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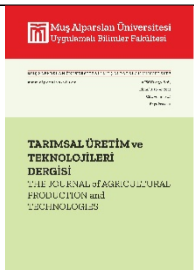

Agrivoltaics and Their Effects on Crops: A review

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Review

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ABSTRACT

Agrivoltaic systems are combined systems of agriculture and photovoltaics. This systems generally reduce yields of crops but increase land equivalent ratio, sunlight share during biological and synthetic energy harvesting, PVs efficiency and yield by cooling the surrounding microclimate, humidify the environment by drops, reduce water consumption of plants, decrease gas exchange and short-term stomatal conductance by shadow. Agrivoltaics are very suitable for rainfed, hot and arid climatic conditions, deserts, temperate zone grasslands, fields crop production, production of pollinating insects, pasture-fed rabbit and sheep farming. Pasture establishment in deserts under solar panels may prevent mid-day solar shock on crops. Extremely infertile natural pastures under erosion in Turkey may be covered with these panels to decrease the impact of erosion by reducing the raindrop speed to reach the ground. System also may provide shelters to animals.

1. INTRODUCTION

Power demands are increasing and a significant proportion should be produced by carbon free methods. Among the renewable energy types, solar energy is one of the fastest growing one. More analysis are being conducted on their interaction with local environments (Hassanpour Adeh et al., 2018).

Meeting global energy demand with renewable energy sources such as solar photovoltaic systems require large surface areas. Usage of large lands for solar farms will increase competition for food and energy demand. This land competition can be ameliorated by agrivoltaics (Dinesh and Pearce, 2016).

Agrivoltaic is the combination of agriculture and photovoltaic words (Hau, 2019). Agrivoltaic systems are combined systems that associate crops and solar PV panels on the same area (Marrou et al., 2013; Amaducci et al., 2018).

Figure 1. Agrivoltaic system for field crops (Metsolar, 2018)

The efficiency of photosynthetic process is around 3% while commercial solar photovoltaic panels have average yield of 15%. Therefore solar photovoltaic panels will therefore compete with agriculture for area. Combination of these two on the same land may maximise land use efficiency (Dupraz et al., 2011).

Dupraz et al. (2011) used Land Equivalent Ratios to compare agriculture and energy harvesting modes, light transmission to crops and productivity of shaded crops in a crop model. They determined that agrivoltaic systems may be very efficient. 35–73% increase of land productivity was determined for two different densities of photovoltaic panels. In the study of Trommsdorff et al. (2021), land use efficiency (Land Equivalent Ratio) was increased between 56% to 90%.

Photovoltaic panels in this system are needed to be mounted at a elevated height from the ground to let cultivation practices under the panels. The interest in agrivoltaic systems is increasing, but more environmental and economic analysis are needed to accelerate its implementation (Agostini et al., 2021).

Figure 2. Agrivoltaic system (Metsolar, 2018)

These systems have benefits of sharing sunlight, land and power generation compared to conventional crop production systems (Leon and Ishihara, 2018).

Agrivoltaics can be very suitable for hot and arid climatic conditions to prevent excess thermal stress during harsh periods (Younas et al., 2019).

Temperate zone grasslands and crop fields are best places to install solar panels for higher energy production. But energy companies need information for the efficient livestock production under panels (Andrew, 2020).

Solar PVs harvest excess solar power and leave crops less stressed conditions. Also growing crops around the solar panels cool the microclimate and increase PVs efficiency (Higgins et al., 2018).

Effects on agriculture

Power production by PVs reduces sunlight transmittance and yields of crops (Leon and Ishihara, 2018).

In the study of Elamri et al. (2018), installing tilting-angle solar PVs on agricultural plots provided renewable energy, humidified environment by drops and reduced water consumption by the plants by shadow via decrease of gas exchange and reduction in short-term stomatal conductance.

Amaducci et al. (2018) developed a simulation platform to simulate crops under agrivoltaic. Agrivoltaic growth condition was increased and stabilized rainfed maize yields. Renewable energy land productivity was also doubled by agrivoltaic.

In the study of Marrou et al. (2013), daily air temperature was not changed under the PVPs but crop temperature day-night amplitude, soil temperature and crop thermal pattern was decreased. Growth rate was not decreased under the solar panels (except juvenile phase of plants).

In a study of Nam et al. (2021), Italian ryegrass and barley were used winter forage. In 2018, dry matter (DM) yield of Italian ryegrass was 16.9 t/ha under Agrivoltaics and 16.7 t/ha under conventional conditions. But DM yield for barley was slightly low under Agrivoltaics compared to conventional conditions. In 2019, DM yield of Italian ryegrass with Agrivoltaics was 12.1 t/ha (5.4% lower than open field). Barley yield was 12.2 t/ha under agrivoltaics (11.5% lower than open field). In the summer forage production trial, they produced maize and sorghum×sudangrass. DM yield of maize under Agrivoltaics in 2019 was 13.1 t/ha (17% lower than open field). DM yield of sorghum×sudangrass was 12.5 t/ha under Agrivoltaics (82.5% lower than open field). In 2020, DM yield of maize under Agrivoltaics was 8.1 t/ha (7.9% lower than open field). DM yield of sorghum×sudangrass was 5.7 t/ha (11.4% lower than open field).

Figure 3. Forage and animal production in agrivoltaics (Anonymus, 2016)

Andrew et al. (2021) was conducted a study to compare lamb growth and pasture production in agrivoltaic systems and traditional open pastures for two years in USA, Oregon. Daily water consumption of lambs in open pastures were higher than agrovoltaics in late spring period in 2019. Over two years period, agrovoltaics pastures produced 38% lower herbage than open pastures. But agrovoltaics pastures produced higher forage quality which resulted with similar spring lamb productions in both conditions. Land productivity was also greatly increased by grazing and solar power production on the same land with agrivoltaics.

Figure 4. Forage and animal production in agrivoltaics (Makhijani, A. 2021) (photo source: North Carolina State University Extension)

Malu et al. (2017) assessed potential of agrivoltaic grape farms in India and determined taht tested systems increased income >15 times without any reduction in grape production (Malu et al., 2017).

Figure 5. Agrivoltaics in vineyards (Anonymus, 2020)

In the United States some solar energy producers are filling the underneath of panels pollinating insects to maximize land-use efficiency (Graham et al., 2021).

Three years of field measurements of Higgins et al. (2018) demonstrated 90% increases for biomass production, 350% increase for water use efficiency, and 10% increase for power production by agrivoltaics.

Figure 6. Tomato plants (Solanum lycopersicon) grown on an Agrivoltaic field (Al-Agele et al., 2021)

This dual-use has unique co-optimization requirements for the management of shading, soiling cultivation and spacing (Riaz et al., 2021).

2. RESULTS

Agrivoltaics generally reduce yields of crops but increase land equivalent ratio, increase sunlight share during biological and synthetic energy harvesting, increase PVs efficiency and yield by cooling the surrounding microclimate, humidify the environment by drops, reduce water consumption of plants, decrease gas exchange and short-term stomatal conductance by shadow.

Very suitable for rainfed, hot and arid climatic conditions, deserts, temperate zone grasslands, crop fields, pollinating insect production, pasture-fed rabbit and sheep farming. Pasture establishment in desert by mid-day shock prevention via solar panels.

Extremely infertile natural pastures under erosion in Turkey may be covered with these panels. System may decrease the impact of erosion by reducing the velocity and time to reach the ground. May provide shelters to animals.

For some agrivoltaic systems, panels are required to be mounted at a elevated height. More environmental and economic analysis are needed. Energy companies need information for the efficient livestock production under panels.

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