Enhancing productivity and Economic viability of High- value crops in Agrivoltaics system: A case study of tomatoes and lettuces in Arizona and Alabama.

Objectives of the study:

1. Assess crop performance: Evaluate the growth characteristics , yield potential, and overall productivity of tomatoes and lettuces in agrivoltaic system considering factors like plant growth height, yield per unit area.
2. Evaluate Economic viability: Analyze the economic feasibility and profitability of cultivating tomatoes and lettuce in Agrivoltaics system, considering factors such as investment costs operational expenses, market prices and potential revenue generation.

Research questions:

1. How does the integration of Agrivoltaics system impact the productivity and economic viability of tomatoes and lettuce compared to conventional methods in Alabama and Arizona?
2. What are the optimal cultivation practices and microclimate management strategies for maximizing the productivity and quality of tomatoes and lettuce in Agrivoltaics system in Alabama and Arizona?
3. What are the economic feasibility and potential market opportunities for tomatoes and lettuce grown in agrivoltaics system in Arizona and Alabama?

Hypothesis of the research:

Null hypothesis (H0)

* There is no significant difference in the productivity and economic viability of tomatoes and lettuce compared to conventional methods in Alabama and Arizona.

Alternative hypothesis

* The integration of agrivoltaic system significantly impacts the productivity and economic viability of tomatoes and lettuce, resulting in improved outcomes compared to conventional cultivation methods in Alabama and Arizona.

1. Introduction:

Background and significance

Agrivoltaics, also known as agrophotovoltaics or Agri-PV, is a dual land-use system that has gained significant attention and interest in recent years (Amaducci et al., 2018). The transition to clean energy sources has resulted in negative effects on biodiversity, landscape aesthetics, and land cover and use changes (Allison et al., 2014). This has led to concerns about the scarcity of land for food production due to the increasing demand for land in energy generation (Tilman et al., 2009) The "food vs. fuel" debate, initially focused on biofuels, has now expanded to include other renewable energy sources like wind and photovoltaics (PV) (Adeh et al., 2019). Recent research indicates that PV has significant potential for deployment on cropland areas, raising questions about land-use priorities. Given the context, agrivoltaics (AV) offers a promising solution to address the trade-offs associated with renewable energy systems. AV has been recognized in various studies (Dinesh & Pearce, 2016; Dupraz et al., 2011; GOETZBERGER & ZASTROW, 1982; Miao & Khanna, 2020). as a dual land-use system that enables the simultaneous production of agricultural output and photovoltaic (PV) power on the same land area. This integrated approach significantly improves land-use efficiency compared to conventional ground-mounted PV systems. AV emerges as a viable solution to mitigate the negative impacts of energy transformation on land use and biodiversity while simultaneously supporting agricultural production and renewable energy generation. Hence, the use of high value crops is recommended to enhance profitability and the economic viability of the agrivoltaics system.

This research investigates the impact of integrating agrivoltaic systems on tomatoes and lettuce in Alabama and Arizona. It assesses crop growth, yield, quality, and economic outcomes to understand the benefits associated with agrivoltaic system. The study focuses on growth characteristics, yield potential, and productivity in agrivoltaics systems compared to conventional methods. It explores optimal cultivation practices and evaluates economic feasibility and market potential. Environmental benefits and resource utilization efficiencies are examined. The findings provide practical recommendations for enhancing productivity and sustainability in high-value crop production. The goal is to promote sustainable practices and adoption of agrivoltaics for improved productivity, economic returns, and environmental sustainability.

**High value crops and their Economic importance:**

**High** **Value** **Crops** (HVCs) are those which give significantly higher value productivity or net income per unit of resources used for production, compared to other competing activities. These crop types are recognized for their top-notch quality, customized cultivation requirements, and high profit margins compared to conventional crops. Now, the economic importance of high value crops originated from their ability to create significant revenue for farmers, also play a role to regional economies, and meet the growing consumer demand for diverse and nutritious produce.

**Economic impact of high value crops:**Agrivoltaics systems have the potential to create three sources of revenue for entrepreneurs and farmers, namely, the sale of electricity and agricultural commodities (Guerrero Hernández & Ramos de Arruda, 2022).

The wholesome economic influence of agrivoltaic systems extends to various stakeholders, which include upstream, midstream, and downstream sectors. These stakeholders could mutually help each other, leading to higher income and an increased standard of living. As this can help to enhance the national economy(Agostini et al., 2021). Based on the study by (Proctor et al., 2021). The installation of photovoltaic components in agrivoltaics system alone had the ability to generate equivalent 117,00 jobs in the United States within a 20-year timeframe. Out of these jobs, 40% would be in the form of ongoing operation and maintenance. Hence, it is worthy of note that this estimation does not include the employment opportunities associated with agricultural activities within the system.

Upstream stakeholders surround solar power plant entrepreneurs focused on PV production, agriculturists aiming to install PV systems on agricultural lands, solar cell manufacturers, distribution companies, distributors of agricultural machinery, tools, and equipment, as well as workers. Agrivoltaic systems offer a source of revenue for both entrepreneurs and agriculturist and this also help to minimize expenses generated from the farm. (Chae et al., 2022; Havrysh et al., 2022).

Midstream stakeholders which include community enterprises, agricultural product processing factories, and related businesses can gain from agrivoltaics crops. These crops can be sold fresh and utilized by community enterprises or food factories, creating income and employment opportunities. Additionally, the agrivoltaics system allows the owner of the system and food producers to purchase direct electricity, as this help to contributing and enhanced cash flow in the economy.(Neupane Bhandari et al., 2021).

Downstream stakeholders surround various groups such as community members, consumers, restaurants, distribution centers, electricity authorities, suppliers, and the transportation sector. The execution of agrivoltaics systems, whether on agricultural plots, solar power plants, or abandoned land, can generate financial benefits for the community through increased employment opportunities. This information is supported by studies conducted b(Trommsdorff et al., 2021). Directly buying of electricity from the agrivoltaics system by the owner of the system and food producers will contribute immensely to an increased in economic cash flow (Neupane Bhandari et al., 2021).

**Literature Review**

Definition of Agrivoltaics system: Agrivoltaics systems means the adequately utilization of photovoltaic (PV) technologies, where PV panels are positioned at an appropriate height above the ground to allow for conventional farming practices under or below. These systems not only sustain agricultural land but also improve and increase crop production through judicious water use efficiency and decreased water stress(Agostini et al., 2021).

**Agrivoltaics ideas:**In 1982, Goetzberger and Zastrow, introduced an agrovoltaics system that combined photovoltaic (PV) systems with crops production (GOETZBERGER & ZASTROW, 1982). The PV panels were positioned 2 meters above the ground, with a spacing of 6 meters between individual PV arrays. This arrangement facilitated adequate penetration of solar radiation beneath the PV panels to support crop growth. Prior to the installation of PV systems, Dupraz developed a predictive model that estimated crop yields and electricity generation in agricultural planning when plants are grown under PV panels. It was found that producing plants beneath PV panels can increase land productivity by 35% to 73% (Dupraz et al., 2011). To maximize the benefits of co-producing agricultural crops and electricity, it is important to design and install the PV system appropriately in conjunction with planting. This integrated approach could potentially lead to a land productivity increase of 60% to 70%. In this study, the land equivalent ratio (LER) for the agrivoltaic system ranged from 28.9% to 47.2%. (Katsikogiannis et al., 2022). employed a multi-scale modeling technique to determine the optimal topology for a medium-to-large-scale fixed bifacial agrivoltaic array suitable for various climates and tomatoes and lettuce cultivation. The E-W wing topology, featuring wider cell spacing and a spread cover, created an effective shading schedule and improved microclimate predictability. Compared to conventional systems, the E-W wing topology increased yield potential by 50% while reducing electrical output by 33%. These findings highlight the potential benefits of optimizing agrivoltaics configurations for enhanced crop production and energy generation.

**Benefits, and Challenges**

Constructively, a beneficial agrivoltaics system is the power station wind sheltering effect it provides for the crops grown under the system. The system's structural pillars serve as effective windbreakers, helping in preventing soil erosion resulting from high wind levels. To further enhance wind sheltering, a suggested measure involves creating a tree line on the system's western side using the trees removed during installation. This would establish a natural windbreak, reducing wind infiltration through the system and minimizing its impact on the crops planted underneath the PV system. This is worthy of note to itemize some of the benefits associated with agrivoltaics system.

1. Reduced soil moisture loss and decreased evapotranspiration

One among the advantages of agrivoltaics system is the help in the reduction of soil moisture and decrease in evapotranspiration of water from the soil. According to soil moisture measurements, the summer season resulted in up to a 9.4% increase in water content in the soil of certain crops compared to the reference area. As a result, these improved soil conditions create more favorable conditions for crop growth(Jain et al., 2021). Enhancing water use efficiency in plant irrigation by reducing soil evaporation and crop canopy transpiration(Barron-Gafford et al., 2019).

1. The Crop quality in agriculture

The solar panels utilized in agrivoltaics systems provide crop protection against hail, heavy rain, and sunburn, leading to enhanced crop quality. Consistently, research has demonstrated positive effects on multiple quality attributes. However, assessing crop quality entails considering the economic market value of the crop, as it cannot be adequately captured by a single, comprehensive indicator(Jain et al., 2021).

1. Food

In terms of food production, agrivoltaics systems help to photosynthesis depression caused by heat and light stress, enabling higher carbon uptake for plant growth and reproduction. This advantage promotes improved crop productivity and reproductive success(Barron-Gafford et al., 2019).

1. Energy

Considering energy, the presence of understory crops in agrivoltaic systems contributes to transpiration cooling, lowering temperatures beneath the PV panels. This cooling effect has the potential to enhance the efficiency of the solar panels, resulting in improved energy generation(Barron-Gafford et al., 2019).

However, agrivoltaics also presents many challenges. The start-up costs can be higher compared to traditional agriculture or standalone solar installations, needs careful economic assessment. Furthermore, the design and maintenance of the system need to consider factors such as crop compatibility, optimal panel orientation, and the potential for shading effects. Effective coordination between farmers, energy providers, and policymakers is crucial to solve regulatory and technical barriers and ensure successful execution.(Weselek et al., 2019).

**High-value crops: Characteristics**

High-value crops are agricultural products that command a first-class price in the market due to their quality, nobility, uniqueness, nutritional value, or demand.

1. The uniqueness of the qualities: high value crops are essential known for their unique characteristic in terms of aroma, specificity of flavor, color, and texture.
2. Nutritional Value: high value crops in terms of their uniqueness and specificity are majorly accepted by consumers because of their appealing nature from the health and wellness point of view. These crops often contain higher nutritional essentials and significant nutrient benefits, hence, when compared to conventional crops the dividend of the high value crops is more and far better than the conventional crops.
3. Scare availability: this means that the feature of high- value crops are restricted in terms of their availability in the market. These crops are often regional and seasonal specific, this results in exclusiveness and higher market value. Hence, consumers pay more attention and are willing to pay a first-class price for them.

**Cultivation Practices:**

1. Accurate farming: High-value crops requires precise management techniques such as controlled environments, irrigation optimization, fertilization, and pest management, to ensure consistent quality.
2. Organic and sustainable practices: Many high-value crop producers adopt organic or sustainable cultivation methods to meet consumer preferences for environmentally friendly and chemical-free products.
3. Post-harvest handling: Proper post-harvest practices, such as careful handling, sorting, and storage, are crucial to maintain the quality and shelf life of high-value crops.

**Market Demand and Consumer Trends:**

1. Consumer preferences and taste: The interest in health, wellness, and unique culinary ideas has improved the demand for high-value crops with concrete health advantages and sensory appeal.
2. Premium price: High-value crops usually command higher prices because of their perceived quality, exclusivity, and the willingness of consumers to pay a first-class price for unique and desirable products.
3. Niche markets: Some high-value crops have a niche market, such as organic, specialty food sectors, where consumers are willing to pay a premium for specific features.

**Principles of Agrivoltaics and Crop Selection**

Selecting appropriate crops and agricultural practices is a critical aspect of the Horticulture PV (Photovoltaic) approach since the success of the system largely relies on the chosen crops and their tolerance to shade, hence, Crops such as leaf vegetables or berries, which thrive with lower levels of solar irradiation, are more compatible with the system compared to sun-loving crops like corn, rice, or wheat. Therefore, careful crop selection plays a significant role in optimizing the performance of the Horticulture PV system(Jain et al., 2021).

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