs shoot out photons at single wavelengths, not