Chapter

Solar Technology in Agriculture

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Abstract

Promotion of sustainable agriculture is one of the most priority development goal set by United Nations for achieving the food security to meet the ever-increasing global population food demand. Because of extreme importance of agriculture sector, significant technological developments have been made that played pivotal role for sustainable agriculture by value addition in agricultural products and meeting energy demands for machinery and irrigation. These developments include improved cultivation practices, processing units for agricultural products and operation of machinery and irrigation systems based on solar energy. Moreover, the emergence of new technologies and climate smart solutions with reduced carbon footprints have significantly addressed the ever-increasing fuel costs and changing climate needs. PV based solar irrigation pumps and agricultural machinery is typical example of this. Because, awareness of these technological development is essential to overcome energy issues, availability of energy to perform agricultural activities for sustainable agriculture at farm level and socioeconomic uplift of farming community to meet food requirements needs in the future. Therefore, this chapter attempts at providing the introduction of technologies for direct and indirect use of solar energy in the agriculture sector. The typical examples of direct use of solar energy like greenhouses or tunnel farming for cultivation of crops and vegetables and use of solar dryers for drying agricultural products have been comprehensively discussed. Similarly, the solar powered tubewells, tractors, and lights, etc. are few important examples of indirect use of solar energy and have also been discussed in this chapter. The indirect use is made possible by converting solar energy into electrical energy with the help of photovoltaic devices, called "solar cells". Also radio frequency (RF)-controlled seed sowing and spreading machines are discussed, which provide an eco-friendly method. Moreover, comprehensive discussion is made on solar based technologies in general as well regional context in view of their potential to scale-up and to address anticipated issues. The use of photovoltaics in agriculture is expected to be significant contribution in the near future that require urgent planning for the potential benefits and efficient use at the farm level. Therefore, the co-existence of "agrovoltaics" will be essential for the developments of agriculture and agroindustry.

Keywords: Sustainable agriculture, Solar Energy, Agricultural Machinery, Solar Irrigation, Greenhouse, Solar dryers, Agrovoltaics, Agroindustry

1. Introduction

The demand for energy in agriculture has increased significantly to meet the needs of growing population and increasing demand for food. For which not only the already available sources of energy are inadequate and have dwindled because their reserves are nearing to depletion. Therefore, along with other aspects for development in the field of agriculture, the field of research and exploration of new sources of energy is also the focus of interest of agro-researchers. Sun is an eternal center of energy, where solar fuel is being converted into solar energy by the fusion process since the birth of solar system. The use of solar energy is of central importance to meet energy demands. Fortunately, the blessings of Almighty Allah are that the solar energy has many features, which can be used directly and indirectly. For ensuring a sustainable future and addressing the increasingly serious impacts of climate change, especially global warming, developing countries are urgently seeking to switch from traditional energy to renewable energy [1]. Solar energy is abundant, free, and non-polluting; hence, it is considered one of the most competitive choices of all the renewable energy choices [2]. The agricultural sector also uses different methods to take advantage of these different features of solar energy for different applications. For example, the thermal properties of solar energy are used to dry foodstuffs, vegetables, crops, and meat, etc., which is a direct use of it. Drying of these goods is done by direct use of solar energy, but it needs long time which is a waste of time, also it is more likely to be contaminated with dust, malnutrition, food, insects and flies. In addition, unpredictable climate changes, such as wind and rain, can cause serious damages. In modern times, a variety of solar dryers are used for such direct use of solar energy. For the last few decades, solar energy has been used in various ways after converting it to other forms of energy such as chemical energy and especially electrical energy for various services and research has been given much importance for improvement of the conversion methods to capture solar energy. The conversion of solar energy into electrical energy "soletrical energy" has greatly increased the use in various spheres of life. Much research is being done in the field of agriculture for use of soletrical energy. And its use is sure to not only alleviate energy shortages for a variety of purposes, but is also a cheap, easy, unlimited and widely available source of energy on the whole earth throughout the year. The use of this soletrical energy for water pumping, lighting, pesticides spray, and various types of machinery such as tractors, etc., is being innovated day by day in agriculture. But utilization of solar energy in agriculture in this way is still limited, lot of awareness and research is required to be beneficiary of this blessings and hope of future energy requirements.

This chapter includes the awareness of solar energy and potential role of solar energy in the development of the agricultural sector and agroindustry. To avail the benefits of solar energy and consume it to perform various agro-affairs through different applications are discussed in this chapter. Moreover, research done so far to improve the agricultural sector through its use in various ways is also covered in this study. This study will provide coordination between energy researcher and farmers to utilize solar energy with its different characteristics.

1.1 Solar energy

The solar energy is a solar or sun fuel generating at the sun spreading everywhere in the universe and all planets of solar system rely on it. This is also named as clean energy, green energy, alternative energy or sustainable energy. This is the origin of most of the energy sources on earth. The solar energy coming from the sun is in the form of radiations of a range of values. Most of solar energy is captured in the interstellar space and only a small part of solar energy reaches on the earth. But this small quantity of solar energy reaching on earth surface in only one hour is still higher than the energy generated by all other available sources including hydro, nuclear and fossil fuels etc. At the sun about 4,000,000 tons of solar fuel is converted into energy per second, which is so huge comparatively to the conversion ability of a

1000-MW nuclear power station on earth having the capacity of converting only 0.130 Kg of nuclear fuel into energy in one year. The earth receives about 1366 watts per square meter from the sun, generally which varies with latitude [3]. All the accumulated energy in any form in the earth is because of solar energy, i.e., fossil fuels consisting of natural gas, oil and coal depends directly or indirectly on it. Moreover, all energy reserves are nearly equal to solar energy got from sun only in 20 days. Solar energy is such a fuel which will be lost with the universe. Utilization of solar energy is not a new concept or thinking, human being is utilizing this energy since its birth. Solar energy consists on a spectrum of range of wavelengths of radiations having different energies but most of the solar energy reaches on the earth surface consists on visible light and infrared light as shown in **Figure 1**. Although ultra violet part of this solar energy spectrum is higher in energy strength but lower in intensity. The more intensive part of this spectrum lies in visible part ranging from ~400 nm to 700 nm. Each part of this spectrum has its importance related to applications, i.e., white light for visible purpose lies in the part of solar spectrum 400 nm to 700 nm.

1.2 Assessment of photovoltaic power potential

The assessment of solar energy available in a particular region of the earth is necessary to further harness the source. Because, sustainable and affordable energy supply has strong correlation with the socioeconomic development of any country [5, 6]. Therefore, G20 countries that includes Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, the United States, and the European Union consumes about 80% of the total energy. Most of the global energy requirements are meet from nonrenewable fossils fuels such as coal, oil and gas. Only, 9% energy requirements are meet by wind and solar energy globally for electricity generation. The global power mix trends of the year 2019 reveals that the increase in solar energy among other renewable sources is 24% i.e., about double than the addition of wind energy in a particular year [7].

The estimation of solar energy potential depends on many factors among the land cover is a major factor in the selection of a suitable area for solar PV generation installation. Direct solar resource is either estimated based on the Diffuse Horizontal Irradiance (GHI) or the Direct Normal Irradiance (DNI). However,

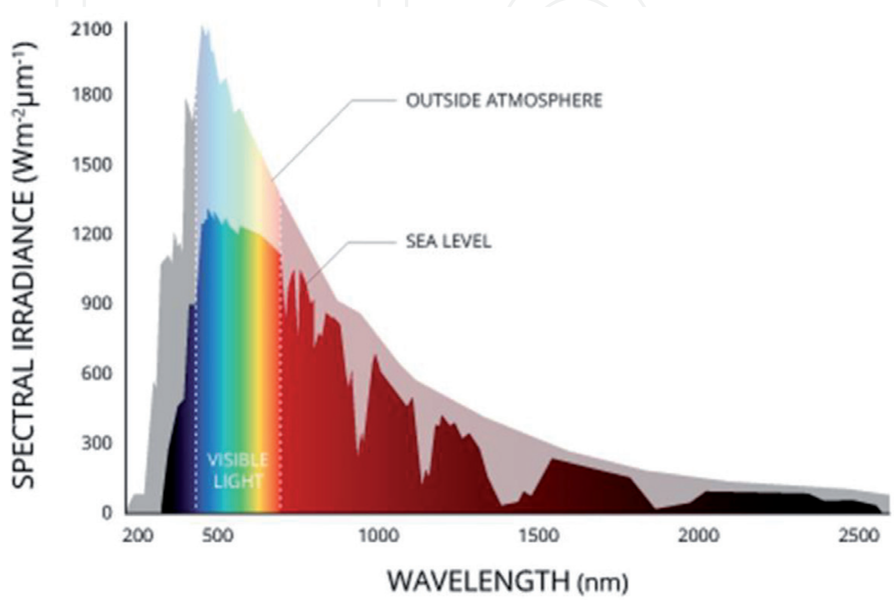

Figure 1.
Solar radiation spectrum [4].

actual solar potential for a region should be assessed by considering geographic, technological and economic potential. Because all the energy reaching to the earth surface cannot be harnessed due to geographically restricted areas, technological limitations due to limited efficiency of solar modules and energy production cost. For example, technological development directly determines the efficiency of the solar power transition. Initially, the PV modules efficiency of monocrystalline solar cells was 15% in 1950 which has now increased to 28% and polycrystalline reached 19.8% [8]. Similarly, governmental policy plays an important role in solar PV generation operation. Therefore, for a comprehensive solar energy potential analysis technological potential, economic potential, and other factors should be considered in addition to the solar energy resource. Researchers are assessing the global solar energy potential by considering these factors. For assessment of the solar potential of 147 countries, the data of Global horizontal irradiance (GHI) air temperature, PV power production potential, Index of seasonal, levelized cost of electricity and economic was used in GIS environment. In addition, some auxiliary data like terrain characteristics, built-up areas, population clusters, tree cover density, land cover and water bodies etc. data was also used to assess the technical potential for solar energy.

The Global Solar Atlas is prepared by Solargis that provides the easy access to solar resource and photovoltaic power potential data globally. Global Solar Atlas 2.0, is a free, web-based application developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). Maps and GIS data are available for 147 countries on online resources (**Figure 2**).

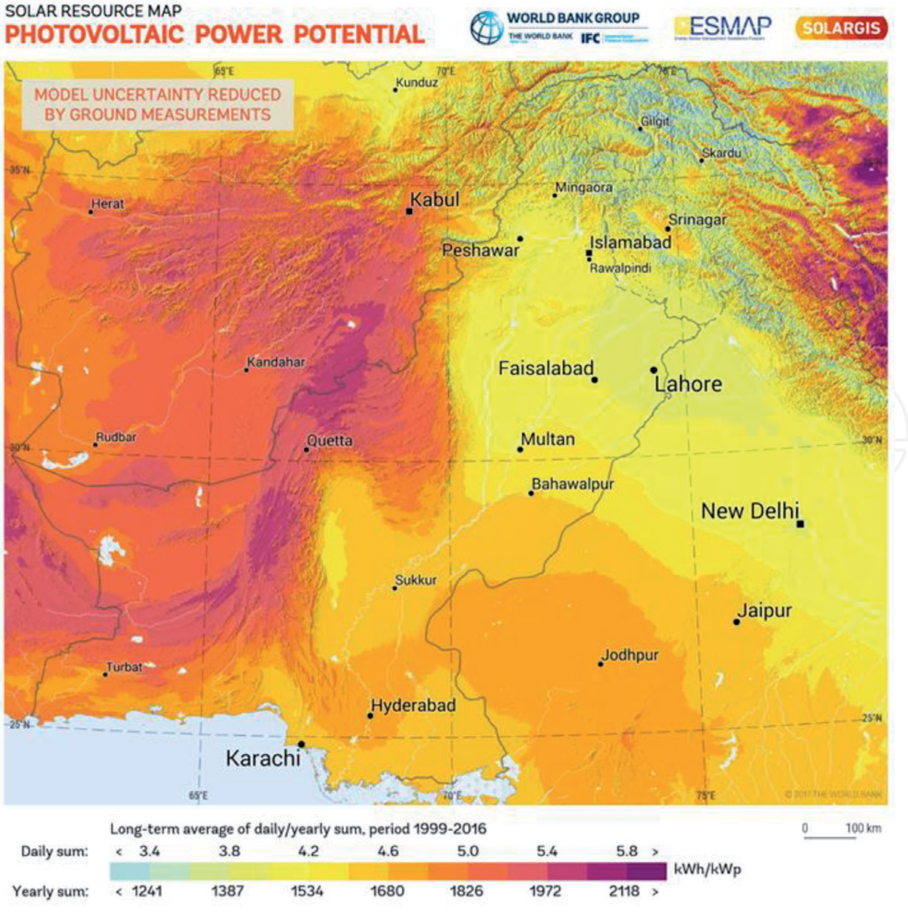

Figure 2.
Solar power potential of Pakistan, https://globalsolaratlas.info/map [7].

The direct solar radiation, having potential of concentrated Solar Power (CSP) and photovoltaic (PV), ranges 5–5.5 KWH/m^2 /day for more than 300 days a year in Southern Punjab. The range in almost all areas of Punjab is 4–6.5 KWH/m^2 /day [9].

2. Scope of solar energy

Climate change is caused by the human's activities relating to energy uses, as carbon dioxide emission is increasing 1.3% annually for the duration of 2014–2019 [10]. Meanwhile, the energy sector taking the responsibility by supporting the policies in technologies and renewable technologies are leading the energy market globally for new energy generation capacity [10]. The year 2020 was a best year for photovoltaic and wind energy market with almost 115GW and 71 GW were added respectively [11, 12]. However, the pace of world's energy transition from traditional fossil fuels to these renewable technologies is far from alignment with Paris Agreement [10]. Although 90% of total electricity energy will be generated with renewable supply by 2050, for which 63% of total electricity needs will be supplied by wind and solar photovoltaics [10]. Solar photovoltaic installed power generation would reach to 14000 GW by 2050 [10]. Solar energy and solar photovoltaic are attractive candidates to fulfill the electricity needs for domestic utility and to run electric vehicles, also cooling and heating requirements.

2.1 Solar technologies

Solar technologies are in common use in simple forms like drying in sun and basking in sunshine since the birth of earth, and people are using some other simple solar technologies including solar water heating and solar cookers by consuming direct sunshine or solar energy. The global solar PV market has rapidly grown by 50% over the past decade [13]. During 2011, more than 29 Giga Watt (GW) new solar PV industry was installed worldwide which was 70% increase compared to the year 2010. Global PV capacity exceeded 69 GW with 70% installed in European countries. During 2017, close to 73 GW of solar capacity added worldwide [7]. Since last few decades, solar energy is being used by converting it into electrical energy with the help of devices called solar cells or photovoltaic devices. These devices are now set up on the hope to fulfill the energy needs and becoming a technology ladder. Another energy converting device is thermocouple which consists on a pair of semiconducting wire with one end connected and other ends are free and when connected end side heated with solar energy than a potential difference is appeared across free ends. Under ordinary sun light efficiency of thermocouples is very low but concentrated sun energy can increase the efficiency of thermocouples. Solar cells convert directly sunlight energy to electricity while thermocouple convert heat from sunlight into electricity [3]. A schematic flow chart of solar energy utilization via different ways is shown in **Figure 3**.

2.2 Solar Technologies in Agriculture

Technology at agricultural farms is changing and improving rapidly. These developments are improving the farm machinery and equipment, farms facilities and buildings, both for crops and animals at farms. As we all know solar energy is the largest and cheapest energy resource on earth. Solar energy can easily fulfill energy provision and supply at agriculture farms. Various solar energy absorbing devices and systems have been developed and are in work for agricultural

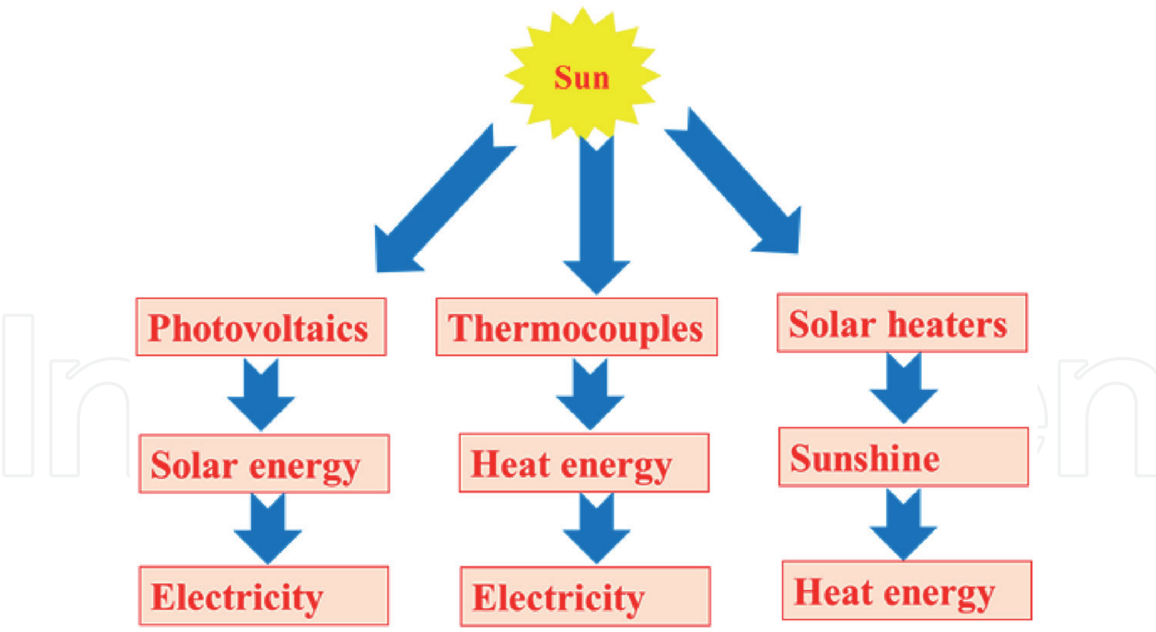

Figure 3.
Utilization of solar energy via different ways.

applications. This includes solar thermal and electric devices such as solar spraying machine, solar greenhouse heating, solar crop dryers, solar water pumps, ventilation for livestock, solar aeration pumps, solar electricity etc.

- **Solar PV operated water lifting/pumping system:**

Solar PV pumping systems are quite helpful to operate the pressurized irrigation system. Specifically, solar pumps may be useful as water lifting devices in irrigation canals and also to evenly distribute water in those areas where traditional water systems could not have access, such as in the elevated hilly lands.

- **Solar spraying and seed sowing machines:**

The solar pesticides sprayer machine is designed for small farmers to improve their productivity. They can easily carry and handle these machines with rechargeable batteries and direct solar illumination options. Mostly pesticide spraying activity is done in the day time, so these spray machines could be used by directly capturing solar energy, which prevents the installation of batteries in these machines. Also, solar powered seed spreading and sowing machines introduce a simple and convenient way of seeds spreading and sowing to small fields, and also in those areas where traditional machinery could not be available. It will be more useful for small farmers and agrarian society. Thus, solar-powered automatic pesticide sprayer and seed sowing machines will facilitate farmers to leave the heavy-duty machines and also provide easy access to work in remote areas of the countryside where general machinery is not readily available [14]. Today radio frequency controlled solar sowing machines are also designed to provide farmers eco-friendly sowing and spreading of seeds. These RF solar controlled sowing machines work with the help of blue tooth, which sow the seeds at controlled depth and distance between seeds [15].

- **Solar crop drying:**

One of the applications of solar energy in agriculture is a solar drying system which is based on variety of options. Solar dryers are available different shapes and structures. Different types of solar dryer are available for various applications, which is used for drying of agricultural products like potatoes, grains, carrots and mushrooms. Depending upon heating arrangement active dryers and passive dryers are two main types. In active solar dryers, external means are used for solar energy heat transfer, like pumps and fans are used for solar energy flow from solar energy collector to crops drying beds, while passive dryer heat is circulated in natural way by wind pressure or buoyancy force or with the combination of these both [16].

- **Solar greenhouse heating:**

Generally, greenhouses around the world use sunlight to meet their lighting needs for photosynthesis, but they are not ready to use the sun for heat. Rather, they rely on conventional energy sources, such as oil or gas, to produce greenhouse temperatures for winter plant growth. However, solar-powered greenhouses (SGHs) are built to use solar energy for both heating and lighting. Also, these greenhouses reduce the damage caused by excess solar energy from the ambient to the greenhouse during hot sunny periods. A controlled environment is available in these SGHs.

- **Solar powered tractors:**
  Tractor is a fundamental machinery in agriculture, which made the farming much easier and increased the crops yield and production. Tractor converted the agriculture farming into agroindustry by performing lot of functions with the help of variety of tools and equipment. Usually, tractors consume oil to run and work, which increases the budget of farming also cause the pollution in atmosphere by producing carbon dioxide during combustion. Solar powered tractors became good option which could work directly under the sun by consuming solar energy through PV system in day time and also could continue working in night time with the help of utilizing energy stored in batteries. Although solar powered tractors are in preliminary stage of development but results are hopeful for bright agriculture future [17].

2.2.1 Solar machinery and tractors

Tractor is a most important and central technology and machinery at any agricultural farm. A tractor provides power to perform many tasks, including plowing, seeding, planting, fertilizing, spraying, cultivating, and harvesting crops at farms. Tractor are also used for transporting crops and materials at farms and market. Modern agricultural developments and to increase production to accomplish the needs of human being best farming can be done by using multifunctional compact tractors. Tractors have great social and economic impact on agricultural activities.

Commonly tractors use diesel oil as an energy source. Solar machinery and tractors use solar energy converted in to electricity. One way of using solar energy in form of electrical energy is by using solar panels fixed on machinery or tractors, a schematic diagram is shown in **Figure 4**.

Another way of using solar energy is converting it into electricity at solar power station and charging the batteries of tractors. But in this way energy stored in batteries of a solar electric tractor is very small and a tractor could not work for a long time with a single charging of batteries at solar power station. A challenge for solar electric tractors working in the fields is that the energy density of batteries is low which reduce the working efficiency of tractors. Also charging time of batteries is comparatively is large so exchangeable batteries idea could be used to run tractors for long time [18].

2.2.2 Solar irrigation

Irrigation is a basic need for the crops to grow that play to meet the global food demand. Irrigation demands for crops can be meet by three different sources

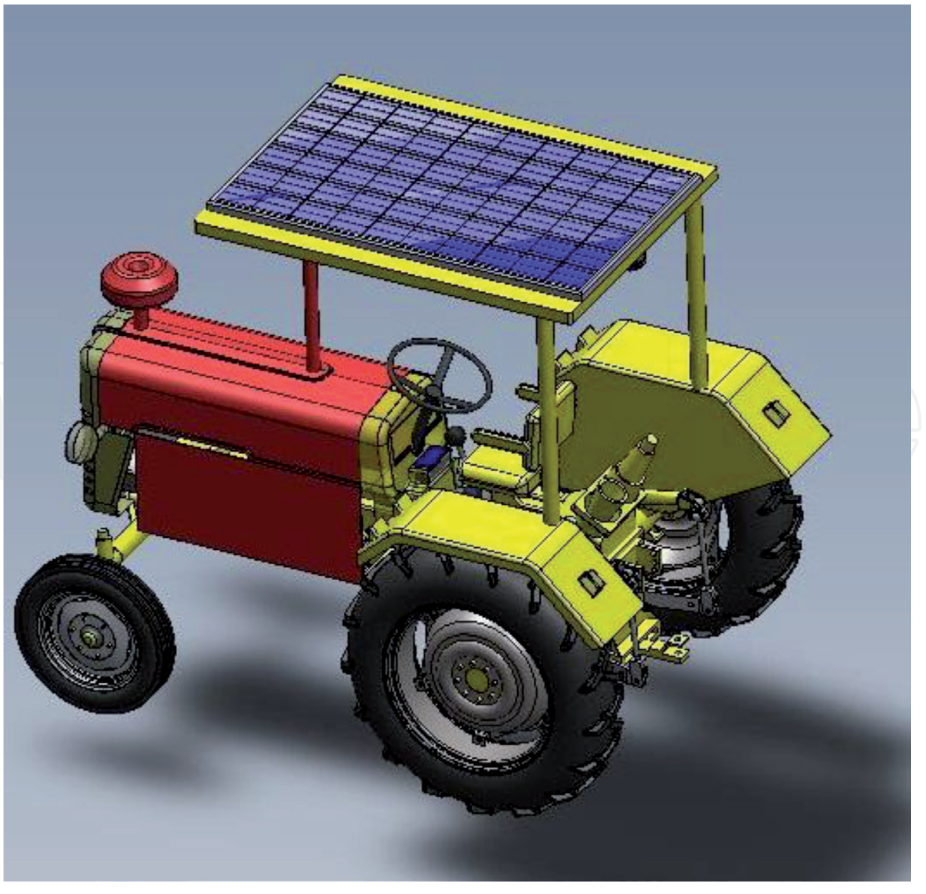

Figure 4.
Schematic diagram of solar powered tractor [18].

categorized as green water, blue water and non-renewable groundwater. Green water refers the use of effective precipitation for crop growth that is stored in the soil root zone and blue water to the surface freshwater available in rivers, lakes, reservoirs and the groundwater. Agriculture sector is the major water consumers in the world and accounts for approximately 70% consumption of fresh water [19]. An estimated 67% of the world's crop production still comes from rainfed agriculture [20], where crops requirements are fulfilled from the water held in the root zone of soil. Moreover, the large solar energy potential i.e., more than 6 kWh/m^2 and existence of underground water potential make the solar irrigation well suited for arid and semi-arid regions.

In Asia, especially Pakistan, China, India, and the United States account for 68% of fresh water withdrawals for irrigated agriculture, out of which ~34% is consumed by India only. In Pakistan and India, about 37 million electric and diesel tubewells have been installed in the irrigated area. Therefore, there is great potential to convert these tubewells on solar energy. In Pakistan, there is a 2,900,000 MW solar energy potential due to its geographical location with more than 300 sunshine days, 26-28°C average annual temperature and 1900–2200 kWh/m^2 annual global irradiance [9]. The southern part of Pakistan where annual Direct Normal Irradiance (DNI) is above 5 kWh/m^2/day which is ideally suitable for photovoltaic technologies for irrigation. In Pakistan, about 1.1 million tubewells exist out of which 0.8 million are diesel operated and 0.3 million are electric. The use of tubewells have increased in Pakistan because the surface water supplies are not sufficient to meet the irrigation requirements. Therefore, significant withdrawal is done from the groundwater resources that ranks Pakistan at 4th in the world. Overall, at global scale, estimated groundwater abstraction ranges between 600 and 1100 km^3 yr.$^{-1}$ [21]. For the year 2000 the reported abstraction rate and estimated groundwater depletion per country with range of uncertainty of India, United States, China and Pakistan is given in **Table 1**.

Country	Abstraction (km^3 yr^{-1})	Depletion (km^3 yr^{-1})	D/A (%)
India	190 (±37)	71 (±21)	37 (±19)
United States	115 (±14)	32 (±7)	28 (±9)
China	97 (±14)	22 (±5)	22 (±9)
Pakistan	55 (±17)	37 (±12)	69 (±48)

Table 1.
Reported groundwater abstraction rate and estimated groundwater depletion per country with ranges of uncertainty for the year 2000 [21].

Significant withdrawal of groundwater shows the importance and the potential of solar energy in irrigation as a substitute of fossil fuels and ultimately providing an environmentally sustainable solution to address the climate changes. Therefore, solar based irrigation can provide a sustainable solution for groundwater pumping which otherwise requires expensive and unreliable energy. Solar powered tubewells have several advantages over traditional systems. For example, diesel or propane engines require not only expensive fuels but also create noise and air pollution. Moreover, the overall initial cost, operation and maintenance cost, and replacement of a diesel pump are 2–4 times higher than a solar photovoltaic (PV) pump. Therefore, solar water pumping system is a cost effective, environment friendly and have low maintenance solution that makes it ideal system for pumping groundwater particularly for remote locations.

Solar energy can also be used for pumping water from the storage ponds to irrigate the crops. However, solar irrigation is coupled with the High Efficiency irrigation Systems (HEIS) for potential use of available water. Because, it is believed that an economics of solar-powered pumping systems can only be justified, if it is properly designed and linked with high-efficiency irrigation systems such as drip, bubbler, sprinkler or bed and furrow irrigation methods. For example, recently, in Pakistan, solar coupled drip irrigation systems have been installed on 21,255 acres during three years (2016–2017 to 2018–2019) [22]. Moreover, promotion of high value Agriculture through HEIS envisages installation of solar systems on 20,000 acres, especially the water scares and saline groundwater areas. Therefore, there is great potential to adopt the innovative solution for the areas where the solar systems have been installed due to limited water availability and saline areas. Moreover, there is increasing trend in farmers that can be observed to use these solar pumps for surface irrigation in the plain areas. Moreover, these solar pumps are used to irrigate limited lands of farmers. Therefore, after fulfilling the irrigation requirements the energy can be used for other purposes at farm level. However, there is little evidence to use this available energy where option to connect with the grid is not available. Grid connected solar pumping system is being considered economically viable in the rural areas. For example, a study shows that Levelized Energy Cost (LEC) of the grid-connected SWPS through Life Cycle Cost (LCC) is 4–54% less than the off-grid system depending on the size of the pump [23]. Therefore, it is necessary to provide the alternate utilization of the available energy of solar pumping system for better capacity utilization and economic viability, especially for larger solar pumping units.

Solar water pumping is based on photovoltaic (PV) technology that converts sunlight into electricity to pump water. The PV panels are connected to a motor (DC or AC) which converts electrical energy into mechanical energy. This mechanical energy is used to operate a pump to pump out the water from the ground. The capacity of a solar pumping system to pump water is a determined on the basis of head, flow, and power to the pump. The water pump will draw a certain power which a PV array needs to supply. A typical solar pumping system comprise of a pumping unit, solar panels, inverter, PV mounting structure and foot valves etc. The details of the solar pumping system components and its design can be found in literature [24, 25]. Solar water pumps may be categorized as submersible, surface, and floating water pumps. Submersible pumps are preferred to extract the required quantity of water from deeper depths. However, surface pumps are useful to extract water from the shallow groundwater aquifers. The temperature beyond 25°C decreases the solar output. The dust accumulation also decreases the PV panels efficiency. If a sprinkler cleaner/cooler is not installed then it requires the additional 25–30% PV panels to accommodate the dirt and temperature effects. However, it depends on the air quality conditions of the region. The use of a sprinkler for dust removal and reducing the temperature effects has been found to improve PV solar panel performance by 7–9%. Moreover, solar powered pumping systems efficiency can be increased up to 20% by manually tracking the solar panels. The use of automatic sun tracking improves the pump efficiency but increase the system cost considerably [25].

2.2.3 Solar dryer

Preservation of crops to keep them without rotting and decomposition for long time is essential activity in agriculture. It is required to keep them fresh and nutritious to carry them from fields to consumers. This process of preservation may be from domestic to industrial level depending upon farm size and crops distribution strategies. Different preservation methods include freezing, canning, drying and dehydration. Among these, drying of crops and food is simple and easy method which can work at any temperature and environment. Drying is an easy way to remove moisture from crops and food products in order to keep them with desired content of moisture. It also extends the storage life and enhancement of quality for long time. Basically, drying involves some heating process to vaporize moisture from crops and food products kept in dryers. In earlier time, drying was done by putting crops in open sun, but this method was more likely to be contaminated with dust, malnutrition, food, insects and flies. Thus, from last few decades, many sophisticated dryers are used to remove moisture from foods and crops. Main parameter to control is the temperature of crops which is done by providing certain amount of flow of heat. This heat can be provided by hot air blow through the crops, which may be very costly set up. Fortunately, solar radiations are better source of heat, and solar thermal energy can be used for drying purpose to dry crops, foods, vegetables, grains and any other crops' products. These solar dryers are made in different shapes, sizes and structures to enhance their activity. In these solar dry Different types of solar dryers are in practice for various applications depending on method of heat transfer, their geometry and structure, such as [16];

i. Active dryers

ii. Passive dryers

iii. Integrated dryer

iv. Distributed dryer

v. Mixed mode dryer

vi. Solar cabinet dryer

vii. Green house dryer

Most of these solar drying systems either active or passive can be identified in further three sub-classes of solar dryers [26];

- Direct (integral) type
- Indirect (distributed) type
- Hybrid (mixed mode) type

A most common solar dryer is based on racks design attached with a solar collector, which can collect solar energy in higher amount and can achieve higher drying temperature in result. Solar collector could be a simple black box managed with a transparent cover. Natural convection or an ordinary solar fan could be used to flow the hot air from solar collector to the crops placed on the racks as shown in the **Figure 5**. In agroindustry for large scale applications mechanized solar dryer is used, which is an active dryer type, in which solar heated boilers are used to heat the air, and forced to by fans to approach the crops' beds [28].

2.2.4 Solar fertilization

Fertilizers have central role in the modern agriculture to increase the yield of crops. For fertilizers production ammonia is one of the most important chemicals, which is produced through a well-known Haber-Bosch thermochemical process. By this process 140 million tons of ammonia is being produced per year. This ammonia production consumes large amount of energy nearly 2.5 exajoule per year. To run the process hydrogen is obtained from methane which results 340 million tons of CO_2 per year [29]. Due to huge costs for establishment of plants, centralized production of ammonia with <100 plants worldwide are in function. For better utilization of fertilizers decentralization of traditional fertilizers is compulsory. To overcome these hardens solar energy-based fertilizations is a good option. Solar energy can convert dinitrogen into such nitrogen products which became nutrients for crops. Such

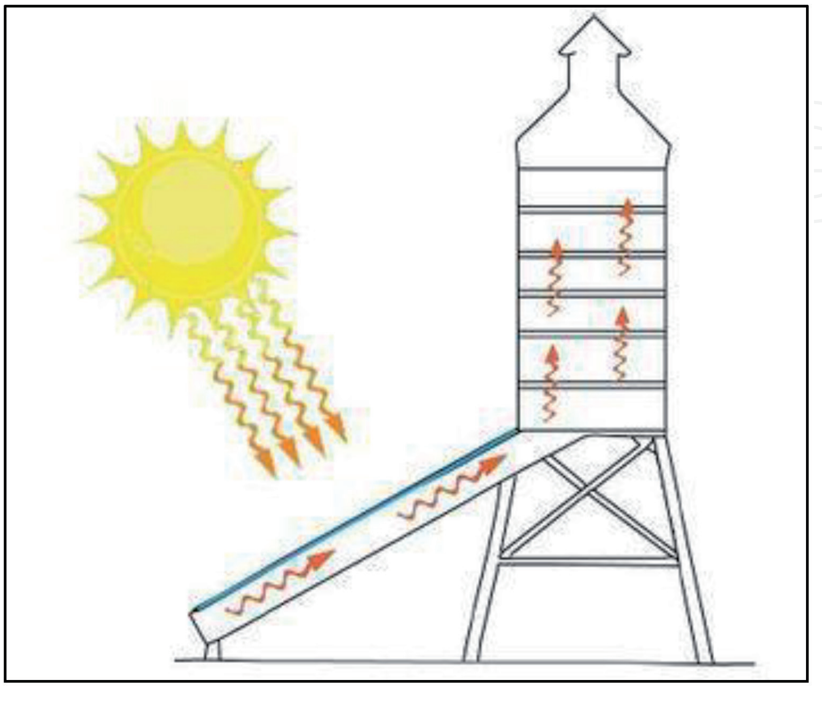

Figure 5.
Indirect solar dryer based on solar collector, racks and chimney [27].

nitrogen products produced by the solar energy are called solar fertilizers. The possibility of producing solar fertilization at country's level may be able to reduce cost of nitrogen based nutrient production by minimizing costs of transportation across the international borders. Also, it will provide employment to jobless workers at country level. Organizing solar fertilizers in developing countries will improve agriculture in remote areas of each country and farmers could become comfortable and satisfied. Above all solar fertilizers will reduce and cut off methane consumption and carbon associated threats to environment. Solar fertilization production is simply based on solar energy, water and nitrogen from air to produce nitrogen-based fertilizers near or at the farms, which also an eco-economic advantage. Management of these solar fertilizers will reduce ammonia use. A study revealed that 250 petajoules of energy/year could be saved by reducing10% use of ammonia or urea-based fertilizers [30].

The developments of solar fertilization need good and reliable strategy for dinitrogen fixation at ambient temperature. These developments can be made by the help of bioengineering, and catalysis research under precise conditions and approach [31, 32]. Such fixation of nitrogen in solar fertilizers can be accomplished by efficient electrochemical and photochemical natural process, which are expected to have significant lower concentration of nitrogen. These solar fertilization with lower concentration is characteristically safer and enable better nutrient managing [33]. The solar fertilizer production is similar in some aspects to the solar hydrogenation production, as light absorption, catalysts' reaction and energy transfer from absorbent material are involved in both processes. However, solar fertilizers would be integrated with agriculture farm infrastructure and for different application. Some of the key aspects of such processes required for production of solar fertilizers include capture or absorption of solar energy, catalysis reaction and separation process for production of solar fertilizers [34–38]. In this whole process of solar fertilizer production sun energy from sun light or solar fuel is absorbed by solar cells and/or photocatalytic particles which provide a potential to initiate an electrochemical reaction to convert dinitrogen, oxygen and water in to nitrogen products like nitrates and including ammonia in aqueous solution schematically shown in the **Figure 6**.

- **Absorption of solar energy**

  As production of solar fertilizers is based on absorption of utilization of solar fuel by solar energy from sun and converting it to chemical energy by two

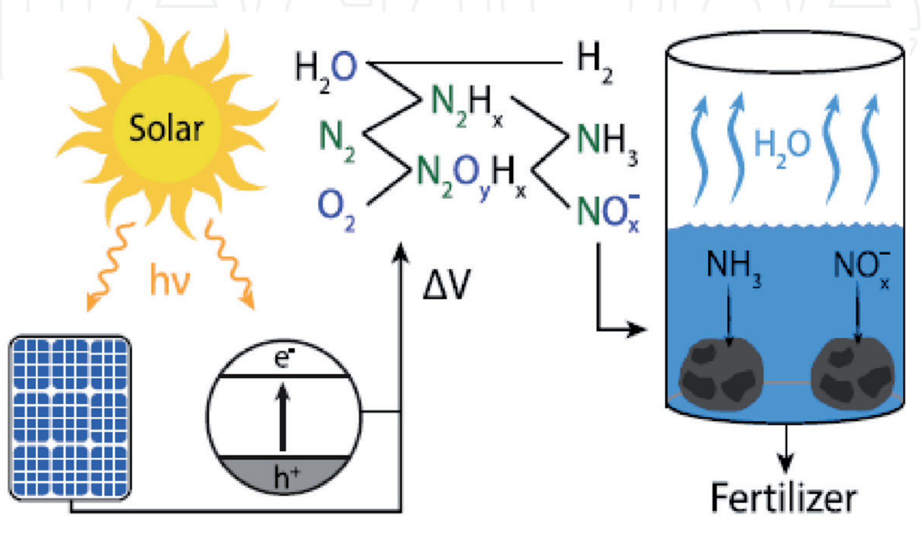

Figure 6.
Schematic diagram of solar absorption, catalysis reaction and separation process for solar fertilizers' production [29].

ways; *i, direct absorption* of sun light in a photocatalysis process (photochemistry), and *ii, indirect absorption* of sun light in a PV-electrolysis (photovoltaics and electrochemistry). A third hybrid approach (direct + indirect) is photoelectrochemistry in which electrical biasing is required absorption of sun light [37, 38]. These solar fuel technologies have good motivations for production and utilization at decentralized remote locations or at agricultural sites as compared to centralized huge industrial production.

- **Catalysis reaction**

After absorption of the solar energy the conversion of molecular dinitrogen, oxygen and water is the central process of production of solar fertilization. For this a catalyst is required to dissociate triple bond of dinitrogen at favorable temperatures. Most approaches for this nitrogen dissociation have focused on chemical reduction of nitrogen to produce ammonia. For nitrogen reduction one of the best catalysts is based on carbon which shows an efficiency of 5% for electrical-to-ammonia in an aqueous solution [39].

- **Separation process for production**

The chemical separation process for generation of reactants and convert the effluents to a fertilizer is an important step of solar fertilization technology. Because nitrates, ammonia and urea are water soluble which make a challenge for separation and concentration of products. Aqueous electrolytes are used in many electrochemical techniques for this separation process. Generally, these separation process require sophisticated techniques and processes for particular catalyst. This separation can be moderated with supported catalysts [40].

2.2.5 Solar dairy farms

Milk value chain from small dairy forms to market could be improved by using solar cooling technology. Milk cooling technology is costly and mostly small dairy farm (SDF) owners have lake of facilities for this purpose. Usually, these SDF owners are associated in dairy cooperatives which are responsible for managing to collect the milk from member owners and then supply collected milk to market or dairy plants. Lake of facilities of milk cooling in hot weather under warm climate conditions can lead to high bacterial contamination in milk. Solar dairy farming is based on solar technology.

- **Solar freezers or refrigerators at dairy farms**

An emergency and simple way of saving milk is by using ice or freezers for cooling purpose. But, most of SDF exists in remote areas where transmission lines are not possible. In these areas solar powered freezers is a good option. Ice produced in these freezers could be used in milk cans for a better and effective cooling. Different institutions are working for developments of solar dairy farms specially for milk cooling. At Institute of Agricultural Engineering of the University of Hohenheim a solar milk cooling system has been designed which is based on the utilizations of ordinary milk-cans in Tunisia. In these designed solar dairy farms solar freezers are being used to produce ice for milk cooling. These milk canes can preserve milk for six to sixteen hours depending on amount of ice put in milk cans [41]. These solar dairy farms have great potential to improve dairy values and more efficient in remote and off grid areas by using environment friendly and clean energy. **Figure 7** dairy farmers' comments and observations on the impacts that those farmers experienced due to use of solar technology [41].

- **Solar heating for steam generation**

  Sterilization process is an important activity at dairy farm for which low temperature steam is used. Parabolic trough collectors are commonly used to generate steam and other high temperature applications. At dairy farms solar water heater could be installed to raise the water temperature from 27–67°C [42]. A lot of furnace oil and other fuels could be saved by using solar heating at dairy farms.

2.2.6. Solar greenhouse production

All crops at agriculture farms needs proper environment including moister in air, temperature and light intensity. These parameters have great impact on for crops growth and yield, but we have not any control on them. All these parameters are controlled and determined by the nature, which are never remain constant and all time favorable. A lot of variations exist in environment and weather, sometime favorable and sometime very bad for crops. For continuous production at agriculture farms a favorable environment and conditions are required. Such a proper environment and promising conditions could be provided at solar greenhouse. Solar greenhouse is a covered structure where crops and vegetables are grown under favorable climate conditions and proper environment for the growth and production of plants. In greenhouse a controlled sunlight is managed for photosynthesis and also an adequate temperature is maintained suitable for plants whether outside is hot or cold. Vegetables could be grown throughout the year in these solar

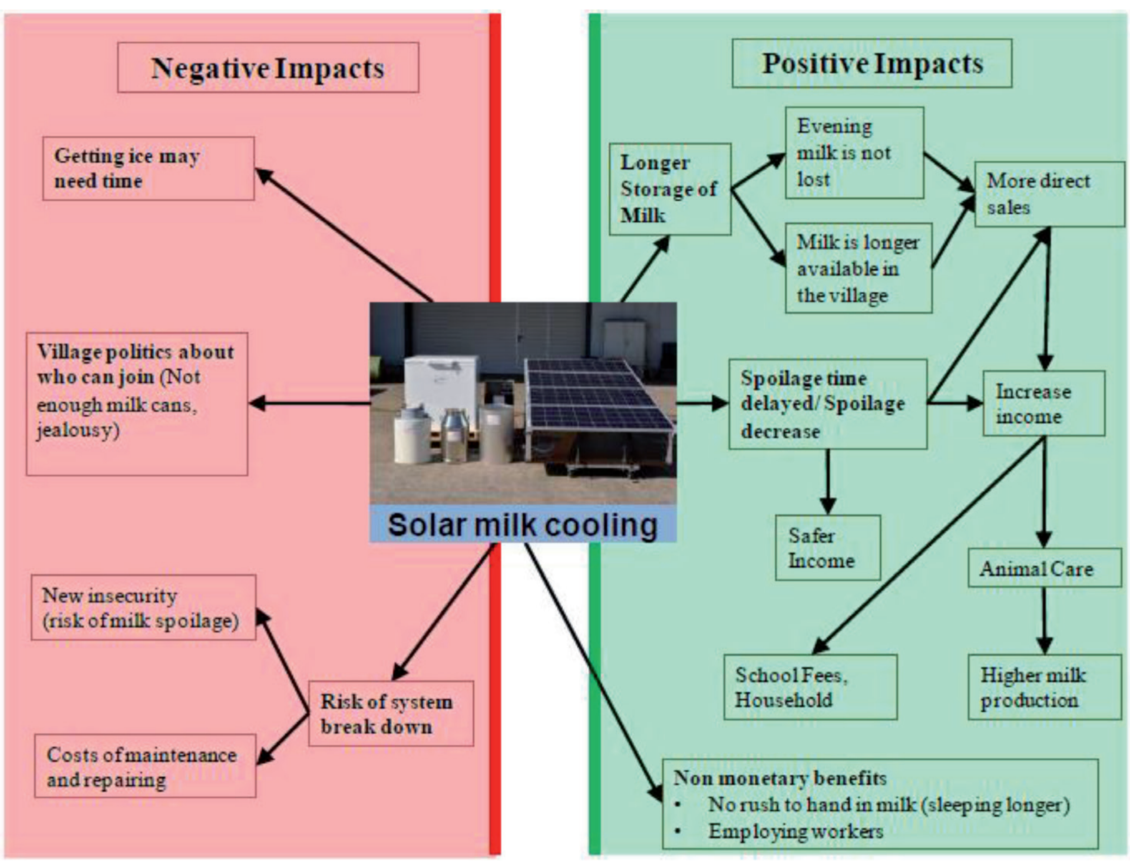

Figure 7.
Effect of small-scale solar milk cooling [41].

greenhouses. In these greenhouses solar energy is collected and stored in many ways and therefore they differ in designs. There are many parameters that effect the growth of plants in solar greenhouses. Among these parameters' intensity of sunlight, temperature of greenhouse, temperature of surroundings, humidity of greenhouse and surroundings, nutrients and carbon dioxide etc. Greenhouses provide such an environment to plants that they can grow in controlled conditions and optimized values of all these parameters.

Sunlight intensity

Sunlight, water and carbon dioxide are essential ingredients to produce carbohydrate and oxygen in photosynthesis process occurred in the chlorophyll of chloroplasts of plant cells. Initially chloroplast is responsible of absorption of sunlight and then for following chemical reaction.

$$H_2O + CO_2 + Sunlight \rightarrow Oxygen + Carbohydrate \quad (1)$$

These carbohydrates are used in the growth of the plants. In the respiratory process the energy is released which is used for the growth of plants and fruits. Better control of sunlight is responsible of efficient photosynthesis process and carbohydrate production. Sunlight intensity varies from beginning of day to time of noon from 0 to 150000 lux respectively. It also varies for weather difference like in cloudy days light intensity goes lower and some types of plants could not grow appropriately. For low and high sunlight intensity level, the photosynthesis process very much effected and plant's growth and yield are limited. Sunlight intensity is different required for photosynthesis in different plants like cucumber can grow in high intensity of sunlight, while tomato, lettuce and carrot need lower intensity of sunlight. Light intensity can be increased in the regions where light intensity is lower by different methods like by painting the walls and roof of greenhouses. Moreover, additional lighting may be required in the darken days to increase the light intensity as well its duration. For this additional lighting different types of lamps are used which are powered by solar cells.

- **Temperature of greenhouse**

Other than sunlight temperature is another parameter which should be optimum for biochemical reactions in the different types of plants. Temperature of plants surroundings and soil is very much dependent on sunlight intensity, humidity, air velocity and carbon oxide in the greenhouse. Temperature may affect different activities like food and water in root system, transportation of minerals in stems and leaves, and photosynthesis process. Also, for different stages of development of plants like germination, growing, flowering, fruit beginning and fruit reap or maturation, different temperature is required as shown in **Figure 8**.

- **Humidity in greenhouse**

Humidity in greenhouse environment plays a vital role in plants' growth and health, as relative humidity ranging from 30 to 70 percent is perfect for plants' growth, while comparatively higher relative humidity i.e., more than 90 percent is harmful for plants' health as it provides a suitable environment to pathogenic organisms' growth. Solar greenhouses provide controlled humidity in the environment and surroundings of plants growing within the greenhouse, where generally relative humidity between 55 to 65 percent and environment temperature between 20 to 25°C could be controlled.

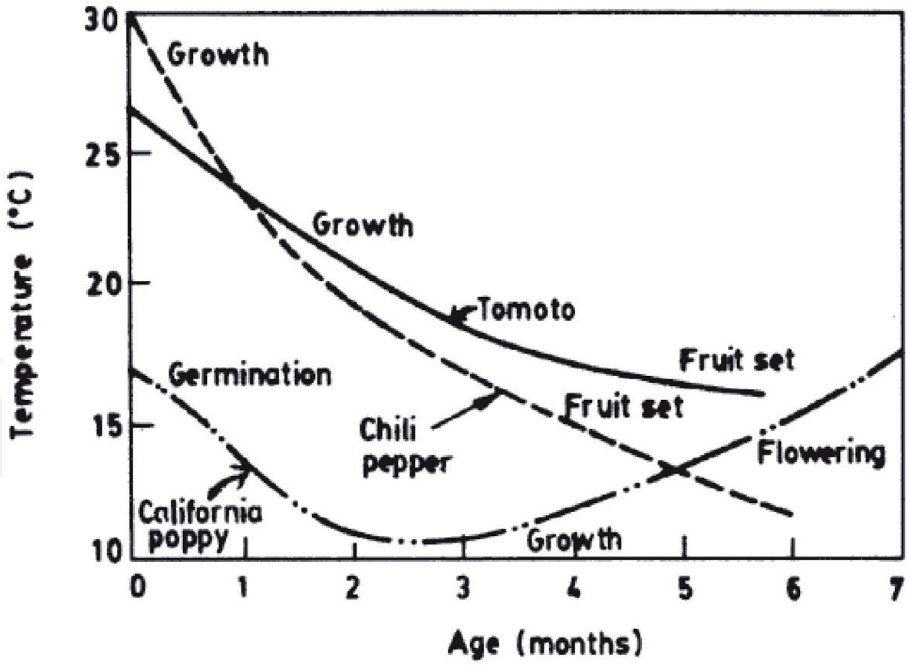

Figure 8.
Optimum temperature at night for growth and production [43].

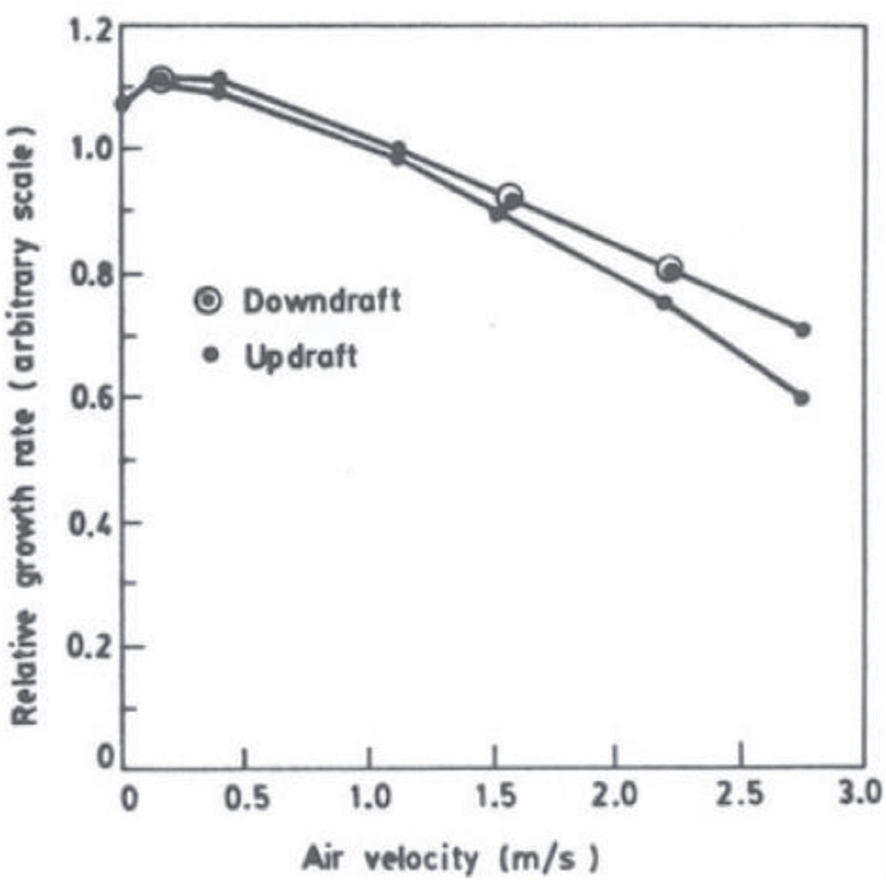

Figure 9.
Effect of air speed on leaf's growth [43].

- **Air transport and carbon dioxide**

Air transport affect the evaporation of water, availability of CO_2, cooling effects etc. so the growth of plants is affected. The air speed the plant's transpiration and

Figure 10.
(A) Shed type solar greenhouse; (B) Quonset solar greenhouse [44].

water vapors from plant to outside air, movement of CO_2 for photosynthesis. The air speed effects the plant growth as shown in **Figure 9** that the leaf's growth is effected by increase in air speed [43].

- **Solar powered greenhouse design**

The design of a solar powered greenhouse is different from an ordinary greenhouse in following few aspects;

- Glazing should be oriented in such a way that it can receive maximum solar energy.
- Use different heat storage materials to hold solar heat in winter.
- Use such glazing materials which minimize heat loss.
- Natural ventilation used for cooling in summer.

Two primary solar greenhouse designs are; i, Shed Type, & ii, Quonset Hut [44]. The orientation of shed type solar greenhouse is based on its length side along east to west direction as shown in **Figure 10A** [44]. Its north wall is painted or covered with some reflective material. The Quonset huts do not have any covered or insulated wall. Their structures are so that absorption of solar energy and distribution of solar heat is enhanced. Although insulation of solar greenhouse walls is required to minimize the solar heat losses, as shown in **Figure 10B** [44].

3. Conclusions

Technologies at agricultural farms are improving rapidly to facilitate farmers and bringing innovations in farming business. But this rapid increase of technology dependent agriculture farming required lot of energy resources. Also, the energy consumption increases the production cost of agriculture products. To overcome these energy and cost issues cheaper, easily and abundantly available energy sources are required. Fortunately, sun is a huge source of energy with abundant solar fuel on it, which can last till the life of earth. Thus, the solar energy is the largest and cheapest energy resource available on earth. Solar energy can easily fulfill energy need and supply at agriculture farms. Solar energy-based agriculture farms can easily accomplish energy requirements and reduce cost production. Utilization of solar energy at agricultural farms includes different types of machinery and equipment depending on task to accomplish by using different characteristics of solar energy like heating or converted in some other form of energy, such electrical or chemical. These applications include solar thermal and electric devices such as solar spraying machine, solar greenhouse heating, solar crop dryers, solar water pumps, ventilation for livestock, solar irrigation pumps, solar electricity etc. These solar energy equipped machineries also include radio frequency solar controlled sowing and spreading of seeds. Solar energy is a trustful and reliable source to compensate all requirements of energy for future.

Acknowledgements

This work was supported by Higher Education Commission Pakistan (HEC) through "National Research Program for Universities (NRPU)" project No: 10304/Punjab/ NRPU/R&D/HEC/ 2017 HEC is gratefully acknowledged for this support.

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