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Agrivoltaics: A Sustainable Method of Farming for Various Suitable Crops

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ABSTRACT

cultivation and electricity generation simultaneously on the same piece of land at the same time. This system enables the farmers to gain several benefits such as optimized land use, productivity improvement in the energy and water sector, economic benefits, etc. India receives ample supply of energy from the sun, but it is not yet utilized efficiently. In an agrivoltaic system, the output of crops will be affected by shade which is provided by panels as they allow very little solar radiation passage for fixation of CO_2 by crop. Solar radiation, PAR, and Light Saturation Point are vital indices to enhance plant biomass. Generally shade-loving or tolerant crops are preferable under agrivoltaics. However, shade-intolerant crops can also be grown in interspaces where crops can capture a sufficient amount (> 50%) of sun-light. The shade provided by APV creates a microclimate suitable for practicing cultivation in arid regions, livestock (rangevoltaics) and aquaponics etc. Some of the crops like cherry, bell pepper, lettuce, grapes, berries, and other cool season crop plants etc. showed better response under APV and reported enhanced growth, yield, and quality compared to conventional farming. The electricity generated by PV would improve the farmer's socio-economic status, and land productivity and helps to curtail environmental pollution.

Keywords: *Agrivoltaics, Light Saturation Point, PAR, Rangevoltaics, Shade-intolerant crops Shade-tolerant crops, and Solar radiation*

1. Introduction

India is the third largest greenhouse gas emitter in the world after China and the U. S. The electricity and heat sector contributed a major share in GHG emissions in India by 2020. Power generation through coal burning (conventional non-renewable energy) creates environmental pollution. In India, coal combustion produced 1.8 $GtCO_2$ in 2021 [19]. All those diesel-powered or fossil fuel power-generated systems were negative. For example, release of CO_2 from diesel pump system might be around 4005 kg CO_2 per annum to irrigate the selected reference farm [4]. According to [6], the generation of electricity from these conventional fossil fuels has a significant impact on greenhouse gas emissions, energy shortage, and acid rain.During COP 26, which was held in Nov 2021, our country set 2030 targets of a total non-fossil energy generation capacity of 500 GW and a share of 50% of electricity generation should come from renewable energy (Fig. 2) which is two times greater than 2020 share (22% share) and net zero emissions of carbon by 2070. Our country has set itself the ambitious target of generating half of its electricity from renewable by 2030, which will result in emissions from the power sector fall by merely 9% per year to 2030. India has established 18 GW of solar PV in 2022. A new mark to expand PV capacity auctioned to 40 GW per annum [10]. To achieve Net Zero Emission (NZE) 2030, the demand for solar PV according to announced projects is 800 GW. While; solar PV manufacturing capacity in 2030 might be better and it is essential to cover 2030 NZE target. Energy generation from coal will be surpassed by Solar PV's power capacity by 2027 and it will become the largest energy generating capacity in the world (Fig.1) [10].

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2. Agrivoltaics

The Agriculture sector is also one of the major greenhouse gas emitters, particularly CH_4 and nitrous oxide [22]. Agrivoltaics is the best option to curb environmental pollution and to improve country's economy as well as to achieve the mile stone of net zero emission target by 2030. [5] defined APV as the same land area used for dual purpose to produce solar electricity and agricultural crops, including aquaculture. [4] defined APV will harvesting solar energy and food production together at a particular piece of land this in turn increases land productivity with additional benefits of higher crop economic yield and socio-economic status of farmers. However, agricultural fields have to be sacrificed for the installation of APV modules. Different terms have been used to describe this technology including solar PV, agri-photovoltaics, agrivoltaic, *etc*. The word agrivoltaics (and in simple form APV or PV) is used in this paper to interpret this technique. “rangevoltaics” refers to using land for both grazing and electricity production [26].

[3] described that Agrivoltaics reduce drought stress, and heat stress and facilitates greater food production due to the shading

effect of panels by decreasing the plant evapotranspiration losses from plants, evaporation from soil and avoiding direct exposure of shade-loving plants to solar radiation. They also stabilize yields of crops where arid, hot and windy and frost conditions prevail by obstructing hot dry winds, collecting scanty rain-water to irrigate fields as life-saving irrigation [20] which was observed at CAZRI, Jodhpur PV plant in India. This plant will harvest and stores rain-water of about 1.5 L. liters of rainwater per annum [21] thus it contributes to bolstering and vitalizing economy and livelihood of rural people [22]. In some cases, shadow will also interrupt the growth of crop plants [4] mostly in heliophytes. To avoid this kind of problem, choosing suitable crops is essential to obtain good results.To gain better results, firstly, crops have to be classified into shade tolerant and susceptible. Later, the selection of suitable APV configuration to that chosen crops helps in better passage of sunlight for both agrivoltaics and crop plants [4].

3. Suitable crops for APV system

[24] summarized several benefits of the APV. Among other authors, the narrator pointed the positive effects of shade underneath the panels on fresh salads and vegetables in desert conditions. Chosen crops in these desert localities should be somewhat dwarf in stature, possibly perennial, creeper or spreading on the ground, and it should not interfere with the functional ability of agrivoltaic panels. To avoid the shade effect of crops on panels, crop height preferably should be less than 0.75 m at the peak vegetative stage [18]. [4] discussed that; there were less growth rates of crop plants under solar APV modules, an increase of land productivity up to 70% because of the co-culture of crops and energy at the same place thereby enhancing economic benefits of farmers.Obviously, shading of panels reduces evaporation and ET from cropped fields and at the same time, they also responsible for the negative effect of declined photosynthetic rates. As per [6], using of shading PV panels in the cropped fields requires more research programs for identifying proper panel percentage on field along with crop plants and their configurations to augment crop biomass and yield. [4] suggested the classification of suitable crops under agrivoltaics as portrayed in Fig. 3. Crops grown better under shading were placed in the "positive" category (green), whereas the crops which are not able to tolerate shade were placed under "Negative" (red). The crops of the "0" category are non responsive to shade.

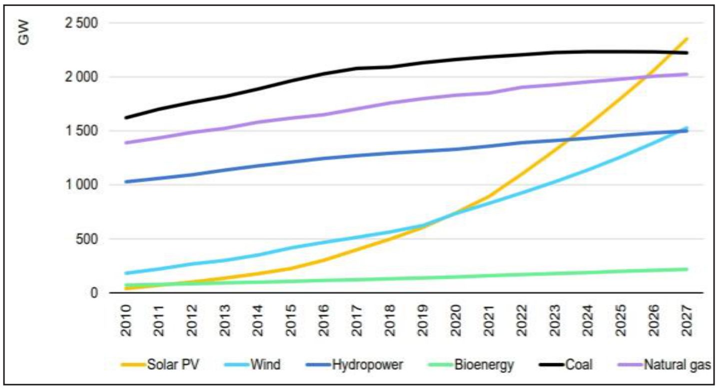


Fig. 1: Cumulative power capacity by technology in the world from 2010 to 2027 [10]

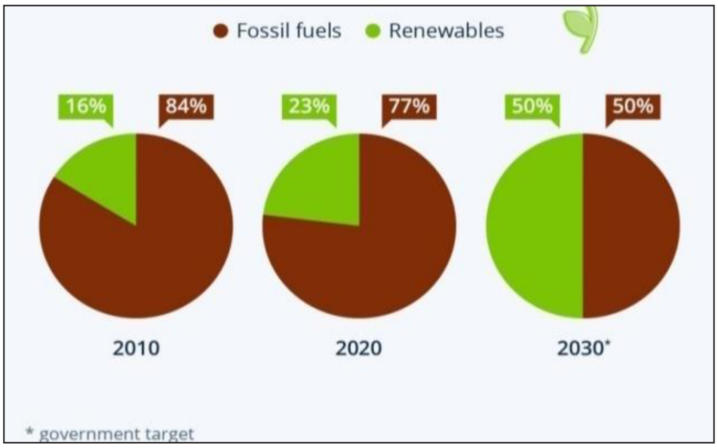


Fig. 2: Electricity generation by source in India in 2010, 2020 and 2030 [10]

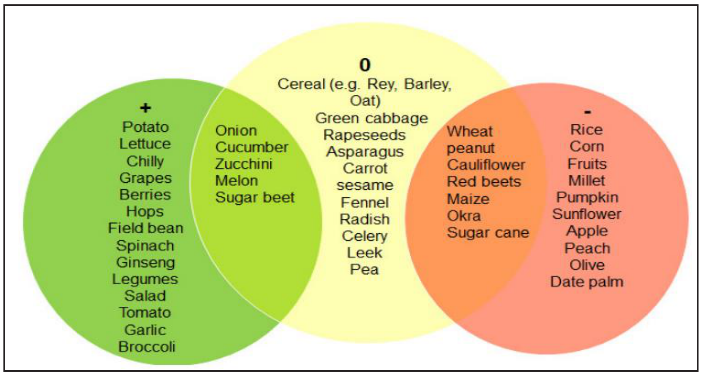


Fig. 3: Suitable crops for APV [4]

Light requirements vary with crop species. [13] studied crop yield changes due to Reduction in Solar Radiation (RSR) in different crops *viz*., berries, grain legumes, C_3 cereals, maize, fruits, fruity vegetables, tuber/root crops, forages and leafy vegetables. C_3 cereals only reported a lesser than proportional yield reduction until 15% RSR. Grain legumes and maize are more susceptible crops to RSR and excessive yield reduction starts from 1% RSR. Berries and fruits have mostly positive responses to RSR (Table 1). Maize is a crop that cannot tolerate to shading among all the tested crops. This is likely because maize is a C_4 plant, which requires greater quantities of solar radiation; because it is most sensitive to restriction of light [8]. Total and specific leaf area of lettuce will be increased under shadow conditions [22], improving light interception [15]. Nevertheless, morphological changes (Decrease in leaf area index and stem elongation *etc*.) due to RSR can reduces crop yields. For example, the yield was reduced drastically in response of RSR in case of grain legumes [12]. [2] revealed that the water content of sugar beet increased significantly under continuous shading. Depending on the level of shading, [13] classified a crop-type may exhibit different response patterns as illustrated in Fig. 4. The "shade benefit" area indicates crops that fall under this region perform better and greater yields can be obtained due to shaded conditions over open light conditions. Under the 'Shade tolerance' region, crops reported less than proportionate yield reductions, and 'susceptibility' is the region that lies below the linear interpolation of 0% RSR to 100% yield and 100% RSR to 0% yield. These three regions determine the specific crop type to the relative level of shade that helps to get better yields.

Based on this response of crops to shade classification (Table 1), forage crops are suitable to shaded areas and benefit until 25% RSR, and tolerant to shade thereafter, while C_3 cereals can able to tolerate shade until 50% RSR and are susceptible when RSR > 50% to shade and again they showed tolerance to shade after 60% RSR until 90% RSR [12]. Berries at 55% RSR are still expected to benefit because of shade over light conditions; they achieved a greater level of yield might be at around 30% RSR. Shading on bell peppers results in a higher marketable yield due to the reduction of sun damage of the fruits [11]. Shading showed a positive effect on fruit production. For example, the number of fruits were increased in blueberries has been reported by [16]. Quality of aroma was increased due to greater concentration of anthocyanin and acidity in case of vineyards under APV [26].

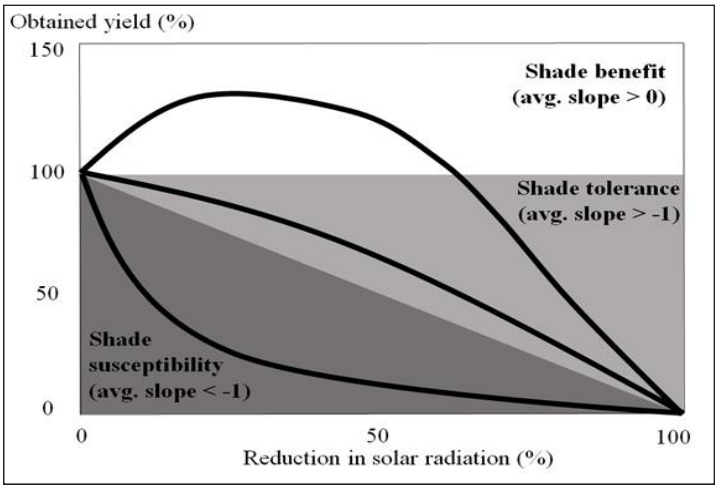


Fig. 4: A conceptual model represents shade sensitivity passing through areas of benefit (more than 0 slope), tolerance (more than -1 slope), and susceptibility (less than -1 slope). Some crops are initially in the area of benefit (white region) and most of the crops are at least for a short period in the region of tolerance (light grey shade), where the desirable yield loss is less than proportionate. Some crops *viz.*, maize and grain legumes *etc.*, fall under the area of shade susceptibility (Dark grey shade)[12].

Table 1: Predicted yields of different tested crops at different RSRs for temperate and subtropical regions [12].

Croptype	RSR	Prediction	(95% CI)	Shade Response	RSR	Prediction	(95% CI)	Shade response
Berries	5	104.7	(100.3- 109.3)	B	50	108.3	(74.3-157.9)	B
Fruits	5	104.6	(100.4-109)	B	50	107.4	(73.6-156.7)	B
Forages	5	102.1	(98.4-105.9)	B	50	84.1	(64.1-110.4)	T
Maize	5	93.3	(90.2-96.5)	S	50	34.2	(26.3-44.4)	S
Grainlegumes	5	94.6	(91.6-97.6)	S	50	39.1	(30.4-50.2)	S
Tubers/rootcrops	5	96.8	(91-103)	T	50	49.3	(27.5-88.6)	S
Fruityvegetables	5	103.3	(97.7-109.2)	B	50	94.7	(55.9-160.5)	T
Leafyvegetables	5	101	(96.4-105.9)	B	50	75.9	(49.8-115.7)	T
C3 Cereals	5	97	(93.8-100.3)	T	50	50.4	(37.7-67.5)	T
Berries	10	108.7	(100-118.1)	B	55	104.2	(68.8-158.1)	B
Fruits	10	108.5	(100.2- 117.5)	B	55	103.3	(67.9-157.2)	B
Forages	10	103.3	(96.4-110.8)	B	55	78.9	(58.5-106.4)	T
Maize	10	86.3	(80.9-92.1)	S	55	29.3	(21.9-39.2)	S
Grainlegumes	10	88.6	(83.4-94.2)	S	55	33.9	(25.7-44.9)	S
Tubers/rootcrops	10	92.9	(82.2-105)	T	55	43.9	(23-83.7)	S
Fruityvegetables	10	105.8	(94.8-118.1)	B	55	89.9	(50.3-161)	T
Leafyvegetables	10	101.3	(92.4-111)	B	55	70.5	(44.3-112.3)	T
C3Cereals	10	93.3	(87.4-99.6)	T	55	45	(32.5-62.2)	S
Berries	15	111.9	(99.1-126.4)	B	60	99.5	(63-157.2)	T
Fruits	15	111.6	(99.3-125.5)	B	60	98.5	(61.9-156.7)	T
Forages	15	103.7	(93.9-114.6)	B	60	73.4	(52.8-102)	T
Maize	15	79.2	(72.2-86.9)	S	60	24.9	(18.1-34.4)	S
Grainlegumes	15	82.4	(75.5- 90)	S	60	29.2	(21.4- 40)	S
Tubers/rootcrops	15	88.4	(73.7-106.1)	T	60	38.7	(19.1-78.4)	S
Fruityvegetables	15	107.5	(91.3-126.5)	B	60	84.7	(44.7-160.4)	T
Leafyvegetables	15	100.6	(87.9-115.1)	B	60	64.9	(39-108.2)	T
C3 Cereals	15	89	(80.9-97.8)	T	60	39.8	(27.7-57.1)	S
Berries	20	114.3	(97.5-133.9)	B	65	94.1	(57-155.4)	T
Fruits	20	113.9	(97.6-132.8)	B	65	93.1	(55.8-155.3)	T
Forages	20	103.3	(90.9-117.3)	B	65	67.7	(47.2-97.3)	T
Maize	20	72	(64-81.1)	S	65	21	(14.7- 30)	S
Grainlegumes	20	76	(67.9- 85)	S	65	25	(17.7-35.4)	S
Tubers/rootcrops	20	83.4	(65.6-106.1)	T	65	33.9	(15.7-72.9)	S
Fruity vegetables	20	108.3	(87.3 - 134.3)	B	65	79.1	(39.4 - 158.7)	T

Leafy vegetables	20	99.1	(83.1 - 118.2)	T	65	59.3	(33.9 - 103.6)	T
C3 Cereals	20	84.2	(74.4 - 95.2)	T	65	34.8	(23.3 - 52.1)	S
Berries	25	115.7	(95.2 - 140.6)	B	70	88.3	(51.1 - 152.8)	T
Fruits	25	115.2	(95.2 - 139.3)	B	70	87.3	(49.7 - 153.2)	T
Forages	25	101.9	(87.5 - 118.8)	B	70	62	(41.6 - 92.4)	T
Maize	25	65	(56.3 - 75)	S	70	17.6	(11.8 - 26.1)	S
Grain legumes	25	69.5	(60.7 - 79.5)	S	70	21.2	(14.4 - 31.2)	S
Tubers/root crops	25	78.1	(57.9 - 105.2)	T	70	29.4	(12.8 - 67.4)	S
Fruity vegetables	25	108.2	(82.8 - 141.2)	B	70	73.2	(34.3 - 156.1)	T
Leafy vegetables	25	96.8	(77.9 - 120.3)	T	70	53.7	(29.2 - 98.6)	T
C3 Cereals	25	78.9	(67.9 - 91.7)	T	70	30.3	(19.4 - 47.3)	T
Berries	30	116.1	(92.2 - 146.3)	B	75	82.2	(45.2 - 149.4)	T
Fruits	30	115.5	(92.2 - 144.8)	B	75	81.1	(43.8 - 150.4)	T
Forages	30	99.7	(83.6 - 119.1)	T	75	56.2	(36.2 - 87.3)	T
Maize	30	58.1	(49.2 - 68.6)	S	75	14.6	(9.4 - 22.6)	S
Grain legumes	30	63	(53.8 - 73.7)	S	75	17.8	(11.5 - 27.4)	S
Tubers/root crops	30	72.4	(50.7 - 103.4)	T	75	25.2	(10.3 - 61.9)	T
Fruity vegetables	30	107.1	(77.9 - 147.2)	B	75	67.2	(29.6 - 152.7)	T
Leafy vegetables	30	93.8	(72.5 - 121.4)	T	75	48.2	(24.9 - 93.4)	T
C3 Cereals	30	73.4	(61.5 - 87.6)	T	75	26.1	(15.9 - 42.8)	T
Berries	35	115.6	(88.5 - 150.8)	B	80	75.8	(39.5 - 145.4)	T
Fruits	35	114.9	(88.4 - 149.3)	B	80	74.8	(38.1 - 146.9)	T
Forages	35	96.8	(79.2 - 118.3)	T	80	50.6	(31.1 - 82.2)	T
Maize	35	51.5	(42.6 - 62.3)	S	80	12	(7.4 - 19.4)	S
Grain legumes	35	56.6	(47.3 - 67.7)	S	80	14.8	(9.2 - 24)	S
Tubers/root crops	35	66.6	(44.1 - 100.7)	T	80	21.5	(8.2 - 56.5)	T
Fruity vegetables	35	105.2	(72.7 - 152.2)	B	80	61.2	(25.2 - 148.5)	T
Leafy vegetables	35	90.1	(66.9 - 121.4)	T	80	42.9	(20.9 - 88)	T
C3 Cereals	35	67.7	(55.2 - 83)	T	80	22.3	(12.9 - 38.6)	T
Berries	40	114.1	(84.3 - 154.3)	B	85	69.3	(34.1 - 140.9)	T
Fruits	40	113.3	(84 - 152.8)	B	85	68.3	(32.7 - 142.9)	T
Forages	40	93.2	(74.5 - 116.5)	T	85	45.1	(26.4 - 77.1)	T
Maize	40	45.3	(36.6 - 56.1)	S	85	9.8	(5.7 - 16.7)	S
Grain legumes	40	50.4	(41.2 - 61.7)	S	85	12.2	(7.2 - 20.9)	S
Tubers/root crops	40	60.8	(38 - 97.3)	T	85	18.2	(6.5 - 51.3)	T
Fruity vegetables	40	102.5	(67.2 - 156.1)	B	85	55.2	(21.2 - 143.6)	T
Leafy vegetables	40	85.8	(61.2 - 120.4)	T	85	37.9	(17.4 - 82.4)	T
C3 Cereals	40	61.9	(49.1 - 78)	T	85	18.9	(10.3 - 34.6)	T
Berries	45	111.6	(79.5 - 156.6)	B	90	62.9	(29.1 - 135.9)	T
Fruits	45	110.8	(79 - 155.3)	B	90	61.9	(27.7 - 138.4)	T
Forages	45	88.9	(69.4 - 113.8)	T	90	39.9	(22.1 - 72.1)	T
Maize	45	39.5	(31.2 - 50.1)	S	90	7.9	(4.4 - 14.3)	S
Grain legumes	45	44.6	(35.6 - 55.8)	S	90	10	(5.5 - 18.2)	S
Tubers/root crops	45	55	(32.4 - 93.2)	S	90	15.3	(5 - 46.3)	T
Fruity vegetables	45	98.9	(61.6 - 158.9)	T	90	49.4	(17.7 - 138.2)	T
Leafy vegetables	45	81.1	(55.5 - 118.5)	T	90	33.2	(14.3 - 76.9)	T
C3 Cereals	45	56.1	(43.3 - 72.8)	T	90	15.9	(8.2 - 31)	T

B: Benefiting, T: tolerant, and S: Susceptible

4. APV configuration

There will be conflicts between crop production and APV for the same land use. Land allocation for panels and their arrangement (Fig. 5b, c &d) is important to avoid the shading effect on shade-intolerant crops and to enhance crop photosynthetic rate and eventually crop growth and yield. Agri-Voltaics can be installed on Roofs of houses, apartments, green houses, and other infrastructure.

Agricultural lands allow dual production of energy and crops as solar panels are intentionally installed along with crop plants to capture energy. At present, farmers of India showing interest in establishing solar PV in the agricultural farms along with crop rows *i.e*. interspaces or on the mounted structures that facilitate crop growth beneath the panels. Interspace PV is usually different from overhead PV agrivoltaics as they have nil or less upright clearance [22]. Normally, 4-4-meter clearance is desirable according to [6], if the mechanical operations with the help of tractors are encouraged under the panels. Evaluation of the cost of construction of fixed panels at suitable heights is important. Space between panel to panel and pillar to pillar is important to carry out necessary cultivation practices. To avoid the shade of a panel on another panel, there must be at least 6-12 m distance between one PV panel to other [18]. Half or less density of panels may be preferable for the crops compared to full-density panels [7]. 95% of PV modules comes from crystalline silicon (c-Si) modules, which too mono-Si crystalline modules in the market compared to multi-Si module in 2019 [22].

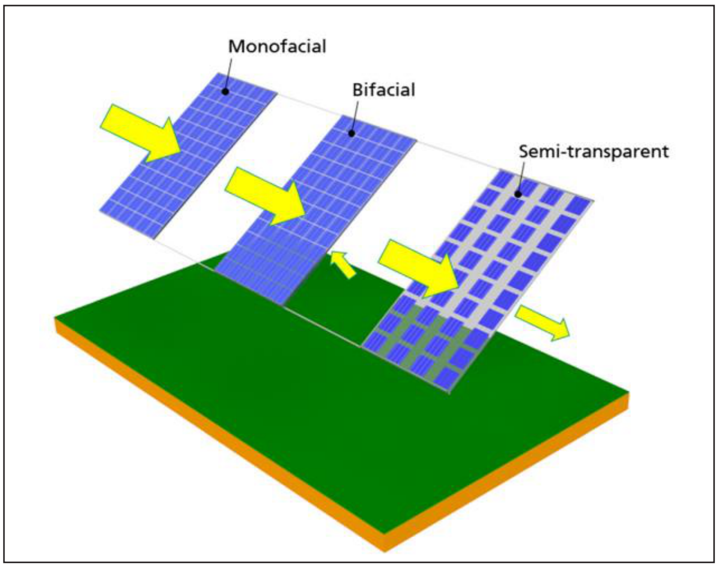
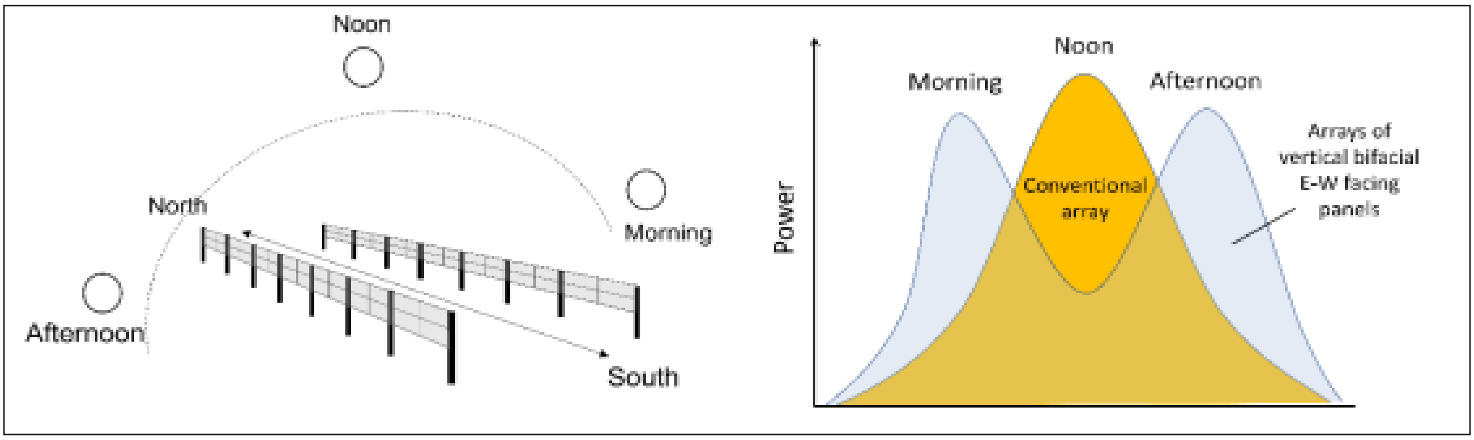


Fig. 5(a) :3 main c-Si modules of APV systems [22]

Fig. 5(b): Some of APV panel arrangements [6 Chamara and Beneragama]



5(c): Layout of Vertical Bifacial Panels and Generation Pattern Compared to Conventional Arrays [27]

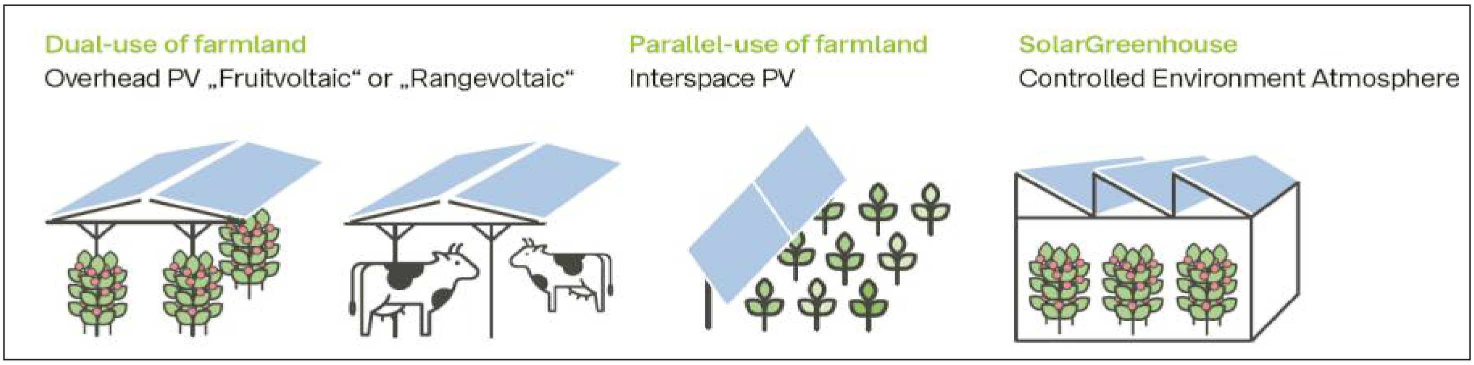


Fig. 5(d): Various configurations of APV panels [1]

Fig. 5(a) illustrated three commonly used c-Si modules in agrivoltaics *viz*., monofacial, bifacial and semi-transparent and Fig. 5(b) portrayed some of the PV panel arrangements as a) Continuous rows, b) Staggered, c) Checker-board and d) Staggered. Fig 5(c) depicts the production of electricity by E/W faced vertical bifacial panels. The generation of electricity would be greater in the hours of morning and evening. Fig. 5(d) explained PV configurations like overhead PV (Installed at a certain height over the cropped field and livestock *i.e*. rangevoltaics), Interspace PV (Installation of PV at the interspaces of crops), and Roof top APV for green-houses.

According to [27], Vertical bifacial PV panels are a kind of interspace PV modules oriented towards E-W direction. Production of energy from these modules would be at times of dawn and dusk (Fig. 5(c)). 5% higher land productivity was observed from E/W vertical bifacial panels than N/S faced fixed-tilt panels at Lahore, India [29]. Full density panels helps to produce an excess amount of power whereas, half density panels are favorable to grow crop satisfactorily as they allow passage of light to crop plants. Solar and controlled tracking are the two algorithms that follow the sun's path during entire day hours by the former and only during certain periods of time by the latter [23].

[17] introduced a sharing of irradiance effectiveness factor with concept of light productivity factor (LPF) which shares radiation for a specific crop of that location and APV array system. This metric identifies some of the design parameters *i.e.* spatial density of panels and orientation of panels etc. pertaining to PAR of crop. LPF value lies in the range of 1 to 2 for APV systems based on shade sensitivity of particular crops, season, and

configuration of agrivoltaics. But, it is low and equals to 1 for pure PV system or crop without APV installation. Depending on the season, Full density and half density or ¾ density panels are suitable for the crops of shade tolerant and moderate to high shadow sensitive ones, respectively. In his investigation, fixed tilt East to West oriented vertical PV performed better with little difference of seasonal crop functioning in the shade-sensitive crops over North to South oriented modules at an optimum tilt.

5. Microclimate

[24] found that soil temperature at night under the modules was lower than that of soil temperatures under full sunny morning hours. Evapotranspiration will reduces the temperature of the surrounding atmosphere under the APV system by around 1 to 1.5°C than ambient temperature [9]. [22] reported a decline of about 14% to 29% of evapotranspiration. Hence, moisture levels near soil and air would be higher beneath PV system. APV panels lessen the impact of heavy rainfall, frost, hail storms and high temperatures on crops grown underneath of it. [28] suggested good plant growth can be anticipated in the regions of hot windy, and turbulent conditions as they act like windbreaks and this could helps to minimize wind erosion.

6. PAR

According to [14] Photosynthetic Active Radiation (PAR) is essential for canopy photosynthesis and sub-divided into direct, diffused, and reflected radiation. PAR_{total} is the combination of both PAR_{Direct} and $PAR_{Diffuse}$. Per unit of PAR_{total}, $PAR_{Diffuse}$ radiation contributes to a greater photosynthetic rate than PAR_{Direct}. The shadow of APV panels will obstruct part of solar radiation based on their density during a full sunny day. During this period, an important source of light for the crop plants is diffused solar radiation. Normally, PAR_{total} is the radiation that is received by crop plants under open field or no APV system conditions, whereas, under an agrivoltaic system, crops will take up the-combination of PAR_{Direct}, $PAR_{Diffuse}$ and $PAR_{reflected}$. The same author also explained the response of light on canopy photosynthesis with the help of a light-response curve which represents a relation between light intensity and photosynthetic rate (Fig. 6). The light compensation point is the minimum light intensity at which photosynthesis and respiration are equal. Net photosynthesis increased linearly with increased intensity of light at light limitation area. After this point, there would be a plateau level of photosynthesis (photo-saturation) and thereafter, declined growth of net photosynthesis at excess intensity of light (photo-inhibition).

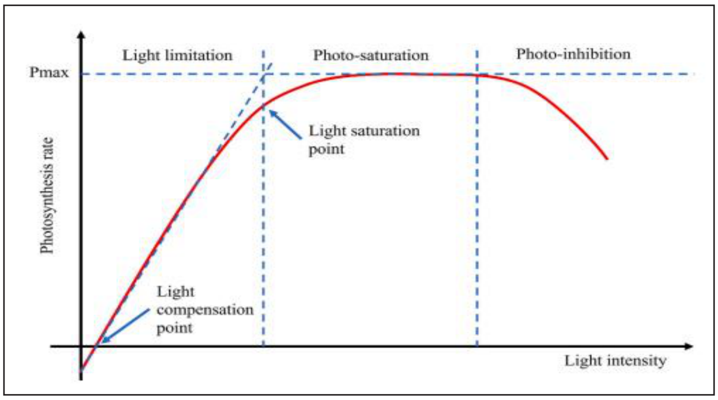


Fig. 6: Light-response curve for photosynthesis [14]

[14] studied seven different stand-alone decomposition models and the EMOS approach model for Global Horizontal Irradiance (GHI) and are tested to predict accurate $PAR_{Diffuse}$ at three locations *viz.*, Lanna, Hyltemossa and Norunda in Sweden. [17] illustrated graphical representation of the response of crops to light intensity and CO_2 fixation rate as in Fig. 7(a). The light intensity at which photosynthesis is equals to PAR until the threshold value (PAR_{th}) is referred as the light saturation point. The excess intensity of PAR above PAR_{th} won't increase the rate of photosynthesis. The light saturation point is considered as a vital factor in defining shade ratio of PV modules and determining the specific crop to be cultivated under this system. Crops under lower LSP can tolerate shade without any reduction in yields (Fig. 7(b)) [22]. LSP is higher for C_4 crops than for C_3 crops. Shading is not only a hindrance factor, but also a beneficial factor as it decreases the crop water demand during a hot summer period.

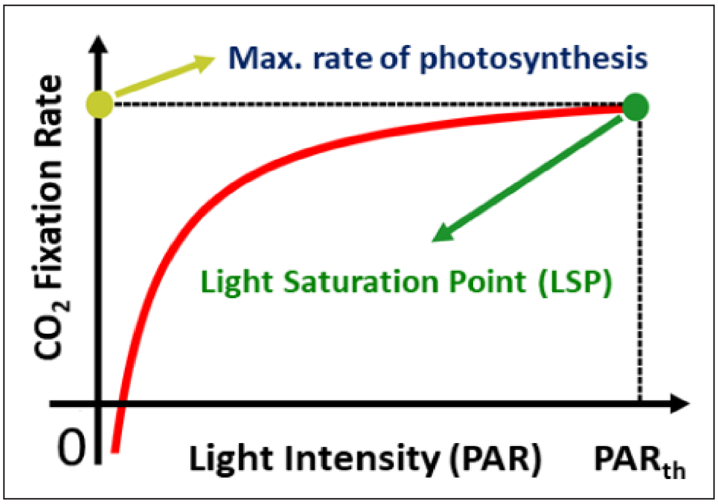


Fig. 7(a) [17]

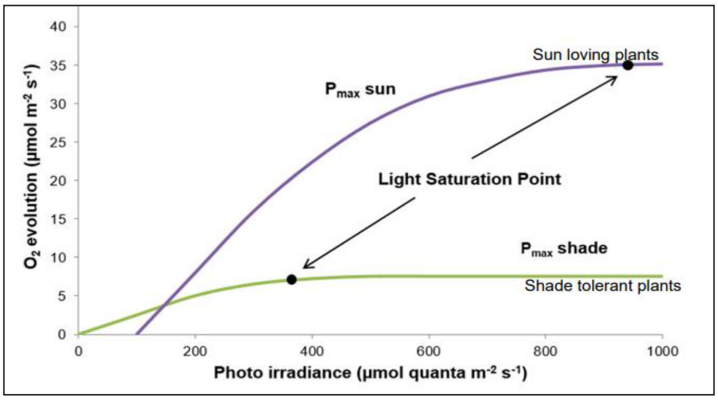


Fig. 7(b) [22]

Fig. 7 (a) & (b): Response of photosynthesis rate against light intensity

Light saturation point for sun-loving plants would be more than shade-tolerant plants as portrayed in Fig. 7(b), thus shade loving plants can flourish under low intensity of light. [25] classified different crops based on the demand of sunlight into three major categories (Class- I, II and III), which again subdivided into six minor classes (each class sub divided as A & B). After integration of different sunlight demands and distribution of light beneath agrivoltaics, they prepared crop layout based on the duration of sunshine and PAR and also considered LSP & Light Compensation Point (LCP). Crops that come under class I- A are majorly shady plants as they have lesser light saturation and compensation points. The area where little shadow received is preferable for growing crops of Class II-A & B. Class-III A and B crops can be planted where a greater amount of sunshine duration received that is around to ≥ 50%. Improved crop layout model presented in Fig. 8. Suitable crops for the above three categories are depicted in Table 2.

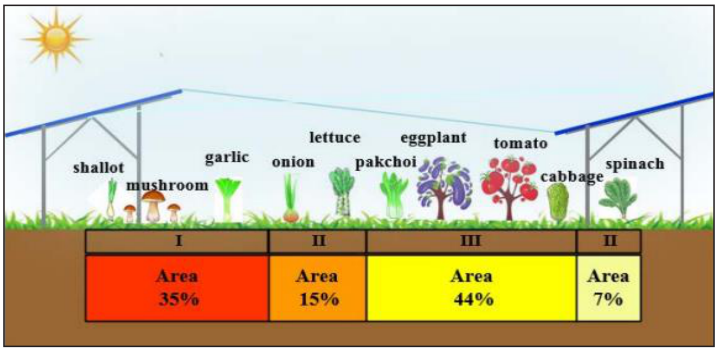


Fig. 8: Crop layout based on sunlight demand and PAR [25]

[22] stated that,If the harvested energy from panels is efficiently used in field, it helps in the reduction of the carbon footprint of that farming unit and it contributes to increasing the productivity of the farmland thus overall earnings of the producers from harvestable crop and electricity sales after usage of generated electricity in the field will be increased automatically. Land use efficiency of the agrivoltaic system could be calculated by using the Land Equivalent Ratio (LER). Apart from APV, this ratio can also be used in the disciplines of agriculture, agroforestry, and aquaponics [9]. It is the sum of production ratios of cropped land and APV as illustrated in the equation (1).

$$LER= \{\frac{Ydual}{Y\ mono}\} + \{\frac{EY\ dual}{EY\ mono}\} \ ...(1)$$

Y_{dual}- Yield in APV sytem
Y_{mono}- Yield in the cropped field alone
EY_{dual}– Electricity yield in APV system
EY_{mono}-Electricity yield in density solar panels alone

LER value greater than 1 denotes, that the system with the integration of crops and PVs is highly efficient compared to separate productions of each system. [23] computed LER for three APV systems (HD: half or 50% density of stationary panels; ST: regular solar tracking; CT: controlled tracking) and found that maximum value was obtained with regular solar tracking panels for two lettuce varieties (Kiribati and Madelona) and in all the seasons of study. For the highest panel density, 15% increase in LER was observed, when crops have an effective tolerance ability to shade. With regard to the orientation of modules, LER decreased when crop has little tolerance capacity to shade for both E-W and N-S faced panels at a given density. For the customary density of modules, light-requiring or sun-loving crops will decrease LER by 11% than maximum shade-loving crops [29].

7. Ground Coverage Ratio

It is one of the major influencing variables in agrivoltaic systems. [26] defined GCR is the ratio of the covered area under the agrivoltaic modules to the area under cultivable land, as given in the equation (2).

$$GCR= \frac{Area\ under\ Pv}{Area\ of\ cultivated\ ground} .....(2)$$

For agrivoltaics, the high GCR value indicates a maximum energy production, whereas the yields from crop will be meager, mainly due to a reduction in the quantity of solar radiation reaching to the ground and resulting in a decline in photosynthetic rate and vice versa. But, it is reverse in the case of rangevoltaics, maximum GCR value is considered as beneficial to produce a greater amount of milk as it reduces the heat stress to livestock.

Table 2: Crops recommendation list based on PAR and demand for sunlight [25]

Class		Speices(Cultiar)	
	Cucumber(Xintai mici)	Tomato(Zhong Shu No.4)	Potato (Tai Shan No. 1)
	Cabbage(Zhong gan No.11)	Chinese chive (791)	Pakchoi(Shanghai qing)
	Lettuce(Ji nan Lettuce)	Spinach(Yuan ye)	Snapbean(Fengshou No. 1)
	Eggplant (Luqie No.1 1)	Watermalon(Fengshou No.2)	Mushmelon (Qitian No. 1)
III	Pepper (Qie men pepper)	Radish (Luluobu No. 1)	White gourd (Fen pi)
	Onion (Ziluo onion)	Sponge gourd (Ordinary)	Balsampear(Bincheng),
	Leaf lettuce(Boli)	Pumpkin(Yunnan black seeds)	Carrot (Wuchun shen)
	Chinese plate cabbage	Lentil (Green lentil)	Taro (Duozi Taro)
	Cauli flower (French snow ball)	Asparagus bean (Zhijiang No.28)	
	Garlic(Cang shan)	Celery (America celery)	Leaf beet (Green stem)
	Welsh onion (Zhang qiu)	Leaf lettuce(Boli)	Heading lettuce (Emperor)
II	Onion(Ziluo onion)	Carrot (general)	Potato (Tai Shan No. 1)
	Ginger (Laiwu ginger)	Taro (Duozi Taro)	Water spinach(White flower)
	Pepper (general)	Chinesecabbage(Lubai	
I	Oyster mushroom	Garlic (genaral)	Malabar spinach
	Hotbed chives	Crowndaisy chrysanthemum	Some edible mushroom

8. Conclusion

Plants require adequate sunshine hours, PAR, and LSP to produce a good amount of biomass or yields. APV system obviously enhances the productivity of the land as well as crops by producing the electricity and biomass of plants, respectively on the same piece of land. A wide range of crops can be cultivated under solar panels by adjusting crop rows according to their demand for light, space, and water. They protect the sciophytes (Pepper, lettuce, spinach, sugarbeets and broccoli *etc.*) from sun-burning effect thus helps in improving vegetative growth and yield with desired quality with enhanced water use efficiency. Berries, Forages and leafy vegetables are the most suitable crops under the APV system even up to 60-75% RSR. Mushroom, garlic, shallot, celery, leaf beet, lettuce, onion, carrot, pepper, cabbage *etc*. crops are beneficial under low to medium LSP and LCP conditions. Grain legumes and maize are not preferable to cultivate under agrivoltaics as they demand huge amount of sunlight.

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Future scope of the study: There is a need to study the system of APV for other possible allied sectors of agriculture.Dual axis tracker type of APVs are useful for almost all the shade tolerant and medium shade sensitive crops.

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