

# Environmental Amelioration Through Nutrient Calibration: Maximizing Carbon Sequestration in Hydroponic Greenhouse Production of *Lactuca Sativa* in Lahore's Spring

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## Research Article

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# Abstract

This study explores the applicability of internationally prescribed nutrient recipes to greenhouse hydroponic production in Lahore. *Lactuca sativa* was hydroponically grown at different nutrient concentrations to uncover optimum nutrition for maximum foliage cover. Conclusions were based on visual analysis of foliage cover, as laboratory analysis of trial plants was beyond the scope of this environmental study. Nutrient levels that displayed the best foliage cover in Lahore-based greenhouse during spring weather were different from concentrations kept in US- or Europe-based hydroponic greenhouses. Plant trials conducted for this article explain the adjustments that must be made to hydroponic recipes discussed in international literature; if they are to be used in polyhouse hydroponic production in Lahore's warmer climate.

## Introduction

Ever increasing carbon dioxide in urban environments requires a proportional increase in leafage, as leaves are the primary and only organ of carbon capture and removal. Leafy plantations in expensive urban plots would remain limited unless their horticulture is highly profitable. Replicating advanced nations' urban hydroponic success in Lahore, Pakistan a city of more than 11 Million people; would require local adjustments, as unlike most of those nations, Lahore has a warmer climate and records high temperatures even in the cooler months of January, February and March. This paper reports hydroponic trials that were conducted between January and March 2020 under the protection of a polyhouse. Hydroponic recipes that work in cooler climates or temperature-controlled glasshouses of more developed nations would not work in basic polyhouses constructed in Lahore's warmer climate. The authors conducted three trials with different nutrient concentrations in a purpose built hydroponic polyhouse to uncover the right mix for Lahore's climate. Local adaptation is essential to first build profitable urban hydroponics and then achieve the environmental goal of carbon capture through leaves grown in those hydroponic facilities.

Atmospheric carbon dioxide is captured and converted into sugars by leaves, and fast-growing leafy green vegetables such as household lettuce can make useful contributions to our struggle against global warming. Urban centers such as Lahore are hotbeds of CO<sub>2</sub> generation due to industrial activity, motorized traffic and other combustion-related activities. The government of Pakistan plans to capture and remove the carbon dioxide produced in Lahore and other urban centers by planting billions of trees under the 'Ten Billion Tree Tsunami Programme'[1]. This is a commendable environmental initiative, as billions of trees would have many trillions of leaves, with each leaf removing a fraction of carbon dioxide from our environment. However, there are three concerns with this programme, all of which can partially be addressed by hydroponic urban leafy green cultivation. First, this is a distant solution to an immediate problem, as trillions of leaves would achieve mass carbon sequestration once the newly planted trees have attained maturity and some trees can take decades to mature. Second, the trees planted in remote scrub or mangrove forests are quite far from the CO<sub>2</sub>-generating city of Lahore. Third, a very small fraction of the Billion planned trees can be planted inside Lahore, as existing landowners would be

reluctant in a plantation drive that does not promise immediate economic returns. These three concerns encourage us to look for additional ways of achieving quick and profitable foliage cover within or near Lahore.

Although leafy greens such as *Lactuca sativa* are miniscule compared to Himalayan cedars or Sindh mangroves planned under the Ten Billion Tree Tsunami Programme, they partially address the three concerns related to this programme. First, *Lactuca sativa* is a very fast-growing leafy green that starts capturing carbon produced in Lahore today. Second, hydroponic greenhouses or polyhouses can be set up within Lahore, even on unutilized rooftops, enabling sequestration of carbon right next to where it is being generated. Third, it can be taken up by existing landowners, as it has the ability to quickly generate a high return on low investment. If *Lactuca sativa*'s contribution to carbon sequestration is to be appreciated and utilized, then the right composition of macro- and micronutrients that can deliver the ideal growth of its leaf should be explored.

Concentrated nutrient solutions with high proportions of nitrogen, phosphorus, potassium and micronutrients can lead to fertilizer induced leaf burn due to high evapotranspiration. A diluted solution on the other hand can limit the growth of leaves by limiting the uptake of essential nutrients. A healthy leaf can sequester maximum carbon dioxide, but to let that leaf develop, an optimum nutrient mix should be provided to roots, which is neither diluted nor concentrated. To determine the right nutrient concentration for ideal leaf development, the authors conducted trials of the same *Lactuca sativa* plants in three different hydroponic troughs. One of these troughs had nutrient concentrations close to those prescribed by Brechner & Both (2013) (Parks & Murray, 2011) (Huett, 1994) (Paulus, et al., 2008) [2–5]. The nutrient concentration in the second trough was adjusted to 0.5 times (half) that of the first trough to make a diluted solution. At the third trough, the concentration was 1.5 times that of the first trough to make a concentrated solution. First trough's nutrient formulation prescribed by multiple scientists would have shown the best results in laboratory settings, but in Lahore's practical polyhouse setting, the author observed the best leaf growth in diluted solution.

Multiple nutrient formulations were studied from extension reports and journal articles published around the world. Although hydroponics is argued by some as an ancient technique first used in hanging gardens of Babylon, the first scientific discussion of nutrient formulation in hydroponics can be traced back to 1938 when a paper titled 'The water-culture method for growing plants without soil' was published by Hoagland & Arnon in 1938) [6]. Both (Jones, 2005) [7] and (Sonneveld & Voogt, 2009) [8], in their respective books on hydroponics and plant nutrition credit (Hoagland & Arnon, 1938) [6] with the first formulation of nutrient solution. They argue that formulations developed in subsequent years were adaptations of this pioneering work. Authors working on different crops developed unique crop-specific formulations. (Parks & Murray, 2011) [3] recommended NPK concentrations of 116-22-201 Parts per million (PPM) for East Asian leafy vegetables such as Bok Choy. Roughly similar NPK concentrations of 125-31-215 PPM were reported for Lettuce by Brechner & Both (2013) [2]. The original Hoagland solution had NPK concentrations of 210-31-235 PPM [9]. This comparison informs us that later scientists working on leafy green nutrient concentrations drove the nitrogen concentration down quite significantly. Trials

conducted for this research paper showed that nitrogen and other concentrations can be reduced even further in the case of polyhouse hydroponic farming in Lahore.

A comparatively low nitrogen concentration was also kept in hydroponic lettuce trials of Singh et al, 2019 [10]. The NPK ratio of (5) N, (4.8 or 5.2) P, and (21.6) K was used by them [10] to grow different cultivars of lettuce in channels using nutrient film technology. They verified the utility of this relatively low nitrogen formulation by comparing the nutrition in their sample lettuce leaves with prior work on lettuce leaf nutrient ranges by Hartz et al. (2007) [11]. They also proved the efficiency of their nutrient formulation; by looking for nutrients in leaf samples using TruSpec Elemental analyzer, by using Chlorophyll meters (SPAD 502), and by studying the dry weight of trial plants.

Nutrient formulation or calculation in the 21st century is automated. A software application developed by Daniel Fernandez titled 'HydroBuddy' helps researchers and hydroponic farmers calculate nutrient concentrations tailored to their needs. This software utilizes the Lettuce nutrient formulation developed by Cornell University's College of Agriculture and Life Sciences and published by (Mattson & Peters, 2014) [12] and (Brechner & Both, 2013) [2]. Nutrient formulations for *Lactuca sativa* can also be found in the works of (Peckenpaugh, 2004) [13] and (Resh, 2013) [14], which this software utilizes along with other formulations. The author of this research paper utilized this software to calculate an average concentration from this software. This average concentration set as the benchmark for later concentration alteration was based on estimates published by most of the abovementioned scholars.

## Materials And Methods

The average concentration recommended in the literature was calculated after a careful review of nutrient formulations advised in the abovementioned literature, which recommended the concentration of all essential elements, including nitrogen, phosphorus, potassium, calcium, sulfur, magnesium, boron, iron, manganese, zinc, copper and molybdenum. A list of locally available water soluble chemical compounds was then compiled, through which these essential elements could be delivered to plant roots. All chemical compounds were sourced from the chemical markets in Circular Road Lahore. The only element that had no available compounds in Lahore's local market in early 2020 was molybdenum; therefore, all trials had to be conducted in a molybdenum-deficient state. Average elemental concentrations and available chemical compounds were then entered into 'Hydrobuddy' software to calculate the benchmark concentration in grams per liter of water. This benchmark concentration was obtained after careful analysis of the literature, and it was considered the right concentration under ideal temperature and relative humidity. Maintenance of ideal conditions around the clock would have required an automated temperature or humidity control system that was not utilized in this study.

To visually analyze the crop response to variation in nutrient concentration, three different concentrations were planned for three different troughs constructed in the experimental greenhouse. The first trough contained the most concentrated solution, which was 1.5 times that of the benchmark. The second trough in the middle had the lowest concentration kept at 0.5 times that of the benchmark, and the third

trough was filled with the benchmark concentration calculated through research. All finally calculated concentrations of locally available chemical compounds are presented in the Table 1 below:

Table 1  
Nutrient concentration available to roots in grams per liter.

<b>Nutrients</b>	<b>1st Tank with highest fertilizer to water ratio {1.5 times of Benchmark tank} (Left tank in figure)</b>	<b>2nd Tank with lowest fertilizer to water ratio {0.5 times of Benchmark tank} (Middle tank in figure)</b>	<b>3rd Tank {Benchmark tank} with medium fertilizer to water ratio, equivalent to the average of nutrient formulations in literature (Right tank in figure)</b>
Calcium Nitrate	1.458	0.486	0.972
Potassium Nitrate	0.67665	0.22555	0.451
Ferrous Sulfate	0.0075225	0.0025075	0.005
Mono Potassium Phosphate	0.19896	0.06632	0.133
Magnesium Sulfate	0.369	0.123	0.246
Manganese Sulfate	0.0102	0.0034	0.007
Boric Acid	0.00525	0.00175	0.004
Zinc Sulfate	0.0036	0.0012	0.002
Copper Sulfate	0.0102	0.0034	0.007
Sodium Molybdate	0	0	0

Trials of *Lactuca sativa* were grown using the deep water culture technique of hydroponics. Three troughs with wooden frames and geomembrane inlays were constructed to store large amounts of nutrient solutions. Each trough was constantly aerated with an aquarium-scale air pump and had a submersible pump to allow round the clock circulation of nutrient solution. The nutrient solution in troughs was covered with polystyrene floats drilled with holes spaced at 7.5 inches. All holes in polystyrene floats were planted with *Lactuca sativa* seedlings on 31 January 2020. A polyhouse over these troughs was constructed on 280 square feet-sized plots in Lawrence Garden (Bagh e Jinnah) Lahore, allocated for this research by the Government of Punjab's Parks and Horticulture Authority (PHA). The coordinates of these

trials were 31.5556937 and 74.3301289. The overall skeleton of the polyhouse was made up of galvanized iron steel pipes of one inch diameter and covered with a 200 micron polyethylene sheet to retain heat. All materials used in polyhouse and trough construction were sourced from local markets of Lahore.

## Results And Discussion

*Lactuca sativa* seedlings were planted in three different nutrient concentrations on 31 January 2020. The pH and ratio of total dissolved solids (TDS) were kept constant between these dates through the use of digital monitors. The results of nutrient variation were only visually observed, as destructive sampling for laboratory analyses was beyond the scope of this research. In first week of growth, all seedlings exhibited roughly similar patterns of growth as shown in *Figure 1*. After 5 weeks however the plants displayed differences in heights and foliage density based on differences in nutrient concentrations. The differences in plant development as a result of nutrient variation can be observed in *Figure 2*. This observation was made on 6 March 2020. The best results were observed in the middle tank with the lowest nutrient concentration, which was half of the benchmark advised in the literature.

The best foliage cover and leaf growth were observed in the tank with the lowest nutrient concentration as shown in *Figure 3*. Lahore's warm climate entails high evapotranspiration, which means a greater flow of nutrient-laden water through the sensitive growing plant. It is believed that trials planted in higher nutrient concentrations did not exhibit the same growth because of the stress that their leaves would have endured due to constant flow of concentrated nutrients through the plant eventual evaporation from the leaf surfaces. Trials with high concentrations were either kept at the benchmark set by existing literature or 1.5 times that of the benchmark, so no fertilizer burns were observed on leaves, but the general foliage cover was poor compared to the low concentration trough, as significant parts of white polystyrene floats were still visible, implying small leaf size and low leaf density. Low concentrations, which are half of those advised in the literature, would be more suitable for Lahore's climate.

Maximum and minimum air temperatures for optimum growth of *Lactuca sativa* leaves are given as 24 and 19 degrees Celsius [2]. To understand the temperature dynamics of Lahore over 6 weeks between Jan 31st and 6th March, maximum and minimum temperature data for these dates were obtained for every year between 2000 and 2017. The data of 2001 was not available. To avoid making judgments based on outliers, an average for each date was calculated using maximum and minimum temperatures that were recorded on that date in 17 different years. That average data is plotted on the following diagram.

The Figure 4 above shows that after 25 February, Lahore starts noting a maximum temperature that is higher than the recommended temperature of 24 degrees Celsius. After 25 February, uncovered *Lactuca sativa* grown in open air would thrive at ideal daytime temperatures. In covered settings such as polyhouses, however, the heat becomes trapped, and the temperature inside the polyhouse is on average 5-10 degrees more than the outside temperature. Temperature inside a polyhouse toward the end of

February would be more than 30 degrees Celsius. *Lactuca sativa* can start bolting at temperatures higher than 30°C, and high temperature can also inhibit the synthesis of normal proteins during plant growth[15]. This research concludes that if lettuce plantations are planned in the spring months of Lahore, then the benchmark nutrient concentration available in the published literature can be utilized for open air uncovered farming. However, for covered polyhouse hydroponic farming, the nutrient concentration reported in the literature should ideally be cut to half.

## Compliance Of Plant Trials

The plant collection and use was in accordance with all the relevant guidelines. *Lactuca Sativa* seeds were sourced from Pride Seeds, located at 99/B/III Hussain Chowk MM Alam Rd, Block B 3 Gulberg III, Lahore, Punjab 54000, Pakistan. <https://www.prideseedstore.com/>

## Declarations

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### Author Responsibilities

MA conceptualized the study, designed and conducted the plant trials, and drafted the manuscript. AT contributed to the study design and contributed to manuscript revision.

### Competing Interests

Authors declare no competing interest

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## Figures



**Figure 1**

Seedlings one week after their plantation on 31 January 2020



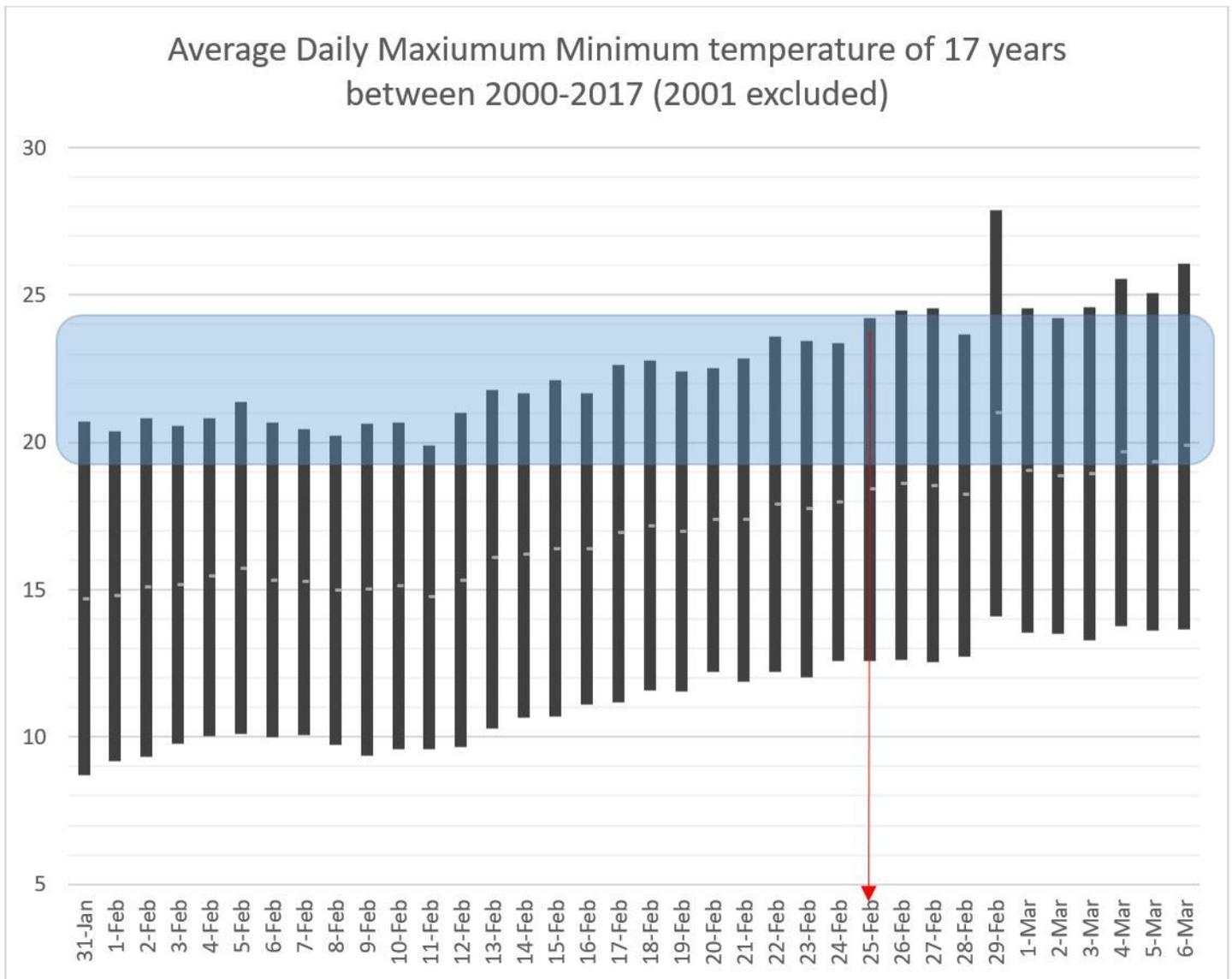
**Figure 2**

Maturity of *Lactuca sativa* trials grown in 3 troughs with different nutrient concentrations 5 weeks after seedling plantation. Dated 6 March 2020



**Figure 3**

Best foliage cover with almost no exposure of white polystyrene float was observed in middle tank with lowest nutrient concentration



**Figure 4**

Average daily maximum and minimum temperatures recorded between the dates of 31st Jan and 6th March recorded over 17 years