Saffron and Solar Farms:
A Win/Win for the Environment and Agriculture

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Introduction. By 2050, demand for food is projected to increase by 50-70%. According to the American Farmland Trust, the best land to support crop production has dropped to less than 17% of the total land area. The number of farms and amount of tillable farmland are being lost to development at an alarming rate. Over 24 million acres of agricultural land have been lost to development since 1982. A 4.3% drop in the number of farms in the US was observed from 2007 to 2012 and this decline is continuing. The American Farmland Trust estimates 40 acres of farmland are lost every hour, mostly to urban sprawl and non-agricultural development. In 2019, 90% of the over 2 million US farms were ranked as "small" family operations, grossing less than $350,000/year. Crop diversification and production of high-value crops and related value-added products are key to their viability. Most of the ~430,000 farms in the US growing specialty crops in 2017 were small-mid size, with 61% of these farming less than 50 acres. In 2018, 58-81% of small farms had an operating profit margin in the high-risk zone. The market value of products sold by farms producing specialty crops averaged $53,670/farm ($3,649/ac). Production of specialty crops boosts economic returns for small farms, and increased profitability is critical to keep these farms operating. University of Vermont scientists started research in 2015 to investigate the potential of saffron as a specialty crop to support Northeastern farms. Saffron (*Crocus sativus* L.) is an emerging high-value crop, valued at $19-75/gram retail, which could contribute to revenues of Northeastern farmers. Saffron is commonly used as a culinary flavoring and coloring agent in Asian and European cuisine. It is also used in nutraceuticals and cosmetics, and is reported to have medical properties that enhance value.

Fig. 1. Saffron blooming in Burlington solar field.

Farmers of all types throughout the US are supporting their existing agricultural production through generation of renewable energy, in particular solar power. Ground-mounted solar arrays are displacing crops, which has resulted in vocal opposition in some regions. The concern is that farmers will take advantage of the lower-risk, higher reward opportunities of energy generation, and discontinue farming, which can be high risk as weather conditions become more extreme and unpredictable. Developing novel high-value crops grown within solar arrays could enhance agricultural revenues and contribute to keeping farming a viable enterprise. Before this trial, saffron had never been grown in association with solar fields, but we projected that it could be grown either between the rows of panels, around the perimeter of the solar arrays, or under the panels. Therefore, to assess the potential of growing saffron in the solar farms, a 3-year experiment was designed in cooperation with iSun (formerly Peck Solar). In the first year (2018), plots were established in New Haven, VT, at a site with heavy clay soil. We hoped that if grown in raised beds containing well-drained soil, these adverse growing conditions could be overcome. We were wrong. Despite providing fertile soil in the growing beds, because of poor drainage under the beds and unusually rainy weather over the winter, the corms planted in the fall succumbed to fungal infection and did not survive the winter. Therefore, a new location with more suitable soil conditions was established in 2019. This report summarizes the results from this site.

Methods. To assess the effect of three planting positions within a tilted solar array on saffron yield, an experiment was conducted at an iSun solar array in Burlington, VT (USDA plant hardiness zone 5a). Three locations (in the aisles, under the solar panels and around the perimeter) and two planting methods (in raised beds vs in the ground) were tested. A factorial (3*2) experiment using a randomized complete block design (RCBD) was devised with three replications. Eighteen planting beds (3 × 5 ft) were established in the summer of 2019 at the solar site. Saffron corms (9/10 cm in circumference) from Roco Saffron, The Netherlands, were planted in mid-September 2019 at a depth of 6 inches with a density of 9 corms/sq. ft. To control rodent damage, the area under the raised beds and on the surface of the in-ground plots were secured by hardware cloth (0.5 × 0.5 inches) (Fig. 2).

Over the blooming season (October-November), the number of flowers was recorded every week. To assess yield, 20% of the saffron flowers were harvested. After separating stigmas from other parts of the flowers, they were dried at 100 °C for 5-7 minutes. The weight of dry stigmas was recorded, and the yield was calculated using the total number of flowers and average weight of saffron stigmas/flower. ANOVA was carried out in SPSS v. 25 to compare the mean number of flowers and saffron yield. In the early summer, after the corms had gone into dormancy, we sampled the beds to determine the average size and number of secondary corms/mother corm (corm propagation rate) (Fig. 3).

Fig. 1. The raised bed and in-ground beds at the solar-saffron research site.

Fig. 3. Corm sampling: separating corms from soil, sizing the corms, the final product.

Results.

Flowers and Dry Saffron Yield.

To interpret the yield results, it is important to understand the production cycle of saffron. This is an annual plant which is grown as a perennial. Corms planted in the first year are not expected to produce large numbers of flowers because they must become acclimated to the conditions. The number of flowers usually increases in the subsequent 2-4 years because each spring the original parent corm produces multiple secondary corms. The parent corm dies after one year, leaving a legacy in the form of several secondary corms. Each year the number of corms in the bed increases, and if weather conditions are favorable more flowers (and saffron) are produced. After 3-5 years, the corms become crowded and yield begins to decline. At that time the saffron bed is usually dug up and the corms are replanted in a fresh bed.

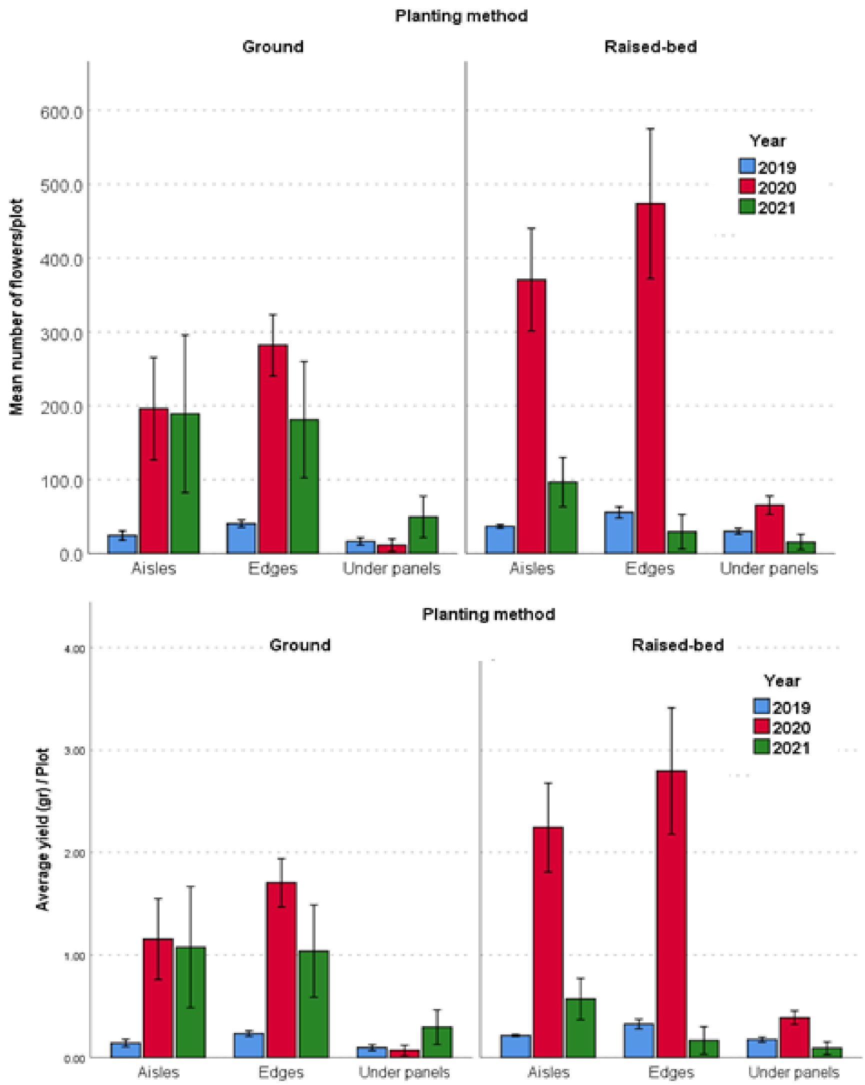

Fig. 4. Average number of flowers and saffron yield produced in the solar-saffron research site.

Results collected during the three study years showed the significant effect of treatments on the number of flowers and saffron yield. We observed more flowers in the second year of saffron production (2020) than 2019 and 2021. The average number of flowers harvested from the plots established around the perimeter was more than those under the panels and in the aisles. Although planting the corms in raised beds resulted a higher yield in the first and second year, more yield was observed in in-ground plots in the third year. In 2021, the in-ground plots yielded over 100% more saffron than the raised beds (Fig. 4). Over the blooming season in 2021, plots located in the aisles produced more flowers than those around the edges and under the panels. Data collected from the research site showed that to produce a gram dry saffron, between 159-179 saffron flowers must be harvested. No significant differences in the average weight of dried stigmas/flower among treatments were observed. A significant decrease in the number of flowers and thus saffron yield was obtained in year 3 (2021). This was likely due to the unusual weather that year—temperatures remained unseasonably high throughout the fall, with the first frost occurring only in late November. Growers throughout the region experienced a disappointing saffron harvest. This is a sad reality in agriculture, which is subject to the vagaries of weather.

Saffron Corms. Corm production in most years, regardless of planting method, corm production was generally similar in all planting locations, ranging from 3-3.5 corms per plot. The greatest number of secondary corms were in raised beds located under the solar panel, which produced an average propagation rate of over 5 secondary corms/parent corm (Fig. 5). Although fewer secondary corms were observed in the raised beds located in the aisles, the corms produced were larger than those in other treatments, resulting in a higher flower/stigma yield the following year.

A correlation between the size of corms and number of harvested flowers in 2021 showed that plots that produced larger secondary corms resulted in more flowers (Fig. 6).

Although the correlations did not show any significant relationships between saffron corm propagation rate and size of secondary corms, we observed larger corms in plots with fewer corms.

Cost and Revenue Analysis. The bottom line for growers is revenue potential. To evaluate the net and gross revenue of saffron production, we used an enterprise budget developed by the UVM Saffron Center researchers. It was adapted and validated using factors observed in the solar-saffron research site. The costs and revenues were estimated using the combined average yield in raised beds and in-ground plots. Figure 7 shows the average saffron yield/acre obtained over the three study years. Revenues were estimated based on a retail market price of $35/g dry saffron and

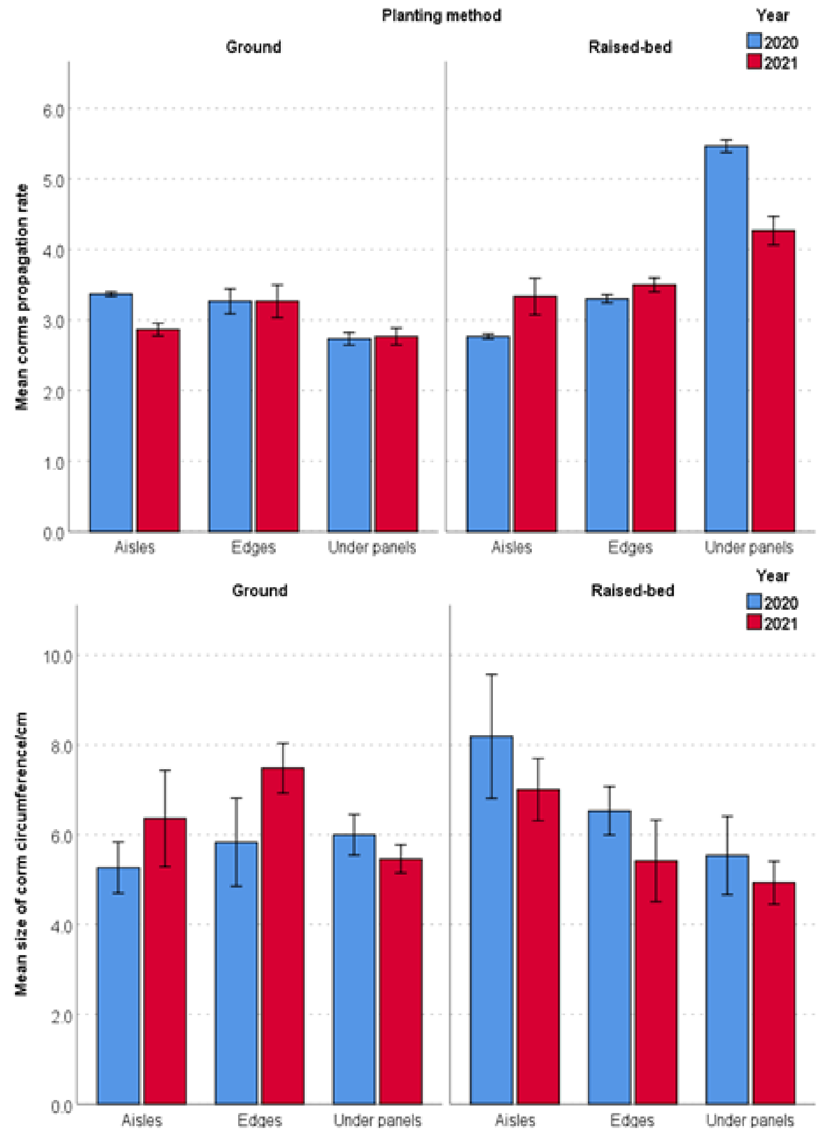

Fig. 5. Average corm propagation rate and size of corms measured in the solar-saffron research site.

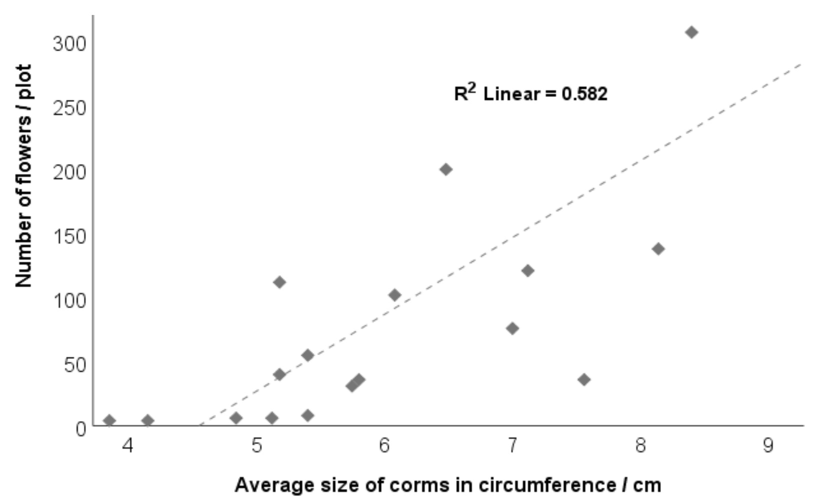

Fig. 6. Correlation between corm size and number of flowers in 2021.

$0.25/corm. These values are fairly conservative, given that some US growers report selling their saffron for as much as $75/gram retail and corms are often sold for $0.45 to $1.00 each.

Our data and observations showed that producing saffron between the solar panel rows (in aisles) was more feasible than under the panels. Therefore, the estimated revenues reported in Table 1 are based on data from plots in the aisles.

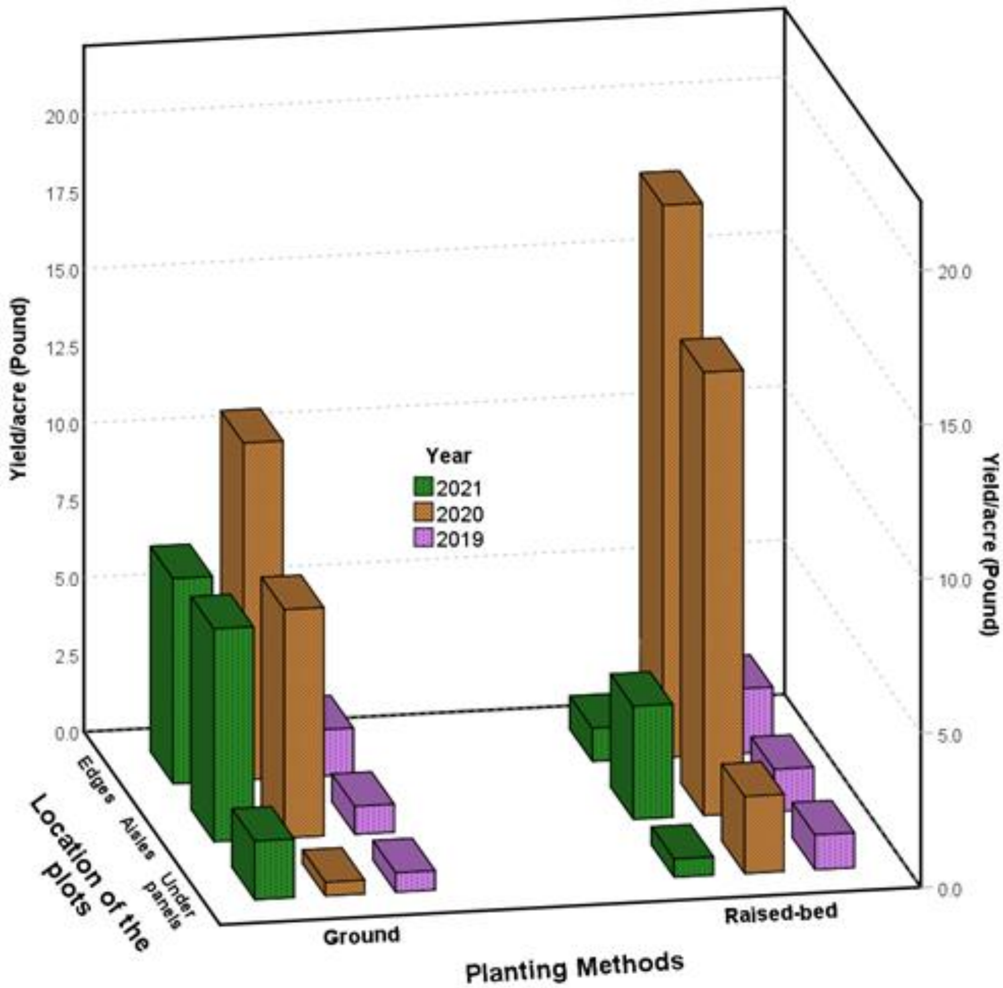

Fig. 7. Average saffron yield (lb/acre) among tested treatments.

The costs of buying corms, compost, fertilizer, limestone, and expenditures associated with bed preparation, labor for planting, harvesting, weeding, pest monitoring and marketing were combined as the main expenses associated with saffron production. Because saffron is a new agricultural crop in U.S., local sources for corms are not available, requiring the purchase of imported corms. The procedure of importing corms into the U.S. and extra costs associated with corm ag certification and shipping and increases the price of the final product. U.S. saffron growers need to invest ~$100,000 for corms to plant in 1 acre. This is around 40% of the total setup cost. Although saffron corms are expensive, this usually is a one-time expense in the first year. Once a saffron bed is established, each corm should produce 3-5 secondary corms/year, enabling growers to produce their own corm stock over time.

Table 1. Costs and revenue estimation for a 1-acre saffron field in an agrivoltaic system when grown in aisles between panels in raised beds or in the ground

Raised Beds					
	Costs	Gross revenue from saffron	Gross revenue from saffron + corms	Net revenue from saffron	Net revenue from saffron + corms
Year 1	-121,734	20,748	20,748	-100,986	-100,986
Year 2	-88,702	209,541	209,541	120,839	120,839
Year 3	-54,405	66,563	164,573	12,158	110,168
Total	$264,841	$296,853	$394,863	$32,012	$130,022
In ground					
	Costs	Gross revenue from saffron	Gross revenue from saffron + corms	Net revenue from saffron	Net revenue from saffron + corms
Year 1	-118,884	13,832	13,832	-105,052	-105,052
Year 2	-48,234	111,340	111,340	63,106	63,106
Year 3	-57,798	107,330	205,342	49,532	147,544
Total	$-224,916	$232,502	$330,512	$7,586	$105,596
Assumptions: retail price for saffron: $35/gram; retail price for saffron corm: $0.25; and a portion of the corms are sold only in year 3.					

This table demonstrates that in year 1, production costs significantly exceed revenues, resulting in a net loss. However, as the number of secondary corms increase within the production area, the amount of saffron produced also increases, such that in year 2, the gains greatly exceed the costs.

Conclusions.

This research demonstrated that when soil conditions are suitable, saffron can be grown successfully within a conventional tilted solar array, generating between $7,500 – 130,000 per acre, depending on whether corms in addition to saffron are sold. Production in raised beds was shown to be more profitable than growing directly in the ground, though it does involve additional labor to establish the beds. Producing saffron under the panels proved to be less ideal than growing between the rows of arrays or around the edges of the array. However, the number of corms produced under the corms was greater than in the other planting locations, though they were not as large. Overall, this study showed that saffron is a viable crop for cultivation in association with fixed tilted solar arrays, and indeed it is a **win/win** opportunity that makes good use of land within an array, while also generating renewable power to reduce the negative environmental effects of traditional petroleum-based energy sources.

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