Economic and Environmental Analysis of Greenhouse Crop Production with Special Reference to Low Cost Greenhouses: A Review

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ABSTRACT. The greenhouse technology can be a key for sustainable crop production and to achieve food security in the regions facing the problems of food scarcity. It gives assured crop production and also increases the productivity. But, the high initial cost is one the biggest concern in the adoption of the technology by the farmers. Over the period, many scientists and engineers helped to reduce the cost of the technology. In most of the cases, it is done by using alternate construction materials or by using innovative environmental control technology. A comprehensive review of low-cost greenhouse technologies is taken in the article. Also, the economic analysis of some of the greenhouse production operations from different parts of the worlds are summarized along with their environmental impacts.

Keywords. Low cost greenhouses, polyhouses, BC ratio, economic analysis, life cycle analysis, LCA, environmental analysis.
Introduction

The quality and yield of any crop depend on the congenial atmosphere surrounding the crop and protection of the crop from natural calamities such as wind, hail storms and insect attacks. Greenhouses artificially provide suitable conditions for crop growth and improve the crop productivity and quality. Depending upon the level of automation, the parameters of crop aerial and root environment are controlled partially to the fullest extent. Capital available and trained personnel availability governs the greenhouse automation level. Between 15-19th century, wood and bamboo were the favorite materials for greenhouse structural frame construction which were later replaced with galvanized iron pipes and channels (Bhatnagar, 2014). This increased both durability and cost of the greenhouse structures. Further, various environmental control technologies installed in greenhouse added to its capital cost.

Low productivity and uncertainty of production are important negative features of agriculture in developing countries. Protective cultivation can be the solution to these problems. But, the higher capital cost of the greenhouse structures and its control systems is one of the biggest constraints in its adoption and use by the farmers. Scientists and engineers are working relentlessly to reduce the cost of the greenhouse technology without compromising its functionality and efficiency. In the modern history of greenhouse development, the dedicated efforts of Dr. Emery M. Emmert reduced the cost greenhouses greatly. In 1948, Dr. Emmert successfully designed and constructed plastic greenhouses by replacing glass with plastic as a greenhouse covering material (Bhatnagar, 2014). Later, research of dedicated scientists helped to develop cost-effective models of greenhouse system. This is done mostly by using cost-effective and reliable sub-systems in construction and environmental control of greenhouses.

In this article, low-cost greenhouse technologies used for crop production are reviewed. The economic analysis of some of the greenhouse production operations from different parts of the worlds are summarized as well as the structures are reviewed for their environmental impacts. The major objective was to study low-cost greenhouse options along with their economic benefits and environmental impacts.

Low Cost Greenhouses

The capital cost of a greenhouse structure is mainly affected by frame material and environmental control system used while covering material affect the cost of a greenhouse to less extent as in many cases it is fixed (i.e. polyethylene), but covering material required will change a bit depending upon the design dimensions (Bhatnagar, 2014). Therefore, one of the approach to have cheap greenhouses is to use the locally available cheap material for greenhouse frames, strong enough to resist local wind forces. At the same time, such frame material(s) should also possess good corrosion or weather resistance to atmospheric and soil moisture and against creatures like rodents, termites, etc.

The glass greenhouses are good at retaining temperature, but glass installation difficulty and overall higher initial cost are the limiting factors in using glass houses for profitable commercial production. Polycarbonate (greenhouse with polyethylene as a covering material) is a good option to glass greenhouse. Reddy (2006) reviewed the different low cost polycarbonate options for Indian conditions. One of the options is lean type Ladakh polyhouse (figure 1). It is typically 10 m X 5 m in size. The polyhouse has three sides (two end walls and one side wall) made from mud-bricks and polyethylene film is supported using wooden or bamboo poles.

Figure 1. Typical Ladakh greenhouse (Image courtesy: www.alimenterre.org).

Trench (underground greenhouse) type is also found useful in high altitude hilly region. Ideal trench size is 10 m x 3 m x 1 m and it is covered with UV-stabilized polyethylene film. During winter nights, this structure is covered with second polyethylene film or other type of insulation cover to reduce heat loss. Low plastic tunnels are also used for better crop production in regions experiencing semi-severe winters. To support the plastic film, arches made from galvanized iron rods are fixed at 1.5-2 m interval. The width and height of such low plastic tunnels vary from 45-60 cm. The plastic film thickness
is 30 to 50 micron. Also, shade houses fitted with shading clothes (mostly HDPE) having shading effects between 25 to 90 % are used as an alternate low-cost crop production option to greenhouses. Shade nets do not provide any protection from rain, but depending upon the design, shade houses can provide good protection form hail storms.

Bhatnagar (2014) reported the work done on low cost naturally ventilated bamboo and wooden greenhouses under the project ‘All India Coordinated Research Project on Use of Plastic in Agriculture’. The structures were constructed in different regions (Uttarakhand, Kashmir and Ladakh valley, and Himachal Pradesh) of India. The UV stabilized 200-micron Low-density polyethylene (LDPE) was used as covering material for all the structures. The life span was 4-5 years which could be extended to 8-10 years choosing the appropriate preservation method for the frame material. The construction cost of these low-cost greenhouses (for the year 2007-08) varied between ₹ (Indian Rupee) 200 -300 per m² of greenhouse floor area. While, the construction cost (for the year 2007) for a bamboo polyhouse and a rain-shelter structure constructed for Meghalaya region were respectively ₹ 142 and ₹ 94 per m².

There are many ways of reducing the cost of greenhouse production. Detailed sensitivity analysis on how various components of total cost affect the final cost of production helps to target the particular factors. Even replacing the containers, the cost of cultivation can be reduced. Nambothiri et al. (2013) discussed the comparative advantages and disadvantages of different alternative containers used for nursery and greenhouse production. The details about alternative containers like recycled plastic geotextile, compostable, and plantable containers and material sources are discussed.

In the tropical climate, even simple shade nets can replace the greenhouses. In the region, the temperature is already enough or higher for most of the crops, the shade net serve other purposes like protect the crop from hails, pests and many times from scorching afternoon sunlight. Even high value cut flowers can be produced successfully in low-cost greenhouses if the region’s climate is not severe. Ranjan et al. (2013) reported the production of cut flowers in North-Western Himalayan ranges using cost effective greenhouses. Carnation and gerbera cut flowers were produced in the naturally ventilated greenhouse. The greenhouse was constructed using bamboo or local wood material for frame and UV stabilized polyethylene sheet as covering material. Being the greenhouses were naturally ventilated, the flower yield was observed minimum during winter period (December to March). About 6.5 gerbera flowers per m² of greenhouse area were harvested during the month of December and March, whereas during February about 1.75 gerbera flowers per m² of greenhouse area were harvested. During January the flower production was almost zero. Maximum number of gerbera flowers (about 19.5 per m² of greenhouse area) were harvested during the months of April and October. The quality of carnation flowers produced in low-cost greenhouses was found superior to flowers produced in open field (outside the polyhouse) conditions.

Many factors affect the cost of greenhouse production. Even properly oriented naturally ventilated greenhouse (considering solar and wind paths) can produce more and help to reduce the production cost. The naturally ventilated low-cost greenhouses having more height (volume) respond slowly to outside changing weather and thus help to maintain uniform inside environment (Kumar et al., 2009). Many researchers tried to use different low-cost greenhouse technologies suitable for the local climate of the region. A case study of East Africa is elaborated here. Many times east African region goes through the state of famine and about 60% population in the region is malnourished. As a part of the solutions and to give more food security to the region, Pack & Mehta (2012) designed the low-cost greenhouse for East Africa, as an alternative to the high priced (about the US $ 2000 each) greenhouses. The newly designed low-cost greenhouses (about US $ 200 bill of materials) were successfully tested to grow tomato corps.

Economic Analysis of Greenhouse Crop Production

Bhatnagar (2014) reported the results of the techno-economic analysis of different low cost naturally ventilated polyhouses constructed in different regions of India under the project ‘All India Coordinated Research Project on Use of Plastic in Agriculture’. In 2007, bamboo framed polyhouses in Uttarakhand region were evaluated for off-season crop sequence: vegetable pea (Dec.-Mar.; season I)-summer squash (Mar.-Jun.; season II)-Tomato (Jul.-Nov.; season III). The study showed the B-C ratio between 1.64 to 2.2 for different sizes of polyhouses. This research also suggested minimum greenhouse area of 80 m² (with typical dimension of 16 m X 5 m) for better production and profit. Also, low cost naturally ventilated bamboo polyhouse was evaluated in Meghalaya region. Under polyhouse conditions, production of tomato and eggplant seedlings were respectively 38% and 32 % higher and seedlings were ready for transplanting 10-12 days early compare to outside open conditions. When the low-cost polyhouses tested for two cropping sequences: capsicum-tomato-lettuce and tomato-French bean-cabbage, B-C ratios observed were 2.1 and 1.7 respectively.

Sharma et al. (2014) explored the economic feasibility of major flower crops (rose, carnation, lilium, gerbera and chrysanthemum) grown in Himachal Pradesh province of India. All the crops were cultivated in the low cost naturally ventilated galvanized iron pipe framed polyhouses. The benefit-cost ratio for roses, carnation, lilium, gerbera and chrysanthemum were respectively observed to be 2.89, 2.37, 1.89, 2.01, and 2.39, suggesting that the rose cultivation might be the most beneficial option. For another crop, Sanjeev et al. (2015) studied the economic feasibility of cucumber cultivation under low-cost naturally ventilated polyhouses successively for two years - 2013 and 2014. The BC ratios (without any government subsidy) of 1.36 and 0.55 were observed for the years 2013 and 2014 respectively. This economic analysis concluded that the capital cost of the structure and market price of the produce affected the returns greatly. In the
second year (2014), for which the BC was just 0.55, the market price of the produce reduced drastically which affected the returns negatively.

Capsicum and tomato are considered the crops most suitable for greenhouse cultivation as they respond more positively to controlled climate. Murthy et al. (2009) studied the tomato and capsicum production under low cost naturally ventilated polyhouses in Karnataka state, India. The capsicum production was found profitable (BC ratio 1.80) over tomato production. The research also concluded that the tomato cultivation will be profitable if the capital cost of the polyhouse be reduced by 60%. On the similar line, Sreedhara et al. (2013) economically analyzed the capsicum cultivation under low cost naturally ventilated polyhouse in Northern Karnataka, India. It was reported that the labor cost component was highest among all the variable costs. The BC ratio of the operation was observed 3.92. Cucumber is another important greenhouse crop. Engindeniz & Gül (2009) analyzed greenhouse cucumber performance under soil-soilless growing conditions in Turkey. The mixture of zeolite and perlite was used as a soil-less media. Net returns were higher for the soil-less growing medium ($\text{€} 1.84 \text{m}^2$) as compared to soil media ($\text{€} 1.48 \text{m}^2$), but cautioned that the market rates and productivity both affect the profitability of the soil-less vegetable production.

Due to the growing health problems in today’s busy and very competitive life, the demand for organic and more naturally produced food is growing rapidly and so is the area under organic crops. In reference to that, Engindeniz & Tuzel (2006) economically analyzed the organically grown greenhouse lettuce in the Turkey. Galvanized metal tube frame low cost naturally ventilated 384 m² greenhouse was used for lettuce production. Four different natural manures: farmyard manure 50 t/ha, E 2001+ allgrow bioplasma + poultry manure 30 t/ha, poultry manure 50 t/ha, and E 2001+ allgrow bioplasma + farmyard manure 30 t/ha; were tried during the study. Depending upon the type of natural fertilizer applied, the net returns varied between US$ 0.376 to 0.901 m². Banaeian et al. (2011) evaluated energy and economics of strawberry production in Iran’s Tehran province. A strawberry production in one ha greenhouse consumed the total energy of 121891.33 MJ. Out of that, about 4.5% came from electricity, chemical fertilizers contributed about 10 % and diesel fuel generated 78%. At 1 % level, developed economic model showed that the impact of all the parameters viz. transportation cost, installation of equipment, fertilizers and labor were significant. The net returns and BC ratio of greenhouse strawberry production were respectively 151907.91 $/ha and 1.74.

Cucumber is mostly used for salad purposes and nowadays, greenhouses are used worldwide for quality cucumber production. Chand (2014) economically evaluated one such cucumber producing naturally ventilated low-cost polyhouse located in Kerala state in India. The greenhouse sized 292 m². The results revealed that if the cucumber was fertilized at rate equal to the 100% of recommended dose, the highest (3.42) BC ratio was obtained.

Cut flower production under polyhouse is widely established business. Tarannum et al. (2014) evaluated the economic performance of naturally ventilated low-cost polyhouse for carnation cultivation located in Karnataka State of India. The three different genotypes of carnations viz. Soto, Dona and white Dona were evaluated. The BC ratios of these genotypes were found respectively as 2.50, 2.00 and 1.85.

**Environmental Impacts of Greenhouse Crop Production**

Multiple web-based tools are available for assessing the environmental impacts of the protected cultivation systems. One of the notable attempts on this front was by Torrellas et al. (2013). This group developed the calculators for southern European climate (specifically for tomato production in multi-tunnel greenhouse system) and for central European climate conditions (specifically for tomato crop in Venlo glass greenhouse system). These calculator can be used to calculate almost all impact category indices such as ADP, GWP, AAP, EUP etc., using very little inputs from the user end.

System level research in horticultural production which helps to quantify the role of a particular component of the production, its cost relevance and environmental impacts, has been becoming very important field of study in today’s competitive world. A Consumer is more concerned about personal and environmental level impacts of the products and services in the marketplace. A tool called Life cycle Assessment (LCA) helps to quantify the environmental impact of any product or services in terms of different indices such as carbon footprint (Ingram & Fernandez, 2012). LCA can be very effectively used to test the production performance of advanced horticultural systems such as greenhouses. Although many scientists have been using LCA in agriculture production system, there are many challenges in its use for agriculture (Caffrey & Veal, 2013). To list: the standard methodology is not available, emission sources are not pointing sources, a system with multi products, temporal variations across the regions, different crop management techniques, etc. So LCA results very widely and are limited to the operation and or the region.

Many researchers studied the environmental impacts of fruits and vegetables production systems under open field and protective conditions. Gunady et al. (2012) conducted life cycle analysis of mushroom, strawberry and lettuce produced and transported to retail outlets (i.e. grower to grocer approach) in the Western Australia. The results were reported for per KJ (energy produced) of lettuces, button mushrooms and strawberries. The strawberries and lettuces were produced under open field condition. The analysis included greenhouse gas (GHG) emissions for three production stages: pre farm, on-farm, and post farm, and transportation to retail stores. The study revealed that the on farm GHG emissions were higher for strawberries and mushrooms, while pre-farm emissions were higher for mushrooms. Total GHG emissions were maximum for lettuces.
For 1 KJ equivalent of lettuces (1.380 g), strawberries (0.746 g) and mushrooms (1.090 g) produced and transported; the respective equivalent CO₂ emissions were 5.180 g, 2.458 g and 3.0 g. Similar LCA conducted for strawberry in Japan, but produced under greenhouse conditions, reported 4.13 g CO₂ emission per KJ of strawberry (Yoshikawa et al., 2008).

Southwestern Ontario has the largest concentration of greenhouse tomato production in North America. Hendricks (2012) studied the LCA of Southwestern Ontario greenhouse tomato production system. The study reported energy use of 2.62 GJ equivalent /m² for heating and 0.192 GJ equivalent /m² for electricity. Total global warming potential (GWP) for greenhouse tomato production was observed to be 2.88 Kg CO₂ equivalent/kg of tomato produced. The heating was identified as the major contributor (85 %) of GWP, followed by electricity and fertilization. In another attempt to calculate the environmental impact of conventional and organic tomato production, (He et al., 2015) studied the urban greenhouses in the areas surrounding the Beijing city of the China. The overall environmental impacts of organic tomato production were 54.87 % lower as compared to conventional tomato production method. The GWP index in organic and conventional production systems was 207.22 Kg CO₂-eq /ton and 260.87 Kg CO₂-eq /ton respectively. In the parallel attempt in Colombia, to verify the thought that greenhouse systems cause considerable environmental damages, Bojacá et al. (2014) carried out the life cycle assessment of the Alto Ricaurate province, the key tomato growing area in the country. The CML2001 v.2.05 impact assessment method was used and the study also followed the ISO 14040 guidelines. The emission was calculated per ton of fresh tomato production. The GWP index of production was observed to be 74.0 Kg CO₂-eq / ton.

Khoshnevisan et al. (2013) modelled the energy consumption and GHG emission of Iranian Greenhouses. Acidification and Eutrophication indices were lower for greenhouse production (2.48 kg SO₂ eq. and 0.27 kg PO₄³− eq., respectively) as compared to open field strawberry production (2.56 kg SO₂ eq. and 0.38 kg PO₄³− eq., respectively). The GWP100 of greenhouse production was 695 kg CO₂ eq. as against 585.19 kg CO₂ eq. for open-field cultivation.

Yousefi et al. (2013) conducted environmental analysis of 22 pepper producing greenhouses located in Esfahan province. The functional unit selected was an area of greenhouse and all the indices were calculated per 1000 m² of greenhouse area. The energy productivity and GHG emissions calculated for these greenhouses were respectively 0.016 kg/MJ and 14390.85 kg CO₂ equivalent/ 1000 m² area. It was also observed that replacing diesel with natural gas was not the effective way to increase energy productivity of the greenhouse. Instead, total energy management approach must be explored in which clean and renewable sources of energy may be used to achieve better energy efficiency.

The energy efficiency of greenhouse production changes with the type of the structure and crop. Similarly, their environmental impacts are also different. Cellura et al. (2012) studied the LCA of Italian tunnel and pavilion type greenhouse for the production of Cherry tomatoes, zucchini, peppers, tomatoes, and melons. The data on these crops were collected form a producer company located in southern Italy. LCA analysis was carried out by following procedure referred in ISO 14040 series. All the environmental indices were reported per 1000 Kg production of fresh vegetables. Human toxicity was observed maximum (1746.4 Kg of 1,4-DB) for Zucchini and minimum (430.4 Kg of 1,4-DB) for tomatoes. Acidification index was again maximum for Zucchini (3 kg SO₂eq) and lowest (5.7 kg SO₂eq) for tomatoes. The similar trend was observed in water consumption for Zucchini i.e. maximum 172.4 m³ for Zucchini and minimum 77.7 m³ for cherry tomatoes. GWP index was also maximum for Zucchini (1571 kg CO₂eq) and minimum for tomato (740 kg CO₂eq). Overall results recorded for these crops shown that the highest environmental burdens were for Zucchini production and lowest for tomatoes, except for the wastes category.

**Summery**

The greenhouse technology can be a key for sustainable crop production and to achieve food security in the regions facing the problems of food scarcity. It gives assured crop production and also increases the productivity. But, the high initial cost is one the biggest concern in the adoption of the technology by the farmers. Over the period, many scientists and engineers helped to reduce the cost of the technology. In most of the cases, it is done by using alternate construction materials or by using innovative environmental control technology. A comprehensive review of low-cost greenhouse technologies is taken in the article. Also, the economic analysis of some of the greenhouse production operations from different parts of the worlds are summarized along with their environmental impacts.

**References**


