लेट्यूस में कुशल फर्टिगेशन शेड्यूलिंग के लिए एरोपोनिक्स सिस्टम का डिजाइन और मूल्यांकन

DESIGN AND EVALUATION OF AEROPONICS SYSTEM FOR EFFICIENT FERTIGATION SCHEDULING IN LETTUCE

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DESIGN AND EVALUATION OF AEROPONICS SYSTEM FOR EFFICIENT FERTIGATION SCHEDULING IN LETTUCE

A Thesis

By

KUNDAN KUMAR

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This is to certify that the thesis entitled **'Design and evaluation of aeroponics system for efficient fertigation scheduling in lettuce'** submitted to the Post-Graduate School, ICAR–Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the award of the degree of **Master of Technology in Agricultural Engineering**, embodies the results of *bonafide* research work carried out by **Mr. Kundan Kumar (Roll No. 20927)** under my guidance and supervision, and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help availed during the course of investigation as well as source of information have been duly acknowledged by him.

Date: 23/8/2019

Place: New Delhi, India

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(Murtaza Hasan)

Chairman Advisory Committee

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Kundan Kumar

Date: 22/8/2019 **(Kundan Kumar)**

New Delhi

Dedicated

To

My beloved parents

&

My respected teachers

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

BCM	Billion Cubic Meter
VMD	Volume Median Diameter
NMD	Number Median Diameter
ICAR	Indian Council of Agricultural Research
ET	Evapotranspiration
WUE	Water Use Efficiency
CPCT	Center for Protected Cultivation Technology
IARI	Indian Agricultural Research Institute
WSP	Water Sensitive Paper
lpm	Liter per minute
EC	Electrical Conductivity
RH	Relative Humidity
Kg	Kilogram
m	Meter
cm	Centimeter
CRD	Completely Randomized Design
R^2	Coefficient of Determination
ANOVA	Analysis of Variance
DF	Degree of Freedom

India occupies 2.4% of the world's land area and supports over 17.5% of the world's population. India has more arable land area than any country except the United States of America, and more water occupied area than any country except Canada and the United States of America. It is estimated that by the year 2050 Indian population is going to reach 1.6 Billion and food requirement to feed this population will be about 333 million tons, whereas at present (2017-18) the food grain production is about 278 million tons. To meet high food grain production there are many constraints like water scarcity, climate change, industrialization, urbanization and decreasing land holding. For increasing food production there is need for adoption of new technologies, which can overcome most of the biotic and abiotic constraints like protected cultivation, soilless culture, hydroponics, aquaponics, aeroponics.

. Aeroponics is the most advanced form of protected cultivation, where plants can be grown round the year in closed dark chamber saturated with an aerosol of nutrient solution (Christie and Nichols, 2003). The sprayed nutrient solution that is not absorbed by the roots is usually re-sprayed using a re-circulation system or it is discarded directly. The aeroponics systems for potato seed production is very recently used in Europe. Until 10 year ago, the use of this technology was not used much for crop production. Only some countries such as China and Korea were using aeroponics for the commercial production of potato quality seeds (Kim *et al.,* 1999). Nowadays, aeroponics is being adopted successfully in South America (Mateus-Rodriguez et al. 2011) and attempts are made to introduce this technology in some developing country (Otazú, 2010). Aeroponics system is ten times more successful than conventional techniques, such as tissue culture and hydroponics, which take longer cultivation time and are also more labour intensive (CIP, 2008). Aeroponics system can be effectively used for potato propagation (Goo *et al.,* 1996; Ritter *et al.,* 2001; Factor *et al.,* 2007).

In traditional field farming system there are many challenges like high risk of soil disease, more harvesting and growing time compared to aeroponics system for growing potato, which leads to being sold for more expensive prices to earn back the time. Soil is used as media for growing potato crop and hence longer time is required for decomposition of organic materials. Pesticides are used, which is harmful for health. In a developing country like India, it is very important to use resources like water, sunlight, soil and money most efficiently. Aeroponics system has very high water use efficiency. Almost 99 percent of the water is used without any pesticides. Water soluble fertilizers are used leading to safe and healthy produce of horticultural crops. In aeroponics system all major and micro nutrients are sprayed directly to the plant roots, which results in faster growth of crops.

NAAS (2019) Policy paper on Vertical Farming explored the potential of alternative vertical farming as the sustainable solution for supplement of additional food requirement for urban population in 21st century. The paper explained the importance of various components of vertical farming mainly consisted of aeroponics, hydroponics, aquaponics etc. for growing high value nutritious horticultural crops. Design of structures and water & nutrient management linked fertigation scheduling are the important researchable issues suggested for popularization of vertical farming.

Hasan (2018) presented the details of the protected soilless cultivation technology, fertigation scheduling, drip irrigation & fertigation system details, protected structures suitable for soilless hydroponics system, plug tray nursery technology, hydroponics & aeroponics cultivation technologies for vegetables & flowers, GAP & IPM suitable for hydroponics cultivation technology suitable for Indian farmers & growers. Detailed information related to various aspects of drip irrigation & fertigation, soilless media properties, nutrient formulation techniques & formula, major & micro nutrient fertigation scheduling details for various flowers & vegetables were explained.

Ahirwar and Hasan (2018) reported the possibility of successively growing colored capsicum in soilless system inside greenhouse, which is one of the popular mode used in aeroponics system. They evaluated the impact of EC of irrigation water on water uptake by capsicum in soilless media. Electrical conductivity was found to be the most important index for fertigation management in soilless system.

Lettuce *(Lactuca sativa)* has excellent potential as a year-round greenhouse crop. Lettuce, a good source of Vitamin A, E and folacin, is considered a healthy food choice. With aeroponics, growers can produce lettuce year round, with the potential for more plants per area as well as faster growth and bigger lettuce heads by using very less water and nutrients.

Many studies have clearly shown that aeroponics promotes plant growth rates through optimization of root aeration because the plant is totally suspended in air, giving the plant stem and root systems access to 100% of the available oxygen in the air. Droplet size and frequency of exposure of the roots to the nutrient solution are the critical factors which may affect oxygen availability (Jones J. B., 2014). Large droplets lead to less oxygen being available to the root system, while fine droplets produce excessive root hair without developing a lateral root system for sustained growth (Margaret, C.2012). Three broad categories are generally used to classify droplet forming systems and droplet size; regular spray nozzles with droplet size >100 µm (spray), compressed gas atomizers with droplet size between 1 to 100 µm (fog), and ultrasonic systems with droplet size 1 to 35 µm (mist) (Weathers *et al.,* 2008).

For high-pressure atomization nozzles, the droplet size is classified fine atomization mist of 10 to 100 microns. However, in the aeroponics system, the ideal droplet size range for most of the plant species is in-between 30 and 100 microns. Within this range the smaller droplets saturate the air, maintaining very high humidity levels within the growth chamber. The conventional wisdom is that droplets below 30 microns tend to remain in the air like a fog and fail to achieve continuous plant growth. While droplets size more than 100 microns tend to fall out of the air before containing on the plant root, and too large droplet means less oxygen is present in the growth chamber (Lakhiar *et al.,* 2018). It is essential to select the suitable atomization nozzles to produce required droplet size. Selection of atomization nozzles should be based on the requirements of the aeroponic system mainly plants and other nozzle characteristics.

Indigenous aeroponics chamber design is required along with the protocols for nozzle delivery and fertigation scheduling for popularization of aeroponics system in India. Many research has been done on aeroponics system for potato crops but very few for lettuce and their fertigation scheduling. Keeping the above scenario and challenges following objectives were taken up.

1. Design of aeroponics system for lettuce.
2. Evaluation and standardization of nozzles for efficient delivery of water and nutrient for aeroponics system.
3. Development of fertigation scheduling for lettuce grown under aeroponics system.

CHAPTER II REVIEW OF LITERATURE

At present, hunger and poverty are big challenges for whole world in order to maintain and fulfil the demand of food and making agriculture sustainable. Day by day world population has been increasing and simultaneously cultivable land decreasing, thereby there has been paradigm shift towards strategy to increase the productivity of food grains (Alexandratrs and Bruinsma 2012). In future (By 2050), additional 60% to 65 % world food production will need to feed the growing large urban population (Foote 2015). Almost 1/4th of cultivable land has been unproductive land and not suitable for cultivation, thereby forcing us to use of natural resources like soil, water and air in sustainable way. Soil degradation, climate change improper management of soil, rapid urbanization, continuous cropping, frequent drought etc. are the major problems behind the reason for soil to become unproductive and infertile (Popp *et al.,* 2014). Due to unproductive, infertile soil and scarcity of water, the global food production may not be sufficient to feed an increasing population and provide food security for world population. Also, due to rampant biotic and abiotic stress leading to insect, pest attack, droughts, floods and high winds in the open field cultivation has been seriously affecting the crop yield. Traditional open field cultivation requires more area for cultivation, more land preparation expense, large number of labours and higher amount of water. In contrast, protected cultivation technology requires less area, inputs mainly water and has been able to overcome most of the biotic and abiotic stress factors for round the year production of high quality horticultural produce. Aeroponics system has been the most advanced form of protected cultivation technology.

This chapter includes the objective wise review of available information on design and evaluation of aeroponics system, evaluation and standardization of nozzles for aeroponics system and development of fertigation scheduling and its effect on the growth parameters and yield of lettuce crop in controlled environments.

2.1 Design and evaluation of aeroponics system under controlled environments

Ritter *et al.* (2001) conducted experiment in two different cultivation system i.e. aeroponics and hydroponics. The production of potato minitubers were used for comparison. The selected plants were found to show increased vegetative growth, delayed tuber formation and a drawn-out vegetative succession of almost seven months later transplanting in aeroponics system of cultivation. The tuber yield per plant in aeroponics system was almost 70% higher and tuber number more than 2.5 fold higher compared to hydroponics. The average tuber weight was reduced by 33% in the aeroponics system.

An aeroponics system for the production of root crops used in the herbal and phytopharmaceutical industries was developed at the Campus Agricultural Centre of the University of Arizona in Tucson, Arizona by Hayden *et al.* (2002). An A-frame aeroponics system was designed to maximize root yields and permit free access to the roots for monitoring. Burdock (*Arctiumlappa L.*) plants were grown in aeroponics with controls grown in a greenhouse soilless potting mix for ten weeks in greenhouse. Various traits such as dry weight of aerial parts, roots and chlorogenic acid concentration in the dried roots were determined. The biomass yields of the aerial parts were significantly higher whereas the root biomass showed no significance difference in the aeroponically grown plants compared to the controls. The concentration of chlorogenic acid were also not significantly different. The plant-to-plant variability was significantly lower in the aeroponically grown plants, which implicates the potential for better and more consistent phytochemical yields using aeroponics technique.

A study was conducted by Farran and Castel (2006) for minituber production through aeroponics. They found more number of stolons at minimum plant densities. Preeminent results were obtained after harvesting every 7 days, a total tuber yield of 118.6 g per plant was obtained. Harvesting periods did not have an effect on the number of minitubers and yield with density of 100 plants/m^2. The highest productivity found the study was 800 minitubers/m^2 for weekly harvests and minimum plant density (60 plants/ m^2).

Fascella and Zizzo (2006) studied aeroponics and soilless cultivation. The study was carried out in a climatic controlled greenhouse with the objective to evaluate the productive and qualitative changes of the two dissimilar growing systems. They found that plants in the two growing systems gave an equal amount of flower stalk (26 in 11 months) while aeroponics cultivation produced the highest ones, as well as the higher number of leaves (30 vs. 18 per plant), with the extreme leaf size and petiole length and also soilless anthuriums provided flowers with the broadest spathe.

Abdullateef *et al.* (2010) investigated the effect of number of plants in aeroponics system on minituber production in which nutrient solution was sprayed by fog nozzles every 5 min for 20 seconds. Minitubers larger than 20 mm were removed weekly in eight harvests in total and last harvest, all minitubers larger than 5 mm were evaluated. The highest number of minitubers per plant was obtained in case of 25 plants per m^2 with 40.82 in total, regarding tubers larger than 20 mm with 32.2. The yield per m^2, however, was not affected by the plant density. In the case of 25 plants per m^2, an average of 805 minitubers >20 mm or 11.1 kg could be harvested per m^2 compared with 11.2 and 10.4 kg per m^2 for 35 and 50 plants per m^2, respectively.

Rodriguez *et al*. (2013) compared the aeroponics technology with other mini-tuber production systems developed in Latin America. Various systems such as conventional, semi-hydroponics, and fiber-cement tiles technology were compared. They found that aeroponics as promoted by the International Potato Center (CIP) has several merits over other methods, including high multiplication rates (up to 1:45), high production efficiency per area (> 900 mini-tubers per m^2), savings in water, chemicals and/or energy, and positive economic indicators.

Kaur and Kumar (2014) states that in aeroponics technology plants can be grown in a conditioned, pest and disease free environment. They highlighted that aeroponics system has the potential to produce enhanced vegetative growth without use of any artificial hormones, pesticides or insecticide. This soil-less culture can overcome all the constraints that are present in soil culture production. By using aeroponics systems, 98 percent of total water was saved because of recirculatory system. Fresh, clean, healthy, efficient and rapid food production can be obtained from aeroponics systems throughout the year. Due to clean and sterile growing conditions, plant diseases and infections reduce up to a great extent.

Maroya *et al*. (2014) conducted several experiments at International Institute of Tropical Agriculture Headquarters at Ibadan, Nigeria. The study aimed at checking the viability of aeroponics system for yam propagation and seed yam tuber production. The experiment tested fresh vine cuttings of five yam genotypes of two species in an aeroponics system. Three genotypes of *Dioscore arotundata* and two yam genotypes of *D. alata* were evaluated. The rooting of vine cuttings varied significantly among genotypes with a maximum of 98% for TDa 98/01176 and a minimum of 68% for TDr 89/02665. The weight of Mini-tubers which were harvested after 4 months of growth in aeroponics weighed between 0.2 and 2.7g. A second harvest 6 months later gave mini-tubers of up to 110g. A significant difference among the genotypes for rooting at 2 weeks after vine planting was found, number of plant surviving at 90 days after planting and % of plants with bulbils.

Perez V. M. (2014) studied the energetics in a vertical aeroponics farm and found that the usage of energy only for lighting is about 133 million kWh, which is comparable to 12,330 American families throughout a year, the water foot print is 35 times less than traditional crops, which is about 237l H_2O/kg of lettuce produced. They also included data of the carbon foot print which is 56,260 tons of CO_2 per year, comparable of releases made by estimated 3,210 Americans throughout a year. The productivity of the vertical farm of 10 floor vertical farm and sizes of 100m × 100m with arranged drums would be about 8,485 tons of lettuce per year. The produce was adequate to fulfill the everyday requirements of fresh vegetables of more than 100,000 persons if only were eating lettuce.

Tierno *et al.* (2014) evaluated different systems cultivars for production quality in potato. Aeroponics, greenhouse beds and two types of cultivation systems were analysed for its performance through peat moss substrate, 3 potato cultivars (Agria, Monalisa and Zorba) with changed vegetative cycle. Plants within aeroponics system had shown increased growth. The vegetative cycle extended between 12 % and 36 % compared to the plant produced in greenhouse beds. Aeroponics system had shown 34 % to 87% higher tuber yield per plant for earlier cultivars Zorba and Monalisa Size distribution for Mini tuber production was also better in aeroponics. The decrease in the % of tubers lower than 12 mm of between 32 and 85 percentages. In soil-less cultivation system average tuber weight improved in Zorba and Monalisa above 60 % but was lesser for Agria.

Bag *et al.* (2015) evaluated the performance in aeroponics system of three potatoes (*Solanum tuberosum* L.) varieties, such as Kufri Megha, Kufri Himalini and Kufri Himsona installed under net cum polyhouse. The result indicated that there was substantial decrease in per plant yield in both Kufri Himalini (162 g to 102 g) and Kufri Himsona (138 g to 39.30 g) accompanied by decrease in number of tubers per plant (38 to 27 tubers in Kufri Himalini and 29 to 11 tubers in Kufri Himsona) and average mini-tuber weight also decreased from 4.40g to 3.90g in Kufri Himalini and 5.04g to 4.15g in Kufri Himsona.

Barbosa *et al.* (2015) compared the land, water, and energy requirements of hydroponics system with conventional agriculture for lettuce cultivation in Yuma, Arizona, USA. They obtained information from crop budgets and administrative agricultural statistics and contrasted with theoretical data for hydroponic lettuce production resulting from using engineering equations populous with literature values. Yields of lettuce per greenhouse unit (815 m) of 41 ± 6.1 kg per m per y had water and energy demands of 20 ± 3.8 L per kg per y and 90,000 ± 11,000 kJ per kg per y (±standard deviation), respectively. In comparison, conventional production yielded 3.9 ± 0.21 kg per m per y of produce, with water and energy demands of 250 ± 25 L per kg per y and 1100 ± 75 kJ per kg per y, respectively. Hydroponics produced 11 ± 1.7 times more yields but required 82 ± 11 times more energy compared to traditionally produced lettuce.

Salachas *et al.* (2015) studied the consequence of the available root zone volume on yield and quality characteristics of aeroponically grown sweet basil (*Ocimumbasilicum*, L.) plants. Plants were cultivated with 10 m length and 0.67 m width for depths of 0.15 m, 0.30 m and 0.70 m respectively. Plants growing in canals with the minimum depths 0.15 m and 0.30 m, results increase in dry biomass production, height of plants, root length, leaves per plant, total chlorophyll content, net photosynthesis rate, transpiration rate and stomatal conductance, with comparison to plants growing in canals with the highest depth of 0.70 m and also exhibited statistically increased root dry biomass production. No significant differences were found for the total leaf phenolics content. They also found crucial oil content 0.83%, 0.79% and 0.80% (v/w) for the three growing canals with depth 0.15m, 0.30m and 0.70m respectively, characterized by more linalool content of 63.85 %, 67.02 % and 66.58 % respectively.

Rykaczewska (2016) performed an experiment cultivated in aeroponics on potato minituber production from micro tubers with a density of 36 and 42 plants per square meter and by traditional method. The experiment was continued over the course of 2 years 2012–2013 in Jadwisin, Poland and observed that the minituber production was on average 32.5–36.0 per plant and 1268–1396 per m^2 and number of minitubers was two to three times greater in the case of aeroponic production than by traditional method.

Montoya *et al.* (2017) developed an automatic monitored Arduino's based open software platform for aeroponics irrigation system, implemented with analog and digital sensors used for measuring the temperature, flow and level of a nutrient solution in greenhouse. The pH and EC of nutrient solutions were checked using the Arduino's differential configuration. They also found that the overall evaporation throughout the 78 hours' test was 11.90 Litres, whereas the total evapotranspiration was 63.15 Litres. The resultant single plant transpiration rate was 2.18 ml per h. The results showed that Arduino based open software can be used for data acquisition system with differential output sensors like EC and pH probes, using the differential configuration

Qiansheng *et al.* (2018) evaluated aeroponics system and measured the shoot and root length, other root parameters, and mineral content of two lettuce cultivation in aeroponics system and compared with hydroponics and soilless culture. They found that aeroponics system remarkably enhanced root parameters with a significantly higher root biomass, root and shoot ratio, and higher total root length, root area, and root volume. Yet, the higher root growth did not increase to higher shoot growth compared with hydroponics, because of inadequate availability of nutrients and water. It was observed that aeroponics systems may be superior for high value true root crop cultivation.

Singh *et al.* (2018) found that under ideal operating microclimatic conditions has significant effect on sustainable vegetable productions and also it results in shifting of climatic consequences and soil associated problems. The soilless production in open field and greenhouse systems with competent application of water and nutrients has significantly enhanced the greenhouse cucumber productivity compared to traditional cultivation under both protected and open field environments. Adopting controlled hydroponic system also one of the best method to increase water and nutrient use efficiency of cucumber cultivation through zero environmental pollution. The year round cultivation of cucumber has become possible with protected cultivation by making an economically feasible technology for the cultivars. Also, an effort has been tried to make the growth in soilless or hydroponic cucumber cultivation with irrigation and fertigation management, economic feasible and the improving income of growers.

NAAS (2019) Policy paper on Vertical farming cited the importance of vertical farming in paving the way for additional food supplement for burgeoning urban population. Vertical farming proved to be inputs efficient, sustainable and modern technology suitable for rural and urban youths and can be replicated on large scale in peri-urban areas. The important researchable issues highlighted related to vertical farming are cost effective design structures, soilless media, plant nutritional demand, irrigation & fertigation details, plant protection, automation, value addition & marketing.

2.2 Evaluation and standardization of nozzles for efficient delivery of water and nutrient for aeroponics system

Various factors affecting quality and coverage of spray are nozzles type, spray particle size, spray angle, spacing between the nozzles, spray physical properties, quantity of spray, nozzle pressure and distance of nozzle from the susceptible root of crop. Droplet size is also an important parameter for selection of nozzles for aeroponics system. The optimum droplet size for aeroponics system has range for most of the crops species is in between 30 and 100 microns. In this range the lower size of droplets saturates the air and preserving humidity levels about 100% inside the growth chamber. The droplets size lower than 30 microns tend to remain in the air like a fog and fail to attain continuous plant growth whereas droplets size of higher than 100 microns tend to fall out of the air before containing on the plant root, and too big droplet means less oxygen is available inside the growth chamber (Lakhiar *et al.,* 2018). This section includes works done by researchers on various factors that affect spraying quality and coverage.

Azimi *et al.* (1985) reported that if height of nozzle increased then distribution of spray improved and allowed nozzle arrangements at reduced pressure and/or increased spacing. When pressure will increase with its range then distribution of spray fan nozzles improved. Higher pressures created wider spray angles that created less variation in the spray distribution across the swath. The capacity of smaller nozzle was more responsible for poor distribution due to fluctuations height and pressure. when they were operated at 510 mm or larger spacing.

Avvaru *et al.* (2006) conducted experiments to understand the mechanism by which the ultrasonic vibration at the gas liquid interface causes the atomization of liquid. The average droplet size produced by the pseudo-plastic liquid is less than that produced by the viscous Newtonian liquid having viscosity equal to zero-shear rate viscosity of the shear thinning liquid. The droplet size was found to increase initially with an increase in the viscosity up to a certain threshold viscosity after which the droplet size was found to decrease again. Droplet size distribution was found to be more compact with an increasing viscosity of the atomizing liquid.

Ali *et al.* (2015) compared the hydroponic system with aeration to the aeroponics system to study the effect of aeration on the root problems. The results found that the root length increased from 17.17 to 19.13 cm with increasing flow rate from 1.0 to 2.0 L h^{-1} and from 17.45 to 19.56 cm with increasing flow rate from 0.5 to 1.5 L h^{-1} in aeroponics and hydroponic system respectively. The fresh and dry mass of shoot and root as well as the total nutrients uptake were found to be higher in aeroponics system over those of hydroponic systems. The average nitrogen, phosphorus, potassium, calcium and magnesium uptakes were 3.29, 1.25, 2.46, 0.43 and 0.44 % and 2.13, 0.82, 1.81, 0.32 and 0.40 % for aeroponics and hydroponic system, respectively whereas, the average nitrate content was 155.52 and 113.73 mg/ plant for aeroponics and hydroponic system, respectively. The average water use efficiency was 4.75 and 2.93 kg/m^3 for hydroponic and aeroponics system, respectively.

Filho *et al.* (2018) studied on types of nozzle and the coating on the bucket's inner wall on the yield of basic potato seed minitubers at the Federal University of Viçosa America. Tubers of potato cv. Agata were sprouted in a non-acclimatized greenhouse from June to September 2013. Six treatments were evaluated, three types of misting nozzle (32 L per h with anti-drip, 32 L per h without anti-drip, and 9 L per h without anti-drip) and two types of bucket inner lining, with and without polyurethane, with four replications. Dry weight of roots, stems and leaves besides minituber number and tuber fresh weight were evaluated. The "UFV Aeroponics System" effectively produces minitubers and should be equipped with a fogger with an outflow of 32 L per h without anti-drip and no inner lining of the bucket for optimal yield.

2.3 Development of fertigation scheduling for lettuce grown under aeroponics system

Mineral nutrition is one of the basic requirements for plant growth and development. For plants grown by aeroponics system, the composition of nutrient solution is of greatest importance. To optimize plant nutrition, one should consider both, the concentration of nutrients (i.e. their absolute content) and their ratio (i.e. relative content) in nutrient solution.

Mairapetyan and Tadevosyan (1999) reported that an optimization of *Lawsoniainermis* and *Indigofera articulate* nutrient solution for higher leaf productivity in open-air required high demand of nitrogen and potassium. Compare to demand of nitrogen and potassium phosphorus was moderate. The optimal nutrient solution for better leaf productivity of Henna and Indigo N, P, K ratio for, 36:28:36 and 43:23:34 per cent, respectively.

In order to evaluate the influence of different quantities of nitrogen in the nutrient solution on growth, development and nitrate content in aeroponically grown lettuce (*Lactuca sativa*) experiments were conducted by Marsic (2002). The results of experiments showed NO_3^- content could be reduced in aeroponically grown lettuce by lowering the NO_3^-N in the nutrient solution. On statistically evaluating the NO_3^- content in lettuce plants it was found that a sufficiently low NO_3^-N concentration was there in the leaves of lettuce plants grown on nutrient solution with 4mM NO_3^- N in experiments.

Stewart and Lovett-Doust (2003) studied and reported in hydroponic cultivation that total biomass was significantly higher with minimum P treatment (5 mg per liter), followed by the highest P level (200 mg per liter). The higher biomass of plants in the minimum P level was attributed to significantly greater biomass of reproductive tissues and stems. The leaf dry mass with higher P treatment, whereas the other treatment groups observed significantly low leaf dry mass.

Manukyan, A. E. (2005) investigated maximum oil yields of catmint in hydroponics system and compared with soil cultivation. They found five times greater yields than those under the soil control. In catmint, the maximum content and yield of essential oil were 0.245 percentage with high P at a ratio of N: P: K (15:70:15 %), and 1.56 ml per plant (with high N) under hydroponics conditions whereas 0.183 per cent and 0.20 ml per plant were found in soil.

Frezza *et al.* (2005) conducted research on butter head lettuce in order to evaluate the quality in a soilless culture system. Two experiments were performed on butter head lettuce in soilless system. The results showed that plants harvested from the soilless culture had a lower dry weight and leaf area, however significant differences were observed in productivity. Nitrate content was significantly affected by the production system but no difference was there in ascorbic acid. Floating system results showed some variation between the two years of the experiment. In two major inorganic cations K^+ and Mg^{2+} differences were observed between plant harvest from all systems. No variation in incidence of tip-burn relating to different calcium levels was found in lettuce grown in perlite.

Tshisola, S. N. (2014) investigated methods of increasing the number of minitubers produced in aeroponics system including the nutritional requirements of potato minitubers. The interaction between harvesting intervals and plant densities did not influence plant growth, minituber quality or yield. Total tuber number and tuber fresh and dry weight was higher at the irrigation frequency of 20 minutes. The interaction between irrigation frequencies and cultivars on the response to macro and trace elements was not significant for sodium and iron but was for phosphorus, potassium, calcium, zinc and aluminium.

Albornoz and Lieth (2015) conducted an experiment using increasing concentrations of macronutrients applied to the root zone in an aeroponics system in at Davis, California, USA. The result showed that the leaf photosynthetic rates increased when the solution concentration was raised from 0.6 to 4.8 dS m^{-1}. The improvement in photosynthetic rates was directly reflected to higher concentrations of N, P, Mg, and S in leaves and the maximum growth was achieved with 1.2 and 4.8 dS m^{-1} solution concentrations, while at 10.0 dS m^{-1} leaf production was reduced by 30%.

Oraby *et al.* (2015) found that a thoughtful usage of stresses can efficiently stimulate tuberization in aeroponics. They also evaluated the effect of the nutrient solution temperature and the application of different stress treatments at tuberization on several growth variables for two potato cultivars grown in an aeroponics system. The result showed that the plants subjected to nitrogen withdrawal at tuberization out-performed plants of the other treatments as well as the control and exhibited more rapidly tuberization growth, more mini-tuber number and weight as well as significantly more root length, stolon number per plant and number of stolon branches per plant.

Ahirwar and Hasan (2018) explained the greenhouse soilless production technology for growing colored capsicum with drip fertigation. Soilless grow bag technology with stake low pressure drip fertigation system was used to grow colored capsicum inside climate controlled greenhouse. Fertigation scheduling details were discussed and the importance of Electrical conductivity EC in fertigation management was discussed. It was shown that water and nutrient uptake depended upon EC and various major and micro nutrient dosages used in fertigation.

Hasan *et al.* (2018) reported various important soilless hydroponic technologies for growing different horticultural crops under protected cultivation. They explained in details various aspects of irrigation and fertigation scheduling suitable for hydroponics, soilless cultivation and aeroponics system. Protected structures suitable for hydroponics cultivation, soilless media detail, fertigation management details, GAP & IPM and policy issues related to soilless hydroponics technology were discussed in detail.

The experiments were conducted in the greenhouse of Center for Protected Cultivation Technology (CPCT), ICAR-IARI to design aeroponics system for lettuce, evaluate and standardize nozzles for efficient delivery of water and nutrient for aeroponics system and develop fertigation schedule for lettuce grown under aeroponics system. The major activities under taken to complete these objectives were selection of appropriate size of growing chamber, determination of optimum size of pump, evaluation of nozzles for lettuce crop, determination of crop water requirement and fertigation schedule based on major and micro nutrient requirement as per the different growth stage of lettuce and statistical analysis of data developed for aeroponics system.

3.1 Description of study area

3.1.1 Location: -

The experiments were conducted in climate controlled greenhouse located at CPCT, ICAR-Indian Agricultural Research Institute (IARI), New Delhi which lies between Latitude of 28°37’22” to 28°39’05” N and Longitude of 77°08’45” to 77°10’24” E, at an average elevation of 230 m above the Mean Sea Level (fig 3.1).

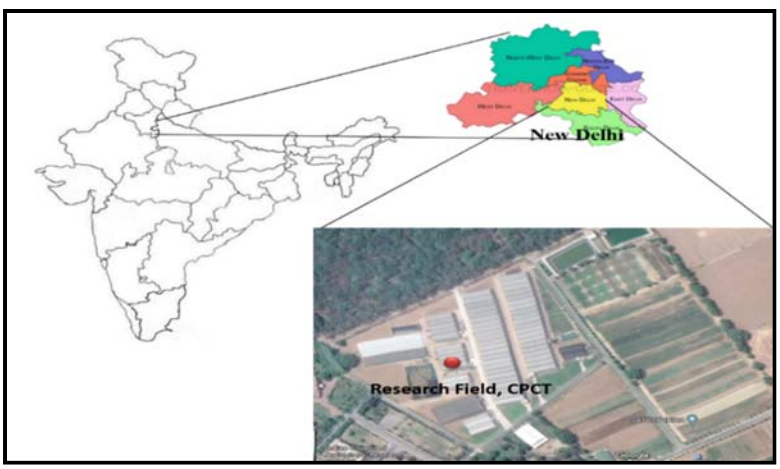


Fig 3.1: Location of the experimental site

3.1.2 Climate

The climate of Delhi region is typical humid subtropical and semi-arid with severe summer and chilling winter temperatures. It comes under the agro-climatic zone of “Trans-Gangetic plains” in the agro-ecological region-IV (Ajdary *et al.*, 2007). Maximum temperature was recorded during May to June ranging between 41^0C to 46^0C while minimum temperature (4^0C to 7^0C) reported during January. Average annual rainfall of Delhi is 740 mm and 75% of rainfall depth is received during the monsoon season between July to September. Average relative humidity varies from 34.1% to 97.9% and the average wind speed ranges from 0.45 to 3.96 m/s.

3.2 Aeroponics Systems Design

Aeroponics is the soilless protected cultivation, where plants can be grown round the year in closed dark chamber saturated with an aerosol nutrient solution (Christie and Nichols, 2004). The study of this research sought to evaluate the performance of three different nozzles by same aeroponics system. It is therefore imperative to design aeroponics system that can house each nozzle in a single unit growing chamber. The functional requirement of design of aeroponics system consists of aeroponics growing chamber, irrigation and fertigation system, size of lateral and main pipe line, selection of nozzles, size of pump, selection of crop, plant to plant spacing and root length of crop. The schematic representation of designed aeroponics system was given in fig. 3.2.

3.2.1 Design of Growth Chamber

Growing chamber consists of a chamber with provision of suitable micro climatic environment and plant holding with growth system consisting of the pots and plant holding tray. The size of chambers depends upon crop parameters mainly plant spacing, root and shoot length. The growth chamber works as enclosed system for the roots of the plants and serves as the enclosing medium for water and nutrient delivery. This part of the system provides support to the plant and provides control environment access to the plant roots. Their dimensions are usually dependent on the type of crop and number of plants. Growth chambers are made opaque or covered with black polythene to avoid the penetration of light into the root of plants in chamber. The outer body of aeroponics growth chamber is usually made of Wood plastic composite (WPC), Aluminium composite board (ACB), Polyvinyl chloride (PVC), plastic totes, polypropylene (PP), acrylonitrile butadiene styrene (ABS) and acrylics polyethylene (PE), while Styrofoam sheets are commonly used inside the body.

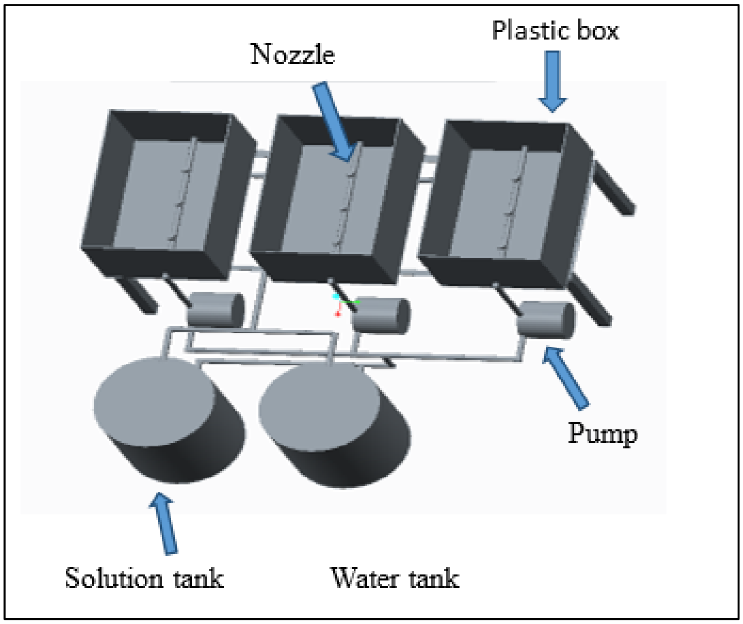


Fig: 3.2 Schematic representation of designed aeroponics system

3.2.2 Irrigation and Fertigation System

The main function of the irrigation and fertigation system is to send pressurized water and nutrient solution to the growing chambers. The capacity of pump is dependent on the system's production capacity. Controllers or timers are usually connected to the pump using valves to help regulate the flow and distribution of water and nutrients. The nutrient solution is provided in cyclic rotation through a sequence of separate tanks, filters and valves before final distribution to the plant roots through the nozzle. The aeroponics system utilised a high pressure pump which was used to atomize the water through small orifice nozzles to create water droplets of 30-100 microns in diameter (fig 3.3).

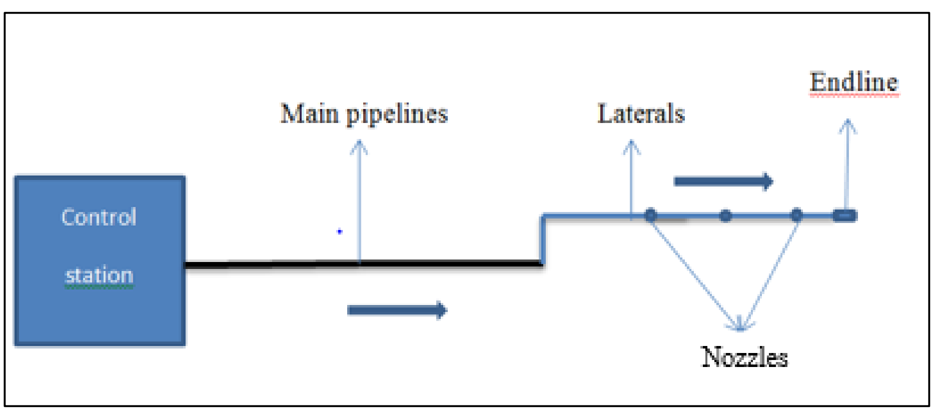


Fig: 3.3 Flow chart for the aeroponics system

3.2.2.1 Selection of Nozzles

The effective diameter coverage and height of the growth chamber are two important parameters considered in the selection of the nozzle. For irrigation and fertigation of the crop roots in a growth chamber, spray is required and it is supplied through nozzle. The number of nozzle per lateral was determined based on the size of growth chambers on the lateral. On the above considerations the growth chamber was designed to have three nozzles on the lateral. Three different types of nozzle were selected on the basis of height, spray angle and discharge of the nozzle. The different nozzles used in the aeroponics system were given in the table 3.1.

Table 3.1 Types of nozzle used in aeroponics system

Serial No.	Item	Types
1	Nozzle 1 (N1)	Flat fan 11004
2	Nozzle 2 (N2)	Hollow cone
3	Nozzle 3 (N3)	Flat fan 11006

3.2.2.1.1 Height and Spray angle of Nozzles in Aeroponics System

In aeroponics hollow cone and flat fan nozzle are commonly used. The spray angle of flat fan nozzle varied from 65º to110º and for hollow cone 45º to 90º respectively. The effective height covered was 50 cm by both the nozzle with good uniformity.

3.2.2.1.2 Discharge rate of the nozzles

The discharge of the nozzle was collected in a beaker for one minute at spray patternator. The discharges were recorded at 2.0, 2.5, 3.0 and 3.50 kg/cm^2 pressure and replicated three times. The average discharge of the replicated nozzle was calculated and relationships between pressure and discharge were developed.

3.2.2.1.3 Determination of Spray droplet size

The experiment with patternator was conducted at testing laboratory of Division of Agricultural Engineering, IARI, New Delhi. A constant pressure regulator and a pressure gauge were placed close to the nozzle to maintain uniform pressure. Adjustments were provided to hold the nozzle at a certain height during spraying.

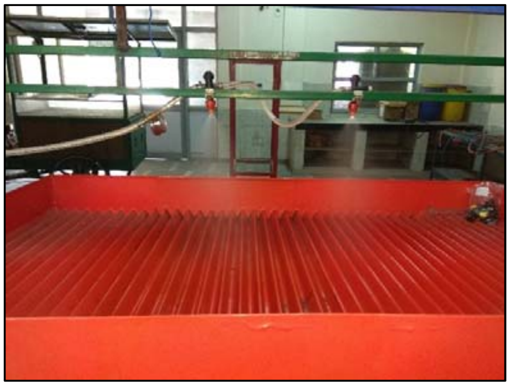
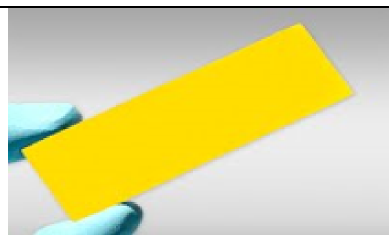
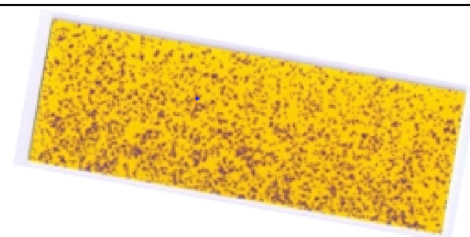


Plate 3.1 Droplet size determination on Spray Patternator

The droplet size was measured by measuring diameter of the circles formed by droplet deposition on water sensitive paper.





WSP before spotting **WSP after spotting**

Plate 3.2 Determination of droplet characteristics using water sensitive paper

Volume median diameter (VMD) and Nominal mean diameter (NMD) are the most widely used parameters to represent droplet sizes in micrometres. VMD is the diameter of the droplet that divides the volume of the spray into two equal halves. Representative droplet spectrum of droplets is divided into two equal parts by volume, so that one half of the spray volume contains smaller droplets than a droplet whose diameter is the VMD and the half of the volume contains larger droplets (Matthews, 1988). NMD is the average diameter of the droplet, which divides the number of droplets into two equal halves. In other words, it is the diameter of the spray droplet, which divides the droplet spectrum into two halves whereas, the total number of spray droplets which are smaller in size will equal to the number of spray droplets which are larger in size (Matthews, 1988).

3.2.2.1.4 Procedure for measurement of Spray droplet size

The droplets collected on water sensitive paper of 26×76 mm^2 was scanned later through a scanner and a spectrum of distributed droplet size of spray was obtained. This spectrum was further analysed in software**.** Scanner machine was used for scanning of water sensitive paper at 600 dpi resolution. The scanned image was converted to Jpg file. This image file was used by BIOVIS image plus software. The image file was loaded into the current window through the software. The image files on jpg format were loaded on the software. The dark spots in X and Y direction were analysed in the software. The dark spots were scanned in the software and the different sizes were detected in terms of pixel till all the sample area exhausted. Based on the magnification used during scanning through the scanning device, the program was used to convert the pixel size to the actual micron sizes which was pre-calibrated into the program initially by scanning an area of 1×1 cm^2 through scanner. The data thus obtained after running the software were total number of droplets, aspect ratio, major and minor axis length of droplets, area equivalent diameter, volume of droplets (plate 3.3). The droplets were arranged in ascending order on the basis of their equivalent diameter or volume equivalent to calculate VMD and NMD. Cumulative volume and cumulative numbers were calculated and the graph was plotted between percentage of volume and percentage of number both in X axis and area equivalent diameter in Y axis. Lines parallel to Y axis at 50 percent of volume and 50 percentage of number were the VMD and NMD respectively. The Droplet density was obtained by dividing total number of droplets to the scanned area analysis by software.

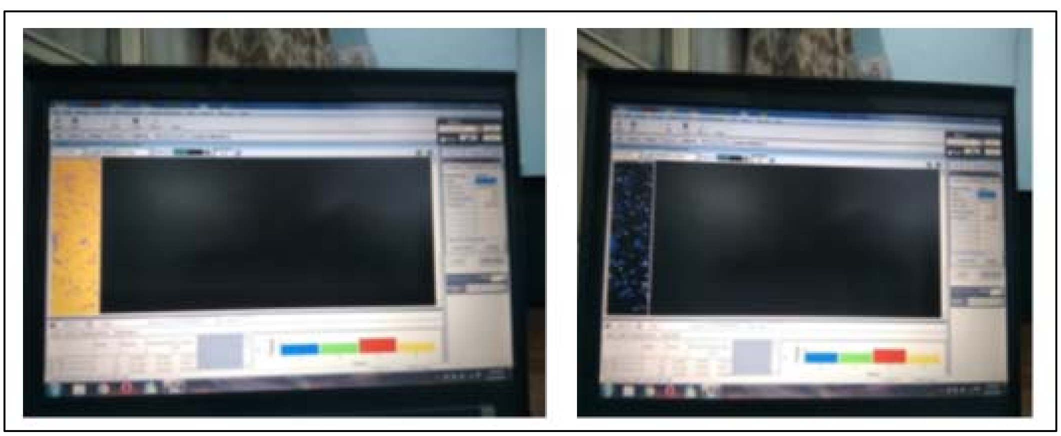


Plate 3.3 Scanned image of WSP before and after analysis with BIOVIS Software

3.2.2.2 Lateral Design

The lateral was designed based on the arrangement and number of the growth chamber. According to the experimental design for nozzle selection, three different nozzles were used in three different chambers and operated with the same nozzle pressure at a particular time. Thus, three boxes (growth chambers) were arranged parallelly on a supported table. The length of each boxes was 0.9 m. The lateral flow rate was determined using the equation 3.1 given by Phocaides (2000).

Lateral flow rate (LFR) = nozzle per lateral × nozzle flow rate ……………. (3.1)

3.2.2.3 Determination of the size of the pipelines

The selection of pipe sizes was based on the equation 3.2 by Phocaides (2000).

$$q = kdH^{x} \qquad \text{…………….} \; (3.2)$$

Where;

q = discharge of nozzle
H = pressure at the nozzle
k and d are coefficients; and
x = an exponent characterized by the nozzle flow regime and the flow rate curve as a function of pressure

The friction factor method, characterized by equation 3.3 by Phocaides (2000) was used in sizing the laterals

$$F_f = \frac{Po \times Pv}{Lc} \qquad \text{………..} \; (3.3)$$

Where,

F_f = Allowable Psi per 100” of pipe (psi/100” = 9.8 KPa/100m)
P_o = Operating pressure of nozzle
P_v = Allowable percentage pressure variance
L_c = Longest run of lateral line (critical length)

Friction pressure loss was computed using equation 3.4 by Phocaides (2000)

$$H_f = [0.2083] \left(\frac{100}{C}\right)^{1.852} \left(\frac{Q^{1.852}}{d^{4.866}}\right) \times 0.433 \qquad \text{………..} \; (3.4)$$

Where,

H_f = Friction loss per 100m length
C = Coefficient of retardation based on pipe material
Q = flow discharge
d = inside diameter of pipe

Main pipe: -

According to Phocaides (2000), the main pipeline is carefully chosen in sizes such that the frictional losses do not surpass approximately 15 % of the total dynamic head needed at the beginning of the systems piped network. Phocaides (2000) further stated that the flow velocity in the main pipeline should be kept under 1.7 m/s in plastic tubes and 2 m/s in other pipes (steel, aluminium etc.). Since the main pipeline supplies directly to the laterals without branching. Velocity through the main pipe line were calculated using equation 3.5

$$V = Q/A \quad \text{……………… (3.5)}$$

Where,

V = Flow velocity
Q = Discharge
A = Pipe cross-sectional area

3.2.2.4 Required Head

The component parts of the system are completed with pump, filters, non-return valve, union joints and shut off valve. The total pressure head required for the system was designed based on Phocaides (2000) sum of the following pressures:

i. Emitter operating pressure,
ii. Frictional loss in lateral line,
iii. Frictional loss in the valves and pipe fittings,
iv. Differences in elevation between pump and nozzle
v. Loss of pressure in head control.

The brake horse power was determined (Phocaides, 2000) using Equation 3.6:

$$BHP = \frac{Q \times TDH}{270 \times e1 \times e2} \quad \text{……………… (3.6)}$$

Where,

Q = flow capacity in $m^3/\square$,
e_1 = Pump Efficiency,
e_2 = Driving Efficiency,
TDH = Total Dynamic Head, and
270 = constant for metric units gives pump efficiency to range between 0.5 – 0.8

3.2.2.5 Selection of Feed Tank

In aeroponics cultivation water is continuously supplied throughout the growing period of crop. Minimum capacity of feed tank should be based on that which provide water and nutrient to the crop at least 20 to 30 days. So that plants could not suffer due to water and nutrient scarcity at the time of critical period of crop. Based on above consideration two 100 litre feed tank was selected to hold the nutrients and water respectively.

3.3 Growing media

Growing media provides for support of aeroponics plants and propagation for seeds. Since aeroponics is a soil-less cultivation, most seeds and seedlings are propagated using other growth media (Chiipanthenga *et al*., 2012). A good growing media must have following characteristics:

i. Provides base and plant support
ii. Reserves plant nutrient and water for few minutes
iii. Contains enough air to allow gas exchange in the root system

Fig: 3.4 Growing media for aeroponics system

Clay balls/clay pebbles are the commonly used growing media for aeroponics and hydroponics based soil-less system. It is the popular name of LECA (Light Expanded Clay Aggregates). It acts as planting medium and insulating material for growing plants in soil-less system. It is very light in weight, low density, neutral nature, provides balance of moisture & air and facilitates great ventilation for roots of plants (fig 3.4).

3.4 Selection of crop

For aeroponics cultivation, lettuce is one of the best suitable crops because it can be produced in a short period and high proportion of the harvested biomass is edible. Income per unit area per unit time is very high for lettuce and this can be grown throughout the year in controlled protected cultivation (Rackocy and Hargreaves, 1993).

a) Plant to plant spacing for lettuce in growing chamber

Generally, the plant to plant distance is taken 30 cm in soil cultivation. But in case of aeroponics systems plant to plant distance was kept less for lettuce with respect to soil cultivation due to continuous availability of water and nutrient throughout the growing season for plants.

b) Height of growing chamber

Height of growing chamber is depended upon root length of crop. Normally root length of lettuce in soil varies from 15 to 20 cm. In aeroponics cultivation effective root length of crop varied from40 to 80 cm because it is free to grow without any intervention.

c) Number of plants

In aeroponics cultivation spacing between plants is taken 15 cm (Hasan *et al*., 2018). Based on this spacing a plastic tote box of size 0.9m x 0.6m x 0.5 m was taken for growing of 24 plants per box.

Plastic tote box and styrofoam sheets based indigenous aeroponics system was designed and fabricated at Centre for Protected Cultivation Technology farm located at ICAR-IARI, New Delhi. The plastic material taken can withstand rot and continuous spray of water and nutrient, prohibits algal growth and its shape can be modificated as per the experimental requirement.

3.5 Selection of material

Based on the above requirement following materials were selected:

Table 3.2 Materials required for aeroponics system

Item	Quantity	Picture
Plastic box	3	
3/4” PVC Tubing		
3/4” Tees	6	
Nylon Drain Pipe Kit	3	
3/4" Elbows	12	
pressure regulator	1	
3/4” PVC to 3/4” Adaptor	6	
Cyclic digital Timer Selec Xt-546	1	
3/4" Valve	4	

3/4" Cap	3	
Nozzle	9	
2” Grow Cups	54	
Clay pebbles		
PVC Glue	1	
Silicone Caulk	1	
Pump	3	

3.6 Assembly of different component of the aeroponics system

After the materials and pipe sizes to be used in the aeroponics system were known, holes were punched in the ply board and through the sides (centrally) to pave way for the insertion of the pipes through the tote boxes. Same process was done beneath the tote boxes to allow for drainage. The lateral pipes were connected with main pipe and consequently to the pump. Completely automatic irrigation and drainage network consisting of nozzles, pumps, pressure regulator, water tanks, Pipes, end plugs, timer was set up in and around aeroponics chamber. The assembled aeroponics system was anchored with the GI pipe based stand for better manoeuvrability (plate 3.4).

Plate 3.4 Developed indigenous aeroponics system

3.7 Determination of crop water requirement for lettuce

In aeroponics cultivation, water is mainly lost due to transpiration and very less due to evaporation from growing media.

The daily ETc of lettuce in each growing boxes was determined by applying the continuity equation (Pelesco and Alagao 2014),

$$\text{Change in storage} = \text{Inflow} - \text{Outflow}$$

$$S_2 - S_1 = I_{added} - ETc$$

Where,

S_1 = Initial storage in litres

S_2 = Final storage in litres

I_{added} = irrigation water or nutrient solution added in litres

ETc = actual evapotranspiration of a growing box in litres

In the aeroponics system, the atomization spray time and interval time are the two essential factors related to irrigation scheduling for successful plant cultivation because aeroponics system is operated without soil. Therefore, it is essential to fix the atomization spray time and interval time based on the plant requirement. The inappropriate irrigation schedule could create serious problems for plant growth and affect the yield of crop. Generally, in aeroponics cultivation 30-sec on and 5-min off spray time and time interval are taken respectively (Ritter *et al*., 2001).

3.8 Determination of fertigation based on major and micro nutrient requirement as per the different growth stage of lettuce

3.8.1 Nutrient solution Feeding System

Nutrient feeding is the application of fertilizers to crops through water in recommended ratio. Nutrient feeding is also described as the application of fertilizers in the right combination, concentration, EC and pH for every fertigation cycle. For aeroponics systems, nutrient solution can be provided through the use of pumps, pipes, filters, irrigation timers, emitters and other irrigation equipment. Nutrient solution was supplied at frequent interval using irrigation timers with on/off facility as mentioned in the table 3.3.

Table: 3.3 Irrigation and fertigation time interval in aeroponics system for lettuce crop

Irrigation Scheduling				
Days	Spray ON time (sec)	**Spray interval (min)**		
		9 AM– 6 PM	**6 PM – 9 AM**	
SEASON 1 (10/12/2018 to 28/01/2019)				
0 - 10	20	4	8	
10 - 20	25	4	8	
20 - 50	30	4	8	
SEASON 2 (31/01/2019 to 21/03/2019)				
0 - 10	20	3	6	
10 - 20	25	3	6	
20 – 50	30	3	6	
Fertigation Scheduling (for both the seasons)				
Days	**Spray ON time (sec)**	**Spray Time**		
0 - 10	20	10-10:30 AM	--	4:30 -5 PM
10- 20	25	10-10:30 AM	--	4:30 -5 PM
20 - 50	30	10-10:30 AM	12:30-1PM	4:30 -5 PM

3.8.2 Concentration of different macro and micro nutrient as per recommended protocols

For supplying of nutrients to the lettuce crop by aeroponics system, different popular protocols are available. Some of the popular aeroponics fertigation protocols were given by Stainer (1984), Cooper (1988), Hemitt (1966) and Hooghland (1938) (table 3.4).

Table: 3.4 Different nutrient concentration protocol for aeroponics system

Nutrient	Stainer 1984	Cooper 1988	Hemitt 1966	Hooghland Arevin 1938
	Concentration in PPM			
Nitrogen (N)	168	200-236	168	210
Phosphorous (P)	31	60	41	31
Potassium (K)	273	300	156	234
Calcium (Ca)	180	170-185	160	160
Magnesium (Mg)	48	50	36	34
Sulphur (S)	336	68	48	64
Iron (Fe)	2-4	12	2.8	2.5
Copper (Cu)	0.02	0.1	0.064	0.02
Zinc (Zn)	0.11	0.1	0.065	0.05
Manganese (Mn)	0.62	02	0.54	0.5
Boron (B)	0.44	0.3	0.54	0.5
Molybednum (Mo)	--	0.2	0.04	0.01
Sodium (Na)	--	--	--	--

3.8.3 Electrical conductivity meter

An electrical conductivity meter (EC meter) was used for measured the electrical conductivity of a solution and fresh water systems to monitor the amount of nutrients, salts or impurities in the water (fig. 3.5). The EC value of nutrient solution for lettuce was maintained between 1.2 to 1.5 dS/m and 1.8 to 2.2 dS/m for first and second season respectively. If EC value is lower than this range, then plants can not get proper nutrient which is required for its growth and if EC value is higher than this range then plants get higher concentration of nutrient. Consequently, lower or higher EC value both affect growth of plants and cause reduction of yield.

Fig. 3.5 Determination of electrical conductivity of nutrient solution by EC Meter

3.8.4 pH meter

A pH meter is an instrument that measures the hydrogen-ion activity in water-nutrient solutions, that indicate its acidity or alkalinity expressed as pH (fig. 3.6). The pH value of nutrient solution for lettuce was maintained between 5.6 to 6.0 and 6.2 to 6.6 for first and second season respectively. pH value lower or higher than this range affect the growth of plants.

Fig. 3.6 Determination of pH of nutrient solution by pH Meter

3.9 Environmental Regulators

The environmental conditions around the root zone of the plant and in the greenhouse is regulated by environmental regulators. Some of the devices that help in regulating environmental factors are described as follows:

a) Thermometer

Temperatures of aeroponics system in greenhouses is monitored by thermometers. When thermometer temperature exceeds or lowered from temperature range required for crops a cooling or heating system starts. Temperature was maintained between 12ºC to 27ºC throughout the growing period.

b) Hygrometer

A hygrometer is an instrument used for measuring the humidity in the atmosphere as well as in growing chambers. Hygrometer helps in maintaining humidity in growing chambers and also measuring humidity in the greenhouse. The humidity was maintained around 100% in growing chamber throughout the growing period.

c) Heaters/coolers

In aeroponics cultivation, temperature of greenhouses must be maintained during the winter or during summers. Heaters and coolers were used for these extreme cases to regulate the temperatures of the greenhouses for optimal plant growth. Shade net was also used to maintain appropriate micro-climatic conditions for the plants in greenhouses. Shade nets, minimise radiation reaching crops in the greenhouse and can influence the direction of radiation.

3.10 Measurement of growth parameters

After 20 days of seedling in soil, lettuce was transplanted in aeroponics system. The different growth parameters such as root length, area of leaf, number of leaf and yield of lettuce were measured at interval of 10 days (Ali *et al.,* 2015).

3.10.1 Root length

The root of lettuce is a taproot type. A taproot is a large and dominant root from which other roots sprout laterally. Lettuce root length was measured with the help of scale ruler at regular interval of 10 days to determine the effect of nozzle type and fertigation scheduling. Last reading of root length was taken with the help of root scanner after harvesting.

Plate 3.5 Measurement of root length by (a) Scale ruler and (b) Root Scanner

3.10.2 Leaf area

Leaf area was measured to know the effect of fertigation scheduling and nozzle types on the yield of lettuce. Leaf area was measured for randomly selected plants with the help of scale ruler at regular interval of 10 days. In each plant, three leaves (one small, medium and large) were selected and corresponding data was taken. Last reading was taken with the help of leaf area meter after harvesting of the lettuce.

Plate 3.6 Measurement of leaf area by Leaf Area Meter

3.10.3 Number of leaf

In order to measure the effect of types of nozzle and fertigation scheduling on the growth of the lettuce in the aeroponics system, number of leaves per plants were counted. The number of fully opened leaves on each plant was recorded. Three plants in each replication was selected and the mean value was used to express the number of leaves.

Plate 3.7 Determination of Leaf parameters of lettuce in aeroponics system

3.10.4 Yield

Yield of the lettuce was dependent on the nozzle types and fertigation scheduling. After harvesting of crop the weight of three randomly selected plants were measured in each replication. The mean value of all three replications in each treatment gave yield of lettuce.

3.11 Statistical analysis of data

The data pertaining to growth and yield parameters were recorded and tabulated as per the treatment T1, T2, T3, T4, T5 and T6 details.

Table 3.5 Treatment details of experiments

Serial no.	Treatment	Symbol
1	T1	N1C1
2	T2	N2C1
3	T3	N3C1
4	T4	N1C2
5	T5	N2C2
6	T6	N3C3

These data were statistically analysed and Completely Randomized Design was carried out. The analysed data were subjected to ANOVA with critical difference values tabulated at five percent level of significance of corresponding degree of freedom.

The experiment was undertaken to design and evaluation of aeroponics system for efficient fertigation scheduling in lettuce. The aeroponics system was designed and developed for selection of nozzle and development of fertigation scheduling for lettuce crop. The effect of nozzle and fertigation scheduling on root length, leaf area, number of leaf and yield were determined. The various results have been discussed in the following sections.

4.1 Design and Development of Aeroponics System

The different steps involved in development of aeroponics system are shown in the plate 4.1 to 4.4. The aeroponics system of size 0.9×0.6×0.5 m was designed and developed based on the design parameters, plant spacing and root length of lettuce.

The first stage indigenous aeroponics prototype consisted of plastic tote poly propylene boxes placed on GI stand and provided with pipes, inlets and outlets for irrigation and drainage.

Plate 4.1 Stage 1 for development of indigenous aeroponics prototype

The second stage indigenous aeroponics prototype was provided with top cover made of plywood and Styrofoam. Top cover was provided with plastic grow cups filled with clay balls for holding the plants. Fertigation system consisting of two tanks, pump, timer, pressure regulator, nozzles, pipes and valves were connected with the main system.

Plate 4.2 Stage 2 for development of indigenous aeroponics prototype

The third stage involved electrical and electronics systems for providing the completely automatic indigenous aeroponics prototype. Timer based circuit board was integrated with the system for providing fully automatic fertigation system.

Plate 4.3 Stage 3 for development of indigenous aeroponics prototype

The final stage indigenous aeroponics prototype was ready for actual crop production. Aeroponics lettuce was shown growing in two different stages.

Plate 4.4 Stage 4 for development of indigenous aeroponics prototype

Table 4.1 Design Specifications of developed aeroponics system

Components/Characteristics	Specifications
Plastic tote box	Length = 0.90m
	Width = 0.60m
	Height = 0.50m
Plant to plant distance	15 cm
Nozzle pressure	3.5 kg/cm^2
Nozzle discharge	0.92 lpm
Number of nozzle	3
Lateral flow rate	2.76 lpm
Lateral length	2m
Size of pump	0.5 hp
Cyclic digital timer	Selec Xt-546

4.2 Effect of operating pressure on discharge rate of nozzles

The effect of pressure on discharge rate for three different nozzles for one-minute time period was studied and represented as follows:

The relationship between pressure and discharge rate of flat fan 11004 nozzle (N1) is shown in the fig. 4.1. The discharge rate obtained at pressure 2, 2.5, 3.0 and 3.5 kg/cm^2 were 0.62, 0.71, 0.79 and 0.84 l/min respectively. The discharge rate was found to be increased with increase in nozzle pressure. The discharge rate of nozzle N1 increased from 0.62 to 0.84 l/min when operating pressure increased from 2 to 3.5 kg/cm^2.

Table 4.2 Effect of operating pressure on discharge rate of nozzle N1

Nozzle type	Pressure (kg/cm^2)	Discharge (lpm)
Flat Fan (11004)	2	0.62
	2.5	0.71
	3	0.79
	3.5	0.84

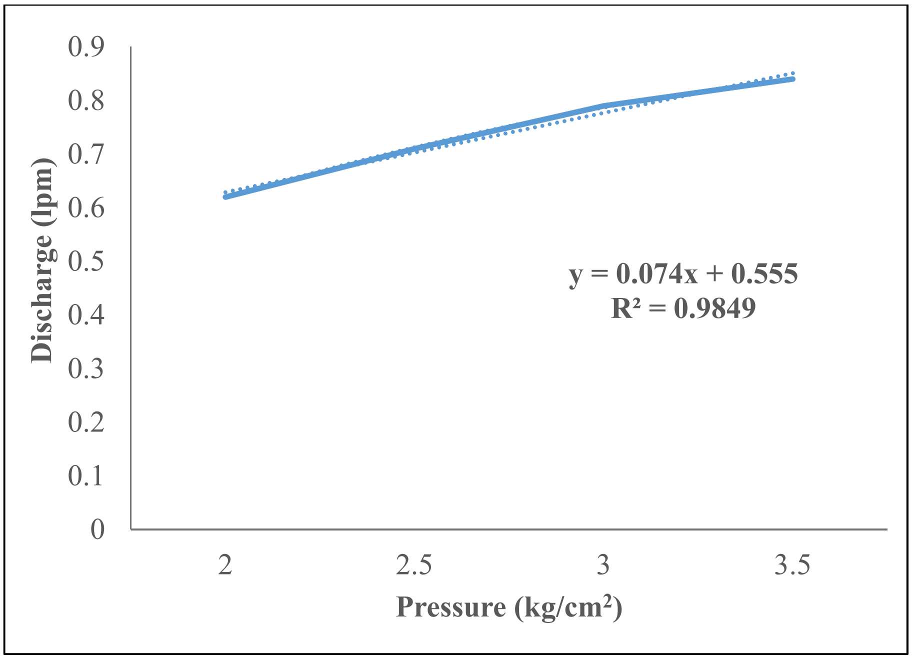


Fig. 4.1 Variation in discharge with pressure of nozzle N1

The relationship between pressure and discharge rate of hollow cone nozzle (N2) is shown in the fig. 4.2. For pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 the discharge rate of hollow cone nozzle was obtained as 0.42, 0.49, 0.55 and 0.61 l/min respectively. The discharge rate increased with increase in pressure. But in hollow cone nozzle discharge rate increased only from 0.42 to 0.61 l/min as pressure increased from 2.0 to 3.5 kg/cm^2 which is very less compared to nozzle N1.

Table 4.3 Effect of operating pressure on discharge rate of nozzle N2

Nozzle type	Pressure (kg/cm^2)	Discharge (lpm)
Hollow cone	2	0.42
	2.5	0.49
	3	0.55
	3.5	0.61

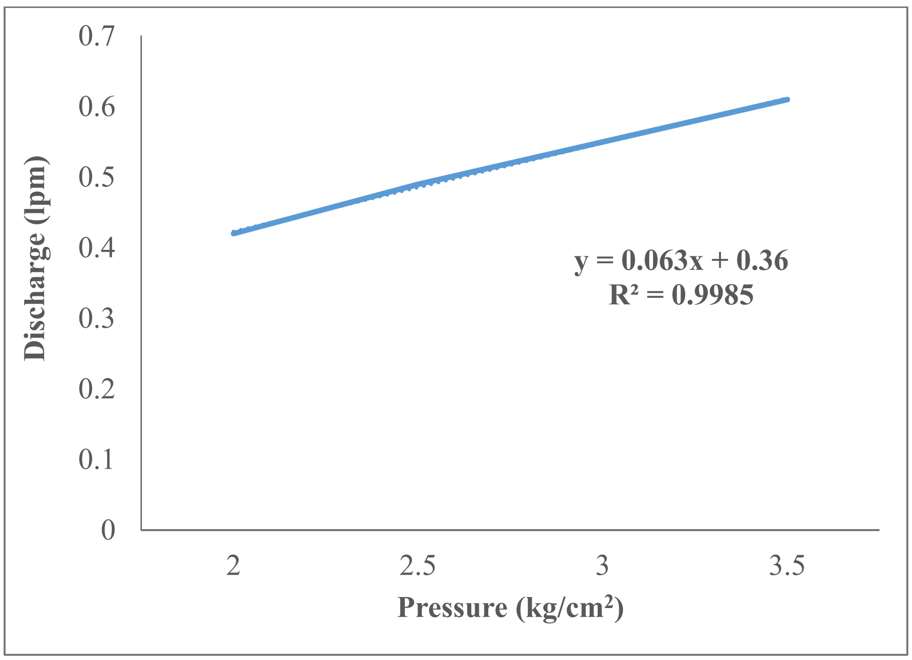


Fig. 4.2 Variation in discharge with pressure of nozzle N2

The relationship between discharge and pressure for flat fan 11006 nozzle (N3) is shown in fig 4.3. The discharge obtained for nozzle N3 were 0.66, 0.78, 0.86 and 0.92 l/min at pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 respectively. The discharge rate obtained in nozzle N3 was high compared to N1 and N2.

Table 4.4 Effect of operating pressure on discharge rate of nozzle N3

Nozzle type	Pressure (kg/cm^2)	Discharge (lpm)
Flat fan (11006)	2	0.66
	2.5	0.78
	3	0.86
	3.5	0.92

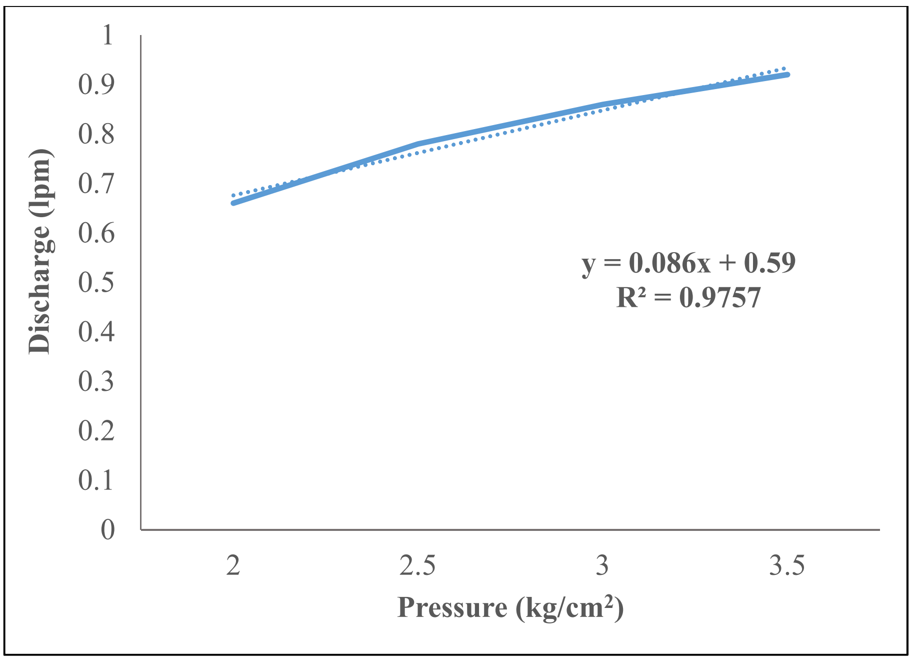


Fig. 4.3 Variation in discharge with pressure of nozzle N3

4.3 Droplet size analysis of nozzles using BIOVIS software

The variation of NMD, VMD and droplet size with nozzle operating pressure for the three different nozzle are presented in fig. 4.4, 4.5 and 4.6 respectively.

For nozzle N1 the NMD and VMD value varied from 25.80 to 32.61 µm and 86.2 to 162 µm respectively, for pressure range of 2.0 to 3.5 kg/cm^2. The droplet size varied from 18 – 402 µm, 14 – 374 µm, 14 – 332 µm and 13 – 291 µm for pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 respectively for nozzle N1.

Table 4.5 Effect of operating pressure on droplet size of nozzle N1

Nozzle type	Pressure (kg/cm^2)	NMD (μm)	VMD (μm)	Droplet size (μm)
Flat fan (11004)	2	32.61	162	18 – 402
	2.5	30.20	134.4	14 – 374
	3	27.41	116.7	14 – 332
	3.5	25.80	86.2	13 – 291

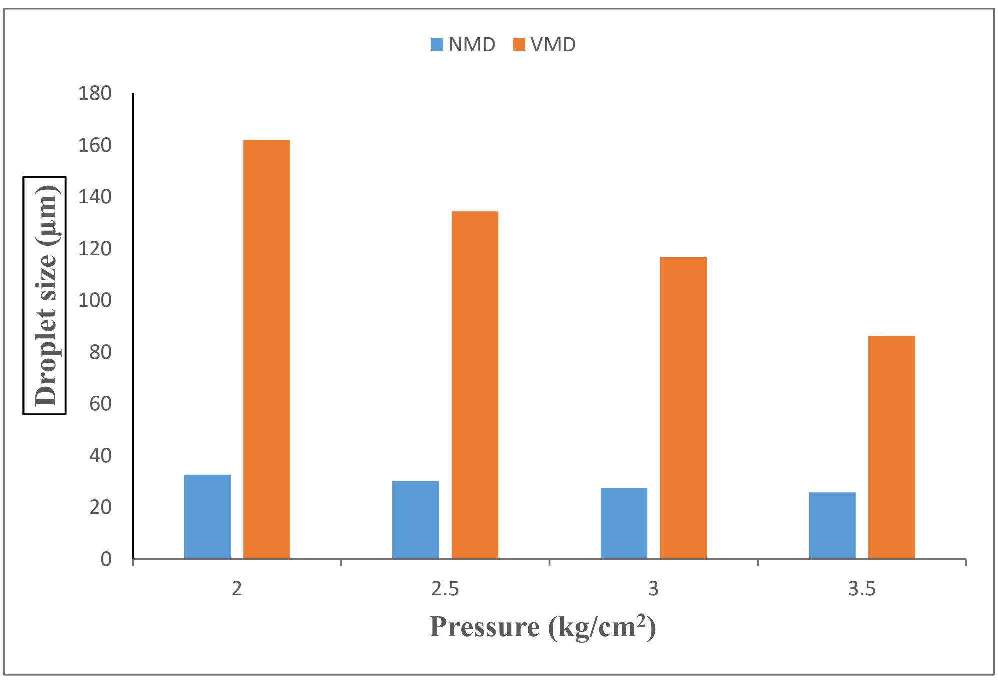


Fig. 4.4 Variation of droplet size with nozzle pressure for nozzle N1

For nozzle N2 the NMD and VMD value varied from 23.21 to 28.34 μm and 79.30 to 155.2 μm respectively, for pressure range of 2.0 to 3.5 kg/cm^2. The droplet size varied from 14 – 392 μm, 13 – 354 μm, 14 – 302 μm and 13 – 256 μm for pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 respectively for nozzle N2.

Table 4.6 Effect of operating pressure on droplet size of nozzle N2

Nozzle type	Pressure (kg/cm^2)	NMD (μm)	VMD (μm)	Droplet size (μm)
Hollow cone	2	28.34	155.2	14 – 392
	2.5	27.65	132	13 – 354
	3	25.44	108.6	12 – 302
	3.5	23.21	79.3	10 – 256

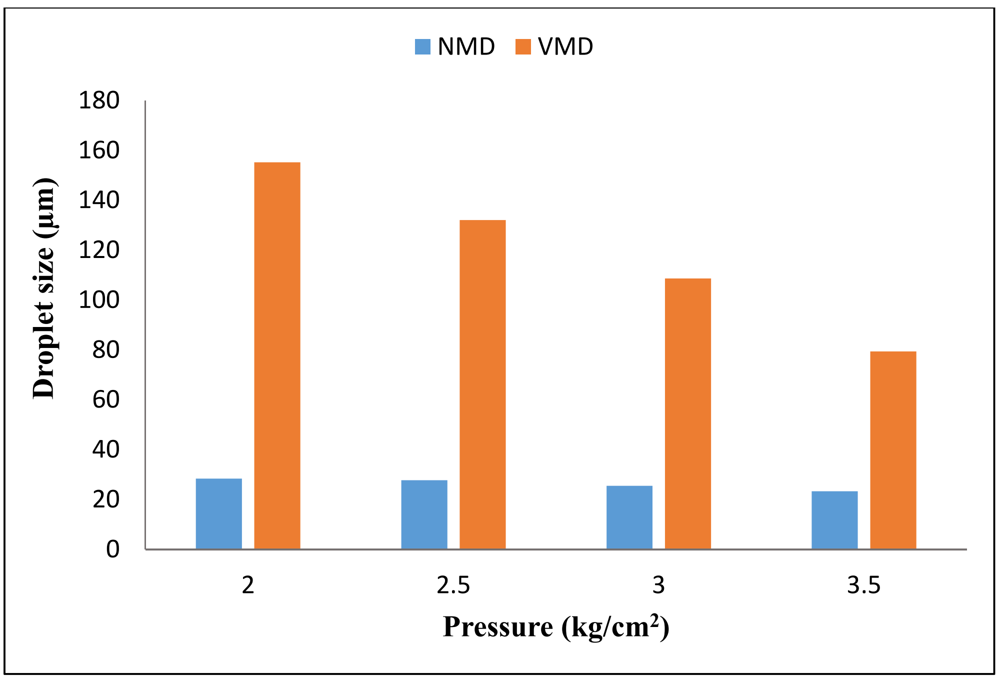


Fig. 4.5 Variation of droplet size with nozzle pressure for nozzle N2

For nozzle N3 the NMD and VMD value varied from 27.91 to 35.52 μm and 93.5 to 170.0 μm respectively, for pressure range of 2.0 to 3.5 kg/cm^2. The droplet size varied from 18 – 426 μm, 15 – 368 μm, 14 – 335 μm and 13 – 302 μm for pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 respectively for nozzle N3.

Table 4.7 Effect of operating pressure on droplet size of nozzle N3

Nozzle type	Pressure (kg/cm^2)	NMD (μm)	VMD (μm)	Droplet size (μm)
Flat fan (11006)	2	35.52	170	18 – 426
	2.5	33.26	141.6	15 – 368
	3	30.57	119.1	14 – 335
	3.5	27.91	93.5	13 – 302

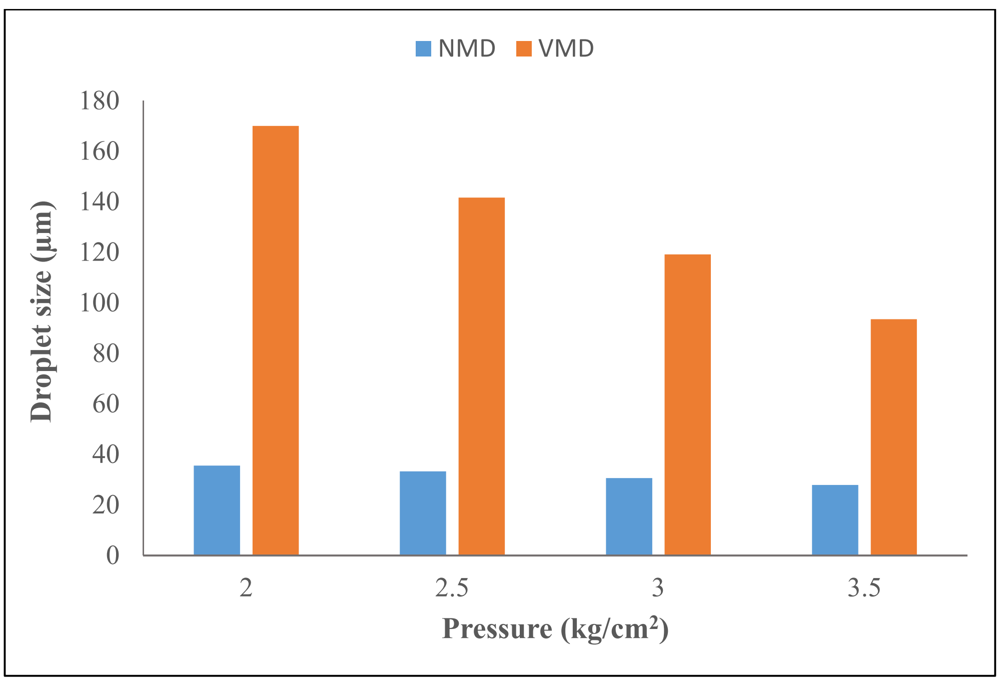


Fig. 4.6 Variation of droplet size with nozzle pressure for nozzle N3

4.4 Crop water requirement of lettuce

The water requirement for lettuce crop in the developed aeroponics system was measured for season 1 (S1) (10th Dec. 2018 to 28th Jan. 2019) and season 2 (S2) (31st Jan. to 21st March 2019) based on continuity equation. The minimum average crop water requirement for growing 72 plants as per the experimental requirement was 2.6 l.day^{-1} and 2.1 l.day^{-1} respectively for S1 and S2 in first 10 days. The crop water requirement was observed to be increasing up to 28th and 29th days for S1 and S2 respectively and then decreased continuously till harvesting. The maximum water requirement was found to be 8.9 l.day^{-1} and 9.4 l.day^{-1} respectively for S1 and S2 (fig. 4.7). The total water requirement was 281 liters and 290.5 liters respectively for season 1 and season 2 respectively.

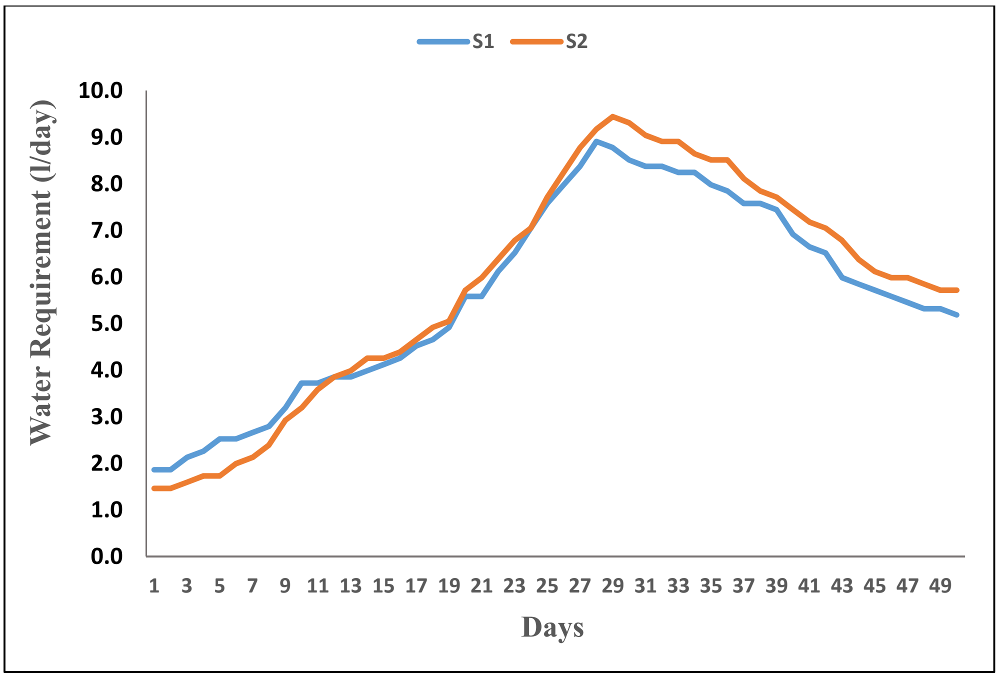


Fig. 4.7 Variation in water requirement per day

4.5 Fertigation scheduling for lettuce

Based on classical aeroponics fertigation protocols and major & micro nutrients requirement for lettuce, two stock solutions of 1000 liters each for two seasons were prepared for fertigation scheduling as shown in the table 4.8. The effects of both stock solutions in two successive seasons on bio parameters of lettuce were studied. Concentration of major fertilisers applied in season 1 was found to be more effective than the concentration of fertilisers applied in season 2.

Table 4.8 Nutrient concentration for lettuce in aeroponics system

Fertiliser	Amount (gm)	
	Season 1 (C1)	Season 2 (C2)
Mono Potassium Phosphate	200	300
Mono Ammonium Phosphate	10	15
Potassium Nitrate (KNO_3)	630	630
Potassium Sulphate SOP	200	250
Fe EDTA	40	40
Calcium Nitrate Ca $(No_3)_2$	1000	1500
$MgSO_4$	200	200
Copper	0.4	0.4
Zinc	3.0	3.0
Manganese	3.0	3.0
Borax	4.0	4.0
Sodium Molybdate	0.2	0.2

4.6 Effect of nozzles and fertigation scheduling on root length

It was found that root length of lettuce in the aeroponics system influenced by types of nozzles and fertigation scheduling. It was observed that treatment T2 (N2C1) gave best result with comparison to other treatments throughout the growing period. The least value of 9.3 cm was observed in earlier days for T2 while the maximum value of 40.2 cm observed during the time of harvesting. The effect of treatment T6 was found to be less as compared to other treatments (fig. 4.8).

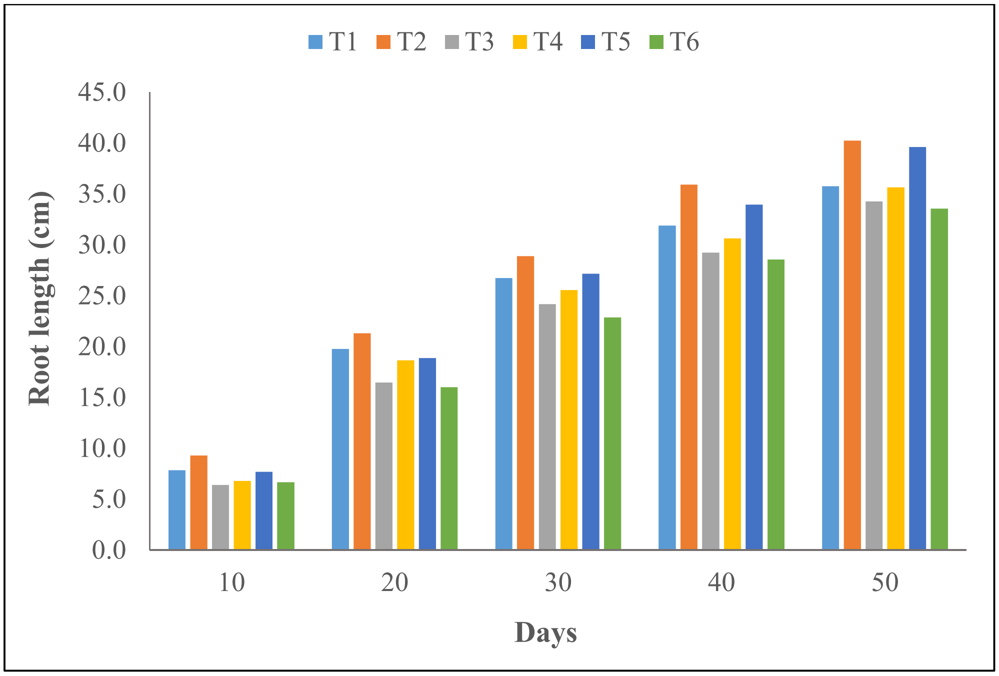


Fig. 4.8 Variation in root length with type of nozzles and fertigation scheduling

Table 4.9 ANOVA for root length with different types of nozzles and fertigation scheduling

Source	DF	Sum of Squares	Mean Square	F Value	P> F
Replication	2	0.534	0.267	2.120	0.171
Nozzle	2	11.348	5.674	45.070	<.0001
Concentration	1	2.722	2.722	21.620	0.201
Noz.*Conc.	2	2.801	1.401	11.130	0.003
Error	10	1.259	0.126		
Corrected Total	17	18.664			

Analysis of variance of root length conducted at 5% level of significance and it was found the nozzle had significant effect on root length ($P<0.0001$). It was also found that the interaction effect of selected variable on root length was significantly different ($P=0.003$).

4.7 Effect of nozzles and fertigation scheduling on leaf area

It was found that leaf area of lettuce in the aeroponics system influenced significantly by types of nozzles and fertigation scheduling. Throughout the growing season, the treatment T2 was found to give best result for leaf area as compared to other treatments. The minimum and maximum value for leaf area was 345 cm^2 and 4002 cm^2 respectively. The treatment T6 was least influenced by type of nozzle and fertigation scheduling as compared to other treatments (fig. 4.9).

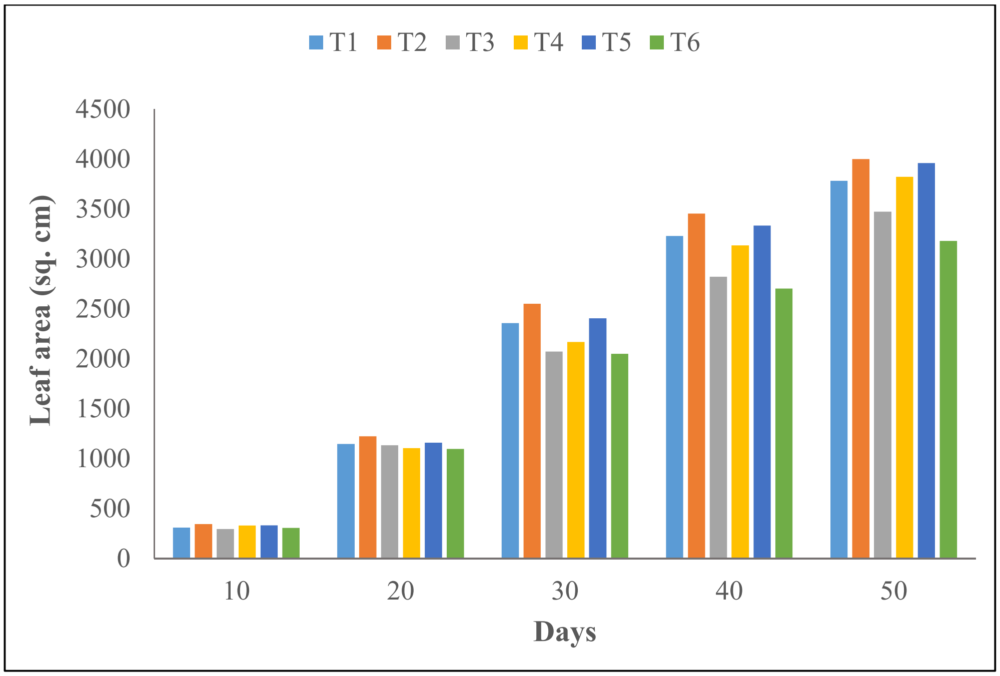


Fig. 4.9 Variation in leaf area with type of nozzles and fertigation scheduling

Table 4.10 ANOVA for leaf area with different types of nozzle and fertigation scheduling

Source	DF	Sum of Squares	Mean Square	F Value	P> F
Replication	2	356.778	178.389	1.220	0.233
Nozzle	2	3996.778	1998.389	13.710	0.001
Concentration	1	174.222	174.222	1.200	0.030
Noz.*Conc.	2	980.778	490.389	3.360	0.136
Error	10	1457.889	145.789		
Corrected Total	17	6966.444			

Analysis of variance of leaf area conducted at 5% level of significance and it was found the nozzle and concentration (fertigation scheduling) had significant effect on leaf area (P=0.0001 and P= 0.030). The interaction effect of selected variable on leaf area was not significantly different (P=0.136).

4.8 Effect of nozzles and fertigation scheduling on number of leaves

The number of leaves in lettuce plant were greatly influenced by types of nozzles and fertigation scheduling in the aeroponics system. It was observed that the treatment T2 gave more number of leaves per plant as compared to other treatment. Average number of leaves per plant were observed to be 5.8 after 10 days of transplanting while the average number of leaves increased to 24.9 at the time of harvesting for treatment T2 (fig. 4.10). Throughout the growing period, the number of leaves per plant was minimum for treatment T6.

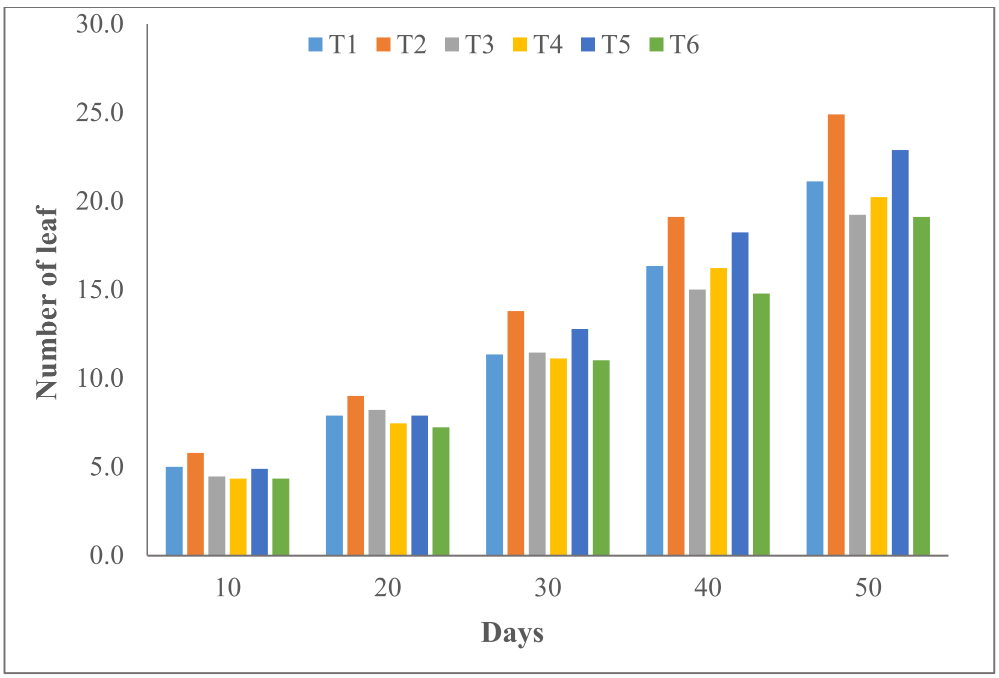


Fig. 4.10 Variation in number of leaves with type of nozzles and fertigation scheduling

Table 4.11 ANOVA for number of leaves with different types of nozzle and fertigation scheduling

Source	DF	Sum of Squares	Mean Square	F Value	P> F
Replication	2	0.181	0.091	0.780	0.147
Nozzle	2	2.938	1.469	12.670	0.002
Concentration	1	1.389	1.389	11.980	0.006
Noz.*Conc.	2	0.431	0.216	1.860	0.206
Error	10	1.159	0.116		
Corrected Total	17	6.098			

Analysis of variance of number of leaves conducted at 5% level of significance. It was found that nozzle had significant effect on number of leaf (P=0.002). It was also found that the effect of concentration (fertigation scheduling) on number of leaf was significantly different (P=0.006).

4.9 Effect of nozzles and fertigation scheduling on yield of the lettuce

It was found that yield of lettuce in the aeroponics system greatly influenced by types of nozzles and fertigation scheduling. The average value of yield was higher in treatment T2 as compared to other treatments (fig. 4.11). The average value of yield for T2 was 366 grams per plant. The lowest average of yield was observed with treatment T6.

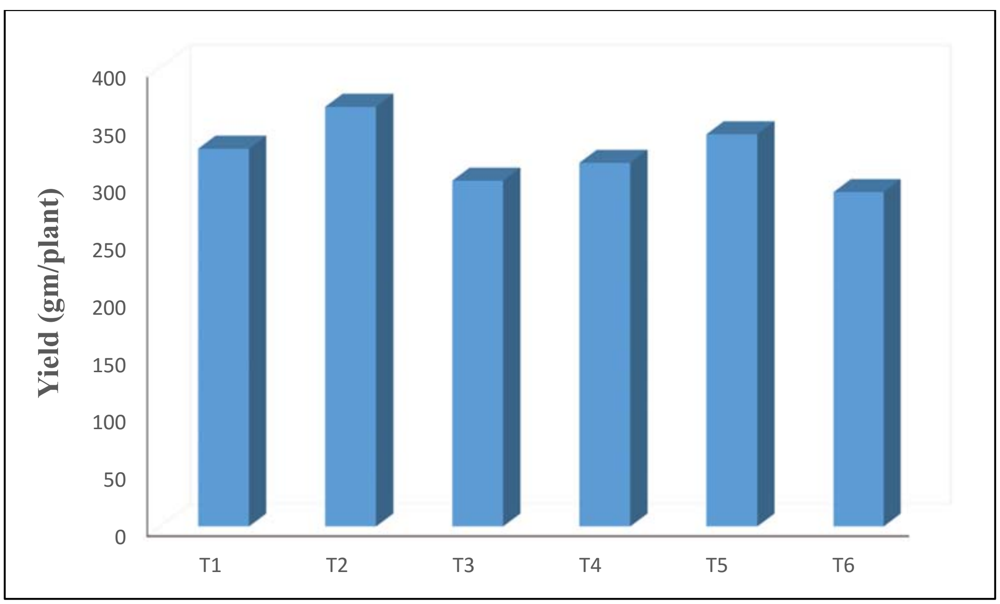


Fig. 4.11 Variation in yield with type of nozzles and fertigation scheduling

Table 4.12 ANOVA for yield with different types of nozzle and fertigation scheduling

Source	DF	Sum of Squares	Mean Square	F Value	P> F
Replication	2	123.11	61.56	12.42	0.219
Nozzle	2	9768.78	4884.39	985.64	<.0001
Concentration	1	1073.39	1073.39	216.60	<.0001
Noz.*Conc.	2	168.78	84.39	17.03	0.0006
Error	10	49.56	4.96		
Corrected Total	17	11183.61			

Analysis of variance of yield of lettuce conducted at 5% level of significance and it was found the nozzle had significant effect on yield of lettuce (P<0.0001). The effect of concentration on yield was significantly different (P<0.0001). It was also found that the interaction effect of selected variable on yield of lettuce was significantly different (P=0.0006).

CHAPTER V DISCUSSION

The indigenous aeroponics system prototype of size 0.9×0.6×0.5 m was designed and developed in four stages based on the design parameters types of plant, plant spacing, root length of lettuce and nozzle characteristics. The first stage indigenous aeroponics prototype consisted of plastic tote poly propylene boxes placed on GI stand and provided with pipes, inlets and outlets for irrigation and drainage. The second stage indigenous aeroponics prototype was provided with top cover made of plywood and Styrofoam. Top cover was provided with plastic grow cups filled with clay balls for holding the plants. Fertigation system consisting of two tanks, pump, timer, pressure regulator, nozzles, pipes and valves were connected with the main system. The third stage involved electrical and electronics systems for providing the completely automatic indigenous aeroponics prototype. Timer based circuit board was integrated with the system for providing fully automatic fertigation system. The final stage indigenous aeroponics prototype was ready for actual crop production with the capacity of 24 plants per box at the spacing of 15cm×15 cm.

The discharge rate of flat fan 11004 nozzle (N1) increased from 0.62 to 0.84 l/min when operating pressure increased from 2 to 3.5 kg/cm^2. The discharge rate obtained at pressure 2, 2.5, 3.0 and 3.5 kg/cm^2 were 0.62, 0.71, 0.79 and 0.84 l/min respectively. The discharge rate was found to increase with increase in nozzle pressure. The R^2 for the developed regression equation (0.074x + 0.555) between discharge and pressure was found to be 0.98. But in hollow cone nozzle (N2) discharge rate increased only from 0.42 to 0.61 l/min as pressure increased from 2.0 to 3.5 kg/cm^2 which is very less compared to nozzle N1. The R^2 for the developed regression equation (0.063x + 0.36) between discharge and pressure curve was found to be 0.99. For pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 the discharge rate of nozzle N2 were obtained as 0.42, 0.49, 0.55 and 0.61 l/min respectively. The discharge obtained for flat fan 11006 nozzle (N3) were 0.66, 0.78, 0.86 and 0.92 l/min at pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 respectively. The discharge rate obtained in N3 was highest compared to nozzle N1 and N2. The R^2 for the developed regression equation (0.086x + 0.59) between discharge and pressure curve was found to be 0.97. Based on the above data available for discharge and pressure relationship, hollow cone nozzle (N2) was found to be best suitable for aeroponics system as it provided optimal discharge at suitable pressure for lettuce crop.

For N1 the droplet size analysis parameters Number Median Diameter (NMD) and Volume Median Diameter (VMD) values using BIOVIS software varied from 25.80 to 32.61 µm and 86.2 to 162 µm respectively, for pressure range of 2.0 to 3.5 kg/cm^2. The droplet size varied from 18 – 402 µm, 14 – 374 µm, 14 – 332 µm and 13 – 291 µm for pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 respectively for nozzle N1. For nozzle N2 the NMD and VMD value varied from 23.21 to 28.34 µm and 79.30 to 155.2 µm respectively, for pressure range of 2.0 to 3.5 kg/cm^2. The droplet size varied from 14 – 392 µm, 13 – 354 µm, 14 – 302 µm and 13 – 256 µm for pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 respectively for nozzle N2. For nozzle N3 the NMD and VMD value varied from 27.91 to 35.52 µm and 93.5 to 170.0 µm respectively, for pressure range of 2.0 to 3.5 kg/cm^2. The droplet size varied from 18 – 426 µm, 15 – 368 µm, 14 – 335 µm and 13 – 302 µm for pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2 respectively for nozzle N3. Based on the suitable droplet size, NMD and VMD values, hollow cone nozzle (N2) was found as best suitable for aeroponics system. Similar values were reported by Lakhiar *et al.* 2018.

The water requirement for lettuce crop in the developed aeroponics system was measured for season 1 (10th Dec. 2018 to 28th Jan. 2019) and season 2 (31st Jan. to 21st March 2019) based on continuity equation. The minimum average crop water requirement for growing 72 plants as per the experimental requirement was 2.6 and 2.1 $l.day^{-1}$ respectively for season 1 (S1) and season 2 (S2) in first 10 days. The crop water requirement was observed to be increasing up to 28th and 29th days for S1 and S2 respectively and then decreased continuously till harvesting. The maximum water requirement was found to be 8.9 and 9.4 $l.day^{-1}$ respectively for S1 and S2. The total water requirement was 281 liters and 290.5 liters respectively for S1 and S2 respectively. The per plant average water requirement was 3.89 liters and 4.03 liters respectively for S1 and S2 respectively. Similar findings were found and reported by Pelesco *et al.* 2014. The total average crop water requirement for the lettuce (Var: Iceberg) grown in open field with drip fertigation was 30 liters per plant. The crop water requirement for lettuce grown in aeroponics system was approximately 8 times less than the open field with drip fertigation, which supports the literatures cited claiming approximately 10 times water saving in aeroponics system.

Fertigation scheduling was developed as C1 and C2 respectively for two different seasons taken during the experiment as Dec-Jan and Feb-March. Mono potassium phosphate, potassium nitrate, potassium sulphate and calcium nitrate were the major sources of major nutrients taken during the experiments with dosage of (200, 630, 200 and 1000 gm) and (300, 630, 250 and 1500 gm) respectively for two seasons for 1000 liter fertigation solution. The micro nutrient dosages during both the seasons were same for Fe, Mn, B, Cu and Mo. The EC and pH varied from 1.2-2.2 dS/m and 5.6-6.6 respectively during both the seasons.

It was found that root length of lettuce in the aeroponics system was influenced by types of nozzles and fertigation scheduling. It was observed that treatment T2 (N2C1) gave best result with comparison to other treatments throughout the growing period. The least value of 9.3 cm was observed in earlier days for T2 while the maximum value of 40.2 cm observed during the time of harvesting. Similar trends of root growth were obtained by Khater *et al.* 2015. The effect of treatment T6 was found to be less as compared to other treatments. Analysis of variance of root length conducted at 5% level of significance and it was found that nozzle had significant effect on root length ($P<0.0001$). It was also found that the interaction effect of selected variable on root length was significantly different ($P=0.003$).

It was found that leaf area of lettuce in the aeroponics system was influenced significantly by types of nozzles and fertigation scheduling. Throughout the growing season, the treatment T2 was found to give best result for leaf area as compared to other treatments. The minimum and maximum value for leaf area was 345 cm^2 and 4002 cm^2 respectively. The results obtained by the experiment were in accordance with the results obtained by Travieso *et al.* 2016. The treatment T6 was least influenced by type of nozzle and fertigation scheduling as compared to other treatments. Analysis of variance of leaf area conducted at 5% level of significance and it was found that nozzle had significant effect on leaf area ($P=0.001$). It was also found that effect of concentration (fertigation scheduling) on leaf area was significantly different ($P=0.030$).

The number of leaves in lettuce plants were greatly influenced by types of nozzles and fertigation scheduling in the aeroponics system. It was observed that the treatment T2 gave more number of leaves per plant as compared to other treatment. Average number of leaves per plant were observed to be 5.8 after 10 days of transplanting while the average number of leaves increased to 24.9 at the time of harvesting for treatment T2. The results obtained by the experiment were in accordance with the results obtained by Travieso *et al.* 2016. Throughout the growing period, the number of leaves per plant was minimum for treatment T6. Analysis of variance of number of leaf conducted at 5% level of significance suggested that nozzle had significant effect on number of leaf (P=0.002). It was also found that the effect of concentration (fertigation scheduling) on number of leaf was significantly different (P=0.006).

It was found that yield of lettuce in the aeroponics system greatly influenced by types of nozzles and fertigation scheduling. The average value of yield was higher in treatment T2 as compared to other treatments. The average value of yield for T2 was 366 grams per plant. This result agreed with those obtained by Ali *et al.* 2015. The lowest average of yield was observed with treatment T6. Analysis of variance of yield of lettuce conducted at 5% level of significance and it was found the nozzle and fertigation scheduling had significant effect on yield of lettuce (P<0.0001). It was also found that the interaction effect of selected variable on yield of lettuce was significantly different (P=0.0006).

CHAPTER VI SUMMARY AND CONCLUSIONS

The study was carried out on the topic "Design and evaluation of aeroponics system for efficient fertigation scheduling in lettuce" with the emphasis on design of indigenous aeroponics system, evaluation and standardization of nozzles for efficient delivery of water and nutrient for aeroponics system and development of fertigation scheduling for lettuce grown under aeroponics system. Experiments were conducted to design indigenous aeroponics system and standardize nozzle specifications and fertigation scheduling for lettuce. The indigenous aeroponics prototype was designed and developed inside the climate controlled greenhouse at the Centre for Protected Cultivation Technology, CPCT located at ICAR-IARI, Pusa, New Delhi. Nozzles and fertigation scheduling related studies were done at CPCT Farm and Division of Agricultural Engineering, ICAR-IARI. The leaf and root related parameters were determined at CPCT farm and Water Technology Centre, WTC, ICAR-IARI. The major conclusions drawn from the study were as follows:

1. The discharge rate of flat fan 11004 nozzle (N1), hollow cone nozzle (N2) and flat fan 11006 nozzle (N3) increased from 0.62-0.84, 0.42-0.61 and 0.66-0.92 l/min respectively when operating pressure increased from 2 to 3.5 kg/cm^2. The R^2 for the developed regression equation (0.074x + 0.555), (0.063x + 0.36) and (0.086x + 0.59) between discharge and pressure were 0.98, 0.99 and 0.97 respectively for the above mentioned nozzles. Hollow cone nozzle (N2) was found to be best suitable for aeroponics system as it provided ideal discharge at suitable pressure for lettuce crop.

2. For hollow cone nozzle N2 the droplet size analysis parameters Number Median Diameter (NMD) and Volume Median Diameter (VMD) values using BIOVIS software varied from 23.21 to 28.34 µm and 79.30 to 155.2 µm respectively, for pressure range of 2.0 to 3.5 kg/cm^2. The droplet size varied from 14 – 392 µm, 13 – 354 µm, 14 – 302 µm and 13 – 256 µm for pressure 2.0, 2.5, 3.0 and 3.5 kg/cm^2. Based on the suitable droplet size, NMD and VMD values, hollow cone nozzle (N2) was found as best suitable for aeroponics system.

3. The total crop water requirement for lettuce crop in the developed aeroponics system for season 1 (10th Dec. 2018 to 28th Jan. 2019) and season 2 (31st Jan.

to 21st March 2019) was 281 liters and 290.5 liters respectively. The per plant average water requirement was 3.89 liters and 4.03 liters respectively for S1 and S2 respectively. The total average crop water requirement for the lettuce grown in open field with drip fertigation was 30 liters per plant.

4. Fertigation scheduling was developed as C1 and C2 respectively for two different seasons taken during the experiment as Dec-Jan and Feb-March. Mono potassium phosphate, potassium nitrate, potassium sulphate and calcium nitrate were the major sources of major nutrients taken during the experiments with dosage of (200, 630, 200 and 1000 gm) and (300, 630, 250 and 1500 gm) respectively for two seasons for 1000 liters fertigation solution. The micro nutrient dosages during both the seasons were same for Fe, Mn, B, Cu and Mo. The EC and pH varied from 1.2-2.2 dS/m and 5.6-6.6 respectively during both the seasons.

5. Root length, leaf area, number of leaves and yield of lettuce in the aeroponics system were influenced by types of nozzles and fertigation scheduling. Treatment T2 (N2C1) the combination of hollow cone nozzle with fertigation scheduling strategy C1 gave best result.

“Design and Evaluation of Aeroponics System for efficient fertigation scheduling in Lettuce”

ABSTRACT

India occupies 2.4% of the world’s land area and supports over 17.5% of the world’s population. It is estimated that by the year 2050 Indian population is going to reach 1.6 billion and food requirement to feed this population will be about 333 million tons, whereas at present (2017-18) the food grain production is about 278 million tons. To meet high food grain production target there are many constraints like huge population, water scarcity, climate change, industrialization, urbanization and decreasing land holding. For increasing food production there is urgent need to adopt new technologies to meet the growing food requirement like protected cultivation, soilless culture, hydroponics, aquaponics, aeroponics etc. which can overcome most of the biotic and abiotic constraints. Indigenous aeroponics system design is required along with the protocols for nozzle delivery and fertigation scheduling for popularization of aeroponics system in India. The present research entitled “Design and evaluation of aeroponics system for efficient fertigation scheduling in lettuce” was carried out during the Year 2018-19 inside climate controlled greenhouse located at Centre for Protected Cultivation Technology (CPCT), ICAR-Indian Agricultural Research Institute, New Delhi. Design of aeroponics system, evaluation and standardization of nozzles for efficient delivery of water and nutrient for aeroponics system and development of fertigation scheduling for lettuce grown under aeroponics system were the main objectives of the study. The indigenous aeroponics system prototype of size 0.9×0.6×0.5 m was designed and developed for growing 24 lettuce plants. Fertigation scheduling was developed for two different growing seasons taken during the experiment as Dec-Jan and Feb-March respectively. The minimum average crop water requirement for growing 72 plants was 2.6 and 2.1 $l.day^{-1}$ respectively for season 1 (S1) and season 2 (S2) in first 10 days. The per plant average water requirement was 3.89 liters and 4.03 liters for S1 and S2 respectively. Three different types of nozzles N1, N2 and N3 and two sets of fertigation scheduling strategies C1 and C2 suitable for aeroponics were taken for experimental study with the CRD design of experiment. Effect of six different combinations of N&C on different plant parameters was statistically analyzed. The results revealed that nozzle N2 (hollow cone) was best suitable for aeroponics system as per the discharge variation and droplet size and the effect of nozzle and fertigation scheduling on plants parameters were significantly different at 5% significance level. It was observed that treatment T2 (N2C1) gave best result against all the plant parameters (root length, leaf area, no of leaves & yield) in comparison to other treatments throughout the growing period. The average root length was found to be 9.3 cm and 40.2 cm, leaf area 345 cm^2 and 4002 cm^2 and number of leaves per plant 5.8 and 24.9 after 10 days and 50 days respectively for treatment T2. The average value of lettuce yield was highest in treatment T2 and reported as 366 grams per plant.

Keywords: Soilless, Aeroponics, Lettuce, Nozzle, Fertigation scheduling.

"लेट्यूस में कुशल फर्टिगेशन शेड्यूलिंग के लिए एरोपोनिक्स सिस्टम का डिजाइन और मूल्यांकन"

सार

भारत दुनिया के भूमि क्षेत्र का 2.4% हिस्सा रखता है और दुनिया की आबादी का 17.5% से अधिक का समर्थन करता है। ऐसा अनुमान है कि वर्ष 2050 तक भारतीय जनसंख्या 1.6 बिलियन तक पहुंचने वाली है और इस जनसंख्या को खिलाने के लिए भोजन की आवश्यकता लगभग 333 मिलियन टन होगी, जबकि वर्तमान (2017-18) में अनाज का उत्पादन लगभग 278 मिलियन टन है। उच्च खाद्यान्न उत्पादन लक्ष्य को पूरा करने के लिए बहुत सी बाधाएँ हैं जैसे विशाल जनसंख्या, पानी की कमी, जलवायु परिवर्तन, औद्योगीकरण, शहरीकरण और भूमि की घटती जोत। बढ़ती खाद्य उत्पादन कि आवश्यकता को पूरा करने के लिए नई तकनीकों जैसे संरक्षित खेती, मिट्टी रहित खेती, हाइड्रोपोनिक्स, एक्वापोनिक्स, एरोपोनिक्स इत्यादि को अपनाने की तत्काल आवश्यकता है, जो अधिकांश जैविक और अजैविक बाधाओं को दूर कर सकते हैं। भारत में एरोपोनिक्स प्रणाली के लोकप्रियकरण के लिए नोजल डिलीवरी और प्रजनन क्षमता के लिए प्रोटोकॉल के साथ-साथ स्वदेशी एरोपोनिक्स सिस्टम डिज़ाइन की आवश्यकता है। वर्तमान अनुसंधान "लेट्यूस में कुशल प्रजनन क्षमता निर्धारण के लिए एयरोपोनिक्स प्रणाली का डिजाइन और मूल्यांकन", जिसे वर्ष 2018-19 के दौरान सेंटर फॉर प्रोटेक्टेड कल्टिवेशन टेक्नोलॉजी (सीपीसीटी), आईसीएआर-भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली में स्थित जलवायु नियंत्रित ग्रीनहाउस के अंदर किया गया था। एरोपोनिक्स प्रणाली का डिजाइन, मूल्यांकन और एरोपोनिक्स प्रणाली के लिए पानी और पोषक तत्वों की कुशल डिलीवरी के लिए नोजल का मानकीकरण और एरोपोनिक्स प्रणाली के तहत उगाए जाने वाले लेट्यूस के लिए फर्टिगेशन शेड्यूलिंग का विकास अध्ययन के मुख्य उद्देश्य थे। स्वदेशी आकार के एरोपोनिक्स सिस्टम के प्रोटोटाइप 0.9 × 0.6 × 0.5 मीटर को 24 लेट्यूस पौधों को उगाने के लिए डिज़ाइन और विकसित किया गया था। फर्टिगेशन शेड्यूलिंग को क्रमशः दिसंबर-जनवरी और फरवरी-मार्च के रूप में प्रयोग के दौरान लिए गए दो अलग-अलग मौसमों के लिए विकसित किया गया था। 72 पौधों को उगाने के लिए न्यूनतम औसत फसल पानी की आवश्यकता पहले 10 दिनों में सीजन 1 (S1) और सीजन 2 (S2) के लिए क्रमशः 2.6 और 2.1 प्रति दिन लीटर थी। प्रति पौधा औसत पानी की आवश्यकता क्रमशः एस 1 और एस 2 के लिए 3.89 लीटर और 4.03 लीटर थी। प्रयोग के सीआरडी डिजाइन के साथ प्रयोगात्मक अध्ययन के लिए तीन अलग-अलग प्रकार के नोजल एन 1, एन 2 और एन 3 और फर्टिगेशन शेड्यूलिंग स्ट्रैटेजी सी 1 और सी 2 के दो सेट लिए गए। पौधों के विभिन्न मापदंडों पर एन एंड सी के छह अलग-अलग संयोजनों का प्रभाव सांख्यिकीय रूप से विश्लेषण किया गया था। परिणामों से पता चला कि नोजल एन 2 (खोखले शंकु) डिस्चार्ज भिन्नता और छोटी बूंद के आकार के अनुसार एरोपोनिक्स प्रणाली के लिए सबसे उपयुक्त था और पौधों के मापदंडों पर नोजल और फर्टिलिटी शेड्यूलिंग का प्रभाव 5% महत्व के स्तर पर काफी अलग था। यह देखा गया कि उपचार T2 (N2C1) ने बढ़ती अवधि में अन्य उपचारों की तुलना में सभी पौधों के विभिन्न मापदंडों (जड़ की लंबाई, पत्ती क्षेत्र, पत्तियों की संख्या और उपज) के खिलाफ सबसे अच्छा परिणाम दिया। औसत जड़ की लंबाई 9.3 सेमी और 40.2 सेमी, पत्ती क्षेत्र 345 वर्ग सेमी और 4002 वर्ग सेमी और पौधों की पत्तियों की संख्या 5.8 और 24.9 के बाद क्रमशः 10 दिनों के बाद और 50 दिनों के बाद उपचार टी 2 के लिए पाया गया था। लेट्यूस उपज का औसत प्राप्ति उपचार टी 2 में उच्चतम था और प्रति पौधे 366 ग्राम पाया गया।

विशिष्ट शब्द: मिट्टी रहित खेती, एरोपोनिक्स, लेट्यूस, नोजल, फर्टिगेशन शेड्यूलिंग

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APPENDIX I

Digital timer specification

Model	Selec Xt-546
Display Configuration	3+3 Digits
Range	9.99 / 99.9 / 999sec, 9.99min, 99.9 / 999min, 9.99hr, 99.9 / 999hr
Operating Modes	ON Delay / Interval / Cyclic ON First / Cyclic OFF First
Reset	Front, Remote, power Interruption
Accuracy	±0.05%
Counting Direction	Down
Supply Voltage	85 to 270 AC, 24V AC / DC
Size	48 × 48 mm
Mounting Type	Panel Mount

APPENDIX II

Water required for 72 lettuce plants in two different growing period

Days	Water Required		Days	Water Required	
	S1	S2		S1	S2
1	1.9	1.5	26	8.0	8.2
2	1.9	1.5	27	8.4	8.8
3	2.1	1.6	28	8.9	9.2
4	2.3	1.7	29	8.8	9.4
5	2.5	1.7	30	8.5	9.3
6	2.5	2.0	31	8.4	9.0
7	2.7	2.1	32	8.4	8.9
8	2.8	2.4	33	8.2	8.9
9	3.2	2.9	34	8.2	8.6
10	3.7	3.2	35	8.0	8.5
11	3.7	3.6	36	7.8	8.5
12	3.9	3.9	37	7.6	8.1
13	3.9	4.0	38	7.6	7.8
14	4.0	4.3	39	7.4	7.7
15	4.1	4.3	40	6.9	7.4
16	4.3	4.4	41	6.7	7.2
17	4.5	4.7	42	6.5	7.0
18	4.7	4.9	43	6.0	6.8
19	4.9	5.1	44	5.9	6.4
20	5.6	5.7	45	5.7	6.1
21	5.6	6.0	46	5.6	6.0
22	6.1	6.4	47	5.5	6.0
23	6.5	6.8	48	5.3	5.9
24	7.0	7.0	49	5.3	5.7
25	7.6	7.7	50	5.2	5.7

APPENDIX III

Average value of root length of lettuce

Days	T1	T2	T3	T4	T5	T6
10	7.9	9.3	6.4	6.8	7.7	6.7
20	19.8	21.3	16.5	18.7	18.9	16.0
30	26.7	28.9	24.2	25.6	27.2	22.9
40	31.9	35.9	29.2	30.6	34.0	28.6
50	35.8	40.2	34.3	35.7	39.6	34.0

Average value of leaf area of lettuce

Days	T1	T2	T3	T4	T5	T6
10	309	345	296	330	331	307
20	1146	1224	1135	1107	1160	1097.5
30	2357	2553	2073	2169	2407	2051.0
40	3231	3455	2822	3136	3335	2702
50	3784	4002	3474	3824	3961	3181

Average number of leaves of lettuce

Days	T1	T2	T3	T4	T5	T6
10	5.0	5.8	4.4	4.3	4.9	4.3
20	7.9	9.0	8.2	7.4	7.9	7.2
30	11.3	13.8	11.4	11.1	12.8	11.0
40	16.3	19.1	15.0	16.2	18.2	14.8
50	21.1	24.9	19.2	20.2	22.9	19.1

Average Yield of lettuce

DAYS	T1	T2	T3	T4	T5	T6
50	329	366.0	302.0	317.0	342.0	292.0

APPENDIX IV

Average Temperature and RH

Month	Open Condition		Greenhouse		Aeroponic Solution
	Temperature (°C)	RH (%)	Temperature (°C)	RH (%)	Temperature (°C)
October, 2018	25	52	24.4	58	-
November, 2018	19.6	55	20.2	61	-
December, 2018	15	66	16.6	72	20
January, 2019	13.1	72	15.5	77	18
February, 2019	16.2	67	18.3	69	24
March, 2019	21	53	21.5	56	32