Enhancing agriculture productivity using Solar Irrigation Technology: Soy beans farming in Namibia.

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Abstract

An increasing global and African population has brought with it social ills and food insecurity. Due to these social problems, it has become increasingly important for farmers to innovate how they conduct farming activities in a way that allows them to produce more and better crop yields. Focusing on Namibia, a common problem related to farming is inconsistent irrigation water supply. The objective of this paper is to explore solar powered irrigation systems as a possible solution to provide sustainable irrigation water supply. Preliminary work was completed on five-hectares of Farm Lynkloof, Namibia in preparation to install a solar irrigation system. The irrigation system uses solar photovoltaic (PV) technologies to pump water for irrigation. Crops will be put under cultivation and water will be supplied by two irrigation systems; drip irrigation and sprinkler irrigation. The paper, through literature, analyzed the performance characteristics of solar irrigation systems and found that these systems are much cheaper to use than grid electricity and present a sustainable source of year-round irrigation water to increase agriculture productivity.

Key words: Solar Irrigation System; Photovoltaic Pump; Drip Irrigation; Productivity

1. Introduction

An ever-increasing African population and the accompanying food insecurity have made it necessary to increase farming and irrigation practices. This desire to boost agricultural yield has necessitated the need to appraise irrigation systems in their entirety with regards to management (Alicia, 2009). Irrigation improves the productivity of agricultural farmland and contributes to increased farmer incomes. A trend in developing countries, including Namibia, is that agricultural production depends largely on rainwater and is adversely affected when rainfall is insufficient especially during the summer periods. Solar powered irrigation systems have emerged as suitable alternatives for farmers in the present state of energy in Namibia. Irrigation would facilitate all year round arable farming. In addition, there is plentiful solar radiation available for most parts of the year, which will enable more water to be pumped to meet requirements. Solar energy is one of the most abundant and environmentally friendly sources of energy in the world, which makes it an ideal power source for irrigation pumps. Solar water pumping is based on photovoltaic (PV) technology that converts solar energy into electrical energy to run a direct current (DC) or alternate current, (AC) motor-based, water pump.

This paper analyses the performance characteristics of solar photovoltaic (PV) irrigation systems with the intention to use the information to implement a similar system to irrigate five hectares of soybean on a farm in the North-West of Namibia. Implementing a solar irrigation system will directly address the problem of inconsistent water supply to most farms in Namibia, which results in poor crop yield and invariably, food insecurity. There is a gap in the literature that exists on the use of solar irrigation systems for commercial agriculture in Namibia. As a result, the research attempts to close this gap by suggesting solar irrigation technology as an alternative tool to increase farmer productivity and thereby attain food security. The findings are based largely on the review of existing literature on the use of solar irrigation technology, some in regions outside of the African continent. Diesel irrigation pumps and solar photovoltaic powered motor-pump systems are compared in order to evaluate their economic feasibility. Solar photovoltaic water pumping systems have different configurations available and in the quest to select the most suitable system in a given situation, the user must identify performance factors such as efficiency-improving techniques.

The increase in oil prices and commercialization of PV technology has resulted in extensive research of solar irrigation systems. In principle, the most effective PV system is that which performs best with respect to the cost (lowest initial capital investment), pumping capacity (volume of water pumped per day) and system efficiency (productivity). The research revealed that diesel powered pumps are much more expensive to operate and maintain, which makes the PV powered pumps more feasible to employ due to their low maintenance and no fuel cost. It costs almost twice as much to replace a diesel pump as it does to replace a solar photovoltaic (PV) pump. The outcome of the research study is to use the findings to select, adopt and install a suitable on-farm solar powered irrigation system to supply consistent irrigation water for soybean farming on Farm Lynkloof. These systems' efficiencies could reach 95% whereas traditional surface methods' efficiency can be often less than 50%.

2. Literature

2.1 Agricultural productivity

In an assessment of the relation between food security and agricultural productivity, Costa (2013) defines agricultural productivity as yield (output per hectare) of selected crops. Empirical study has found that smaller farms achieve more crops per hectare when compared to larger farms. This tends to create an inverted relationship between land productivity and the size of the farm when one considers that most farms in developing countries are smaller then 5 hectares. This implies that developing economies should be farther developed than they are. Studies on the link between farm size and productivity were conducted in the past. There appeared to be a common flaw in these studies, however, as they focused on single factor productivity. Costa (2013) recognized that even if land productivity is higher on small farms, labour productivity tends to be much lower and the use of different inputs often varies by farm size. Thus, when one considers the total inputs, it is unclear whether small farms are in fact more efficient than large farms. In order to have a more accurate measure of performance that tests how farm size influences productivity; one must include total factor productivity (TFP) in the equation. There is no universally accepted optimal agrarian structure, even though farms can experience productivity shortcomings in correlation to their country's level of development and economic environment. Increasing the agricultural labour productivity of emerging economies can help generate much needed incomes so it is critical to monitor and assess productivity at national and global levels Rada (2018).
Rainfall shocks cause low agricultural productivity, which may lead to crop failure. Unfortunately, the rural poor and small-scale farmers are most vulnerable to these risks and have to bear the high cost of rainfall shocks. Conditions created by rainfall shocks further constrain the uptake of new farm technology. Thus, households in areas that experienced rainfall shocks experience low agricultural productivity and low consumption levels, and this is most evident for the poorer households Amare (2018).

2.2 Food Security

Food security is a multi-dimensional and flexible concept that is defined in various ways. One of the most widely accepted definitions, adopted by FAO in 1996 and refined in 2001holds that "Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2002). Availability, access, utilization and stability are defined as the pillars of food security. Alonso (2018)

Food security and culture

Alonso (2018) identifies culture as a crucial aspect in planning and implementing food intervention programmes. According to the author, when it comes to the food we eat, culture affects how we obtain, process, store, prepare, and share the food. The author is of the opinion that even well intended food security intervention may fail if they ignore the cultural element.

2.3 Sustainable Irrigation

Water shortages present many challenges including global food production. An ever growing global population places pressure on water to produce more 'crop per drop'. A study done by Wada et al. (2012) indicated that the global use of non-renewable groundwater abstractions increased by more than three times between the years 1960 and 2000. In order to produce more food, there is a critical need to improve water resource management practices. A highly variable climate such as that of Namibia makes it difficult to implement effective water management Le Roux (2017). According to Albano et al. (2017), irrigated agriculture is the primary user of freshwater globally, responsible for nearly 85% of total water consumption, and affording about 40% of the total food production. The authors call for the development of simple agro-hydrological tools that educate farmers about water-related agricultural management.

2.4 Solar Irrigation Systems

Solar irrigation systems utilize the solar energy from solar panels to automatically pump water from a bore hole directly into a storage tank depending on the intensity of the sun. These systems are designed with a valve mechanism that controls the flow of water into the field. As a composite of a smart irrigation system, the valve is controlled using an intelligent algorithm that regulates the flow of water into the field based on the moisture requirement of the land. The system uses a soil moisture sensor that detects the amount of moisture present in the soil. This performance characteristic of the system is one of the design elements that addresses productivity improvement by ensuring the correct quantity of water is supplied as and when needed. The ability of the system to regulate the flow of water is critical in avoiding over flooding of the crops - instead the solar irrigation system is found to conserve water. Some of the benefits of an automatic irrigation system is to optimize the usage of water, reduce waste as well as reduce the physical involvement of the farmer Harishankar et al. (2014). Excess energy produced using solar equipment may be supplied to the national grid, which serves as a crucial source of additional income. The system requires minimal maintenance and is designed to continuously pump water over the course of the day which enables it to achieve optimum utilization. These elements plus the overall system functionality highlight some of the benefits of solar irrigation systems for farming in Namibia. In order to generate useful statistics for factual decision making, the system may be installed with a pump rate tracker to measure output. This system was found to be particularly feasible for servicing sprinkler irrigation systems.

2.5 Photovoltaic irrigation systems

Photovoltaic Technology is designed to generate electrical energy from converting solar energy. Depending on the system's output requirements and charge regulation, it can be enhanced to perform better by incorporating batteries to counter the fluctuation of solar irradiation available throughout the day. The incorporation of the batteries allows for irrigation to also occur at night when there is gr reduced water losses and increased irrigation uniformity.

The water produced from the irrigation system is used directly for irrigation but alternatively it can also be used to fill up storage tanks. The storage tanks serve as an alternative for the battery system; the potential energy of water stored can be used for drip irrigation. There are certain factors that adversely affect the effective operations of the PV panels, the main factors being varying solar irradiation, dust accumulating on the panels, reduced output as a result of energy conversion, costly tracking systems as well as overheating of panel systems that then reduce efficiency.

2.6 PV irrigation technology reviews

Chandel et al. 2015 reviewed irrigation technology that uses solar energy. The study focused on technology updates, performance analysis, efficiency, correct panel size and the economic and environmental aspects of employing PV technology. When compared with diesel and other conventional electric systems, photovoltaic systems were found to be more economically viable Wazed et al. (2018). This means less resources are required to achieve increased efficiency and improved productivity. The efficiency level of an individual system can be improved by installing positive displacement pumps, diaphragm pumps and progressing cavity pumps. These improvements are able to increase pumping efficiencies up to 70%. The efficiency of the PV water pumping system can also be increased by installing a maximum power point tracking system that converts the high voltage from the DC output of the PV panels to a lower voltage for charging of batteries.

Deveci et al. designed and developed a drip irrigation system that utilizes solar PV power. In order to achieve optimal performance of the pump, a battery-powered DC pump was used to provide consistent voltage. Other research conducted in the field found the use of the batteries increases costs. Deveci et al. however argued that utilizing the battery reduces the overall cost of the system by 63%. In Namibia, PV powered water pumping technologies are readily accessible. According to studies, in order to optimize the cost and design of the PV powered system, the farmer must understand the crop requirements and must consistently survey the site and examine the conditions in which the system operates Gutiérrez et al.(2014).

Agriculture is purported to use 85% of available freshwater resources worldwide, and due to increased food demand and population growth, this water consumption pattern is set to continue. Estimating plant evapotranspiration presents an alternative approach to determine crop irrigation needs (Daoud, et. al 2017). External factors such as the weather, humidity, solar radiation and temperature have a direct bearing on evapotranspiration. Evapotranspiration is also directly affected by crop factors such as soil properties, stage of growth, pests, disease control, management elements, variety and plant density.

2.7 Solar Water pumps

Design of the Solar Water Pumping System

A solar water pump consists of an energy source, the pump and a borehole from which water attained flows into a reservoir. Some of the other components that make up the mechanism of the solar water pump are the solar panels that provide power to the pump of which there are three types: submersible, surface, and floating water pumps. A submersible pump draws water from deep wells, and a surface pump draws water from shallow waters whereas a floating water pump draws water from reservoirs with adjusting height ability. Solar pumps are designed to be corrosion-free and maintenance-free. What makes this possible is that they are constructed from high quality low lead marine grade bronze and stainless steel. This makes the system environmentally friendly in terms of both noise and gas emissions. This design element allows for long-term performance and reliability. This is another reason why the paper advocates for the widespread adoption of solar irrigation systems as an option to improve and sustain agriculture productivity.

Choosing an optimal tilt angle to receive maximum radiation

As was stated above, efficiency is a critical factor to consider in systems design. A reduction in overall performance of a system is a sign of lower efficiency. An effective method to improve efficiency is to adjust the tilt angle of the solar panel to allow it to reach an optimum level of power output and thereby increase the amount of water pumped daily. The availability of such a system establishes a more consistent supply of irrigation water and as such improves the quantity and quality of yield and overall productivity.

Figure 1: Selecting a tilt angle for the solar panels is important.

Water Level Detection System

The process of pumping water requires effective monitoring in order to avoid overflowing and to guarantee that there is sufficient supply of water at all times. To this end, the system has a built-in mechanism that detects the level of water both in the water body and in the borehole, which also gives the farmer control over the water pumping process. The water level detection system allows the farmer to interact with the system remotely by activating or deactivating the pump whenever the level of water falls below or above a certain threshold. In the event the borehole runs completely dry, the pumps have dry-running protection. A GSM-based dialler serves as the link between the pump and the farmer, who receives an electronic communication in the form of an SMS when significant movement is detected in the water level (Ismail 2012). The remote interaction provided by these systems increases the productivity of farmers by enabling them to get more done with less labour. These performance characteristics of the solar irrigation system employ modern technology that increase system efficiency.

2.8 Current state of technology

A solar photovoltaic caps water pumping system consists of a PV array, a DC/AC motor pump set which can either be surface mounted, floating or submersible. During conditions of limited sunshine like at night and during cloudy weather, stored water is used. When water storage tanks are used, there is generally no need for battery for back-up electricity. A notable disadvantage of solar PV pumps is they cannot achieve 100 percent utilization because the intensity of the sun varies during the different times of the day. To offset this apparently inherent disadvantage, the relatively low cost of solar photovoltaic (PV) panels deem solar pumping economically viable for a variety of applications.

PV pumping systems have undergone a transformation in recent years - from centrifugal pumps driven by motors - to pump systems that use positive displacement pumps with low power needs - to the current solar pumping technology that uses electronic systems with increased output power and increased overall efficiency.

Principle of a solar water pump

Solar water pump technology converts sunlight into electricity to pump water. The PV panels use the medium of a motor that converts electrical energy generated by the PV panel into mechanical energy. The pump further converts it to hydraulic energy. There are three main variables that determine the pumping capacity of the system: pressure, flow, and power to the pump. To lift a certain amount of water up to the storage tank requires the pump to generate a certain level of pressure Chandel (2015). This is the work performed by a pump. The elevation difference between the water source and storage tank determines the work performed by a pump. For this reason, the PV array needs to supply certain power that the water pump will draw.

Figure 2: Water pump system.

Water supply source

A river, stream, pond, spring or deep drilled well can be a water supply source which must be able to replenish faster than water is being pumped. If the pumping is happening faster than the source can replenish, the dryness may damage the pump. Some factors to consider in system design are cost, source volume and recharge rate.

2.9 Replacing Diesel with Solar PV

Sarkar et al (2015) models a typical year round irrigation load to analyse the feasibility of replacing diesel irrigation pumps with solar PV powered motor-pump systems in Bangladesh. The study found that diesel powered pumps are more expensive than solar systems. As such, PV powered pumps were found to be more feasible than a hybrid PV Diesel Generator-Battery powered pump systems. In the absence of a storage tank, excess electricity provides an alternative for other agricultural needs. The demand for irrigation water fluctuates because of climate change and the practices of changing cropping patterns. Therefore, it is important to irrigate at appropriate times to increase the yield of crops significantly. A pre-feasibility study identified the optimal condition in which to employ solar PV powered motor-pumps as a replacement for diesel powered irrigation pumps.

To operate, maintain and replace a diesel pump costs 2 – 4 times more than it does for a solar photovoltaic (PV) pump Sarkar (2015). Taking cognizance of the scarcity of grid electricity in rural areas, the application of solar energy in the form of PV pumps is a viable alternative if not solution for Namibian farmers. An increase in diesel prices has contributed to PV water pumping gaining popularity as it becomes apparent that a well-designed PV system is more cost effective in the long term than conventional pumping systems.

2.10 Drip Irrigation

Namibia is mostly a semi-arid country. The increasing use of high-technology irrigation systems has been applied in recent years in order to reduce water consumption Ansari et al. (2015). Although modern irrigation methods such as subsurface drip systems may save up to about half of the water presently used for irrigation, some technical, economical and sociocultural factors hinder the adoption of these technologies (Ansari et al. 2015). With respect to such considerations, it is vitally important to develop traditional irrigation systems which can simply reduce soil evaporation with less cost Ansari et al. (2015).This is a fact that has been ignored by most international developmental programs Bainbridge (2001).

Modern technology makes certain functions possible that can highly increase farmer productivity. A notable technological development is the Internet of Things (IoT) , which is a network that allows direct integration between the physical world and computer-based systems Parameswaran et al.(2016). Network connectivity enables these objects to collect and exchange data as well as to be sensed and controlled remotely across existing network infrastructure, which results in improved efficiency.

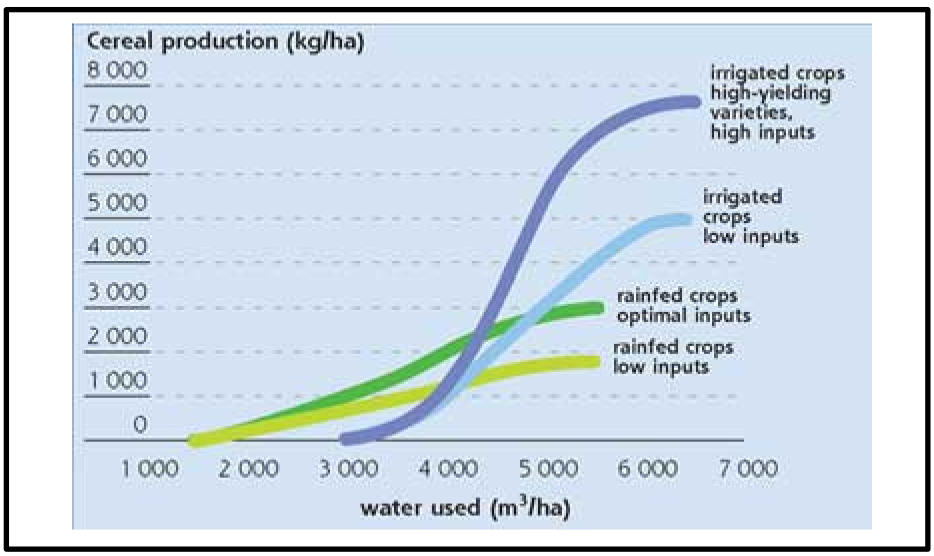

Figure 3 Comparison of input vs yield between irrigated and rain fed cereal crop.
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3. Method

The results of this study are derived from an analysis of existing literature. After an extensive review of solar irrigation literature, conclusions were reached and recommendations made towards implementation. This paper also adopted a case study approach using qualitative methods of data collection.

3.1 Background of Case

Farm Lynkloof in north-western Namibia measures a total of 5000 hectare and is engaged in large-scale cattle farming. The farm is owned and managed by an all female staff of a mother and her three daughters. Of late they have decided to venture into soybean farming, using a solar-powered irrigation system. Land has been set aside for this venture but before the project can be implemented on a larger scale, a trial operation will be set up on land measuring five hectares.

Water analysis and soil tests conducted on the farm determined the feasibility of cultivating on the identified portion of the land. This physical testing also ascertained the appropriate location to construct the storage dams and install the system as well as to plot the proposed layout of the cultivated land. A portion of land was identified, cleared and prepared for soybean cultivation.

Figure 4: Setting up the system

4. Findings

The findings from the literature review reveal that solar irrigation systems are more economically and environmentally feasible than diesel-powered systems and other conventional irrigation systems. Solar systems have low maintenance costs, low operation costs and no fuel costs. Solar irrigation systems use water optimally and reduce the physical involvement of the farmer because they are operated remotely. These systems increase the productivity of farmers. The project findings, based on tests conducted on the actual farm, reveal that the portion of land allocated for the irrigation system is ideal for the installation to commence.

5. Conclusion

As the results of the various research indicate, harnessing the sun rays to generate electricity is a much cheaper exercise then using grid electricity. The use of solar irrigation systems with solar pumps is equally a more cost effective way to irrigate land in comparison to using diesel powered pumps or other conventional electric pumps. In respect of current available technology, employing solar irrigation is evidently a viable option to increase the productivity of farming activities on Farm Lynkloof. Solar irrigation systems offer particular benefits that may be appealing to most farmers in that they can be controlled remotely, allow for year round irrigation and when there is excess electricity generated, it can be used in other areas of agriculture without incurring additional costs. Solar irrigation solves the stated problem of inconsistent supply of irrigation water. In a semi-arid country such as Namibia with over 300 days of sunshine in a year, solar irrigation systems are ideal systems to employ in the pursuit of farming efficiency and food security.

The main objective of this study - to explore solar powered irrigation systems as a possible solution to provide sustainable irrigation water supply was achieved through analysis of literature and observation of key infrastructure installation. The scope was limited to one case study of a project under implementation and for one crop, soybeans, which somewhat limits the generalisation of the results. The scope can be expanded in future research by experimenting with a variety of other crops to give a wider view of the effect of sustainable solar irrigation to agriculture productivity.

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