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Development and performance evaluation of evaporative cool hydroponic fodder production chamber

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Abstract
An evaporative cool hydroponic chamber (ECHC) consisting of a double wall (inner and outer wall), a filler inside the double-wall, fogging system inside the chamber, drip system on the wall and a shading curtain was developed and evaluated for its cooling and humidifying performance and qualitative characteristics of hydroponic maize produced under ECHC. The combined effect of evaporative cooling and misting system maintained the daily average temperature and relative humidity (RH) in the range of 28.6-30.2 ^{o}C and 65.2-75.1%, respectively under ECHC as compared to temperature and RH variations of ambient in the range of 28.5-41.4 ^{o}C and 37-77% respectively. The minimum-maximum temperature and RH range of 25.4-34.3 ^{0}C and 52-88%, respectively were also observed under ECHC. The cooling efficiency of ECHC varied from 57.61 to 83.33% with an average value of 74.06%. Fresh biomass yield of seven days hydroponic fodder maize was observed as 4.00 kg/kg of seed. High crude protein (13.10%) and low crude fiber (15.30%) contents on dry matter basis of hydroponic maize fodder made it more nutritious for livestock.

Keywords: Evaporative, Fodder, Humidity, Hydroponic, Maize, Temperature

Introduction

Adding green fodder to the diet of livestock provides nutrients like protein, carbohydrates, minerals, vitamins, water and others. It has almost all the required nutrients for quality milk production and for maintaining the health of the livestock (Mahanta *et al*., 2020). India has emerged as the biggest producer of milk in the world producing 187.7 million tonnes (MT) of milk in the year 2018-19 (Anonymous, 2020) and the reason is its vast livestock population. Production of fodder is a challenging task for the farmers in adverse climatic conditions or even in suitable growing seasons because of uncertainty in rain-fall, less land holdings, enormous climatic changes and pressure of producing food crops. Because of less area available for fodder production, the urban vacant areas and residential yards may be utilized for fodder production, as an alternative to fertile land. This lack of area for fodder production increases the gap between supply and demand of green fodder in India, which is expected to reach 687.4 MT and 911.6 MT, respectively in 2030 (Anonymous, 2013), which indicates deficit of green fodder by 24.59%. Therefore, to fulfil daily green fodder requirement of the large livestock population and to consistently increase milk production we need to focus on sustainable green fodder producing technologies.

Hydroponics is a systematic and scientific method of growing green fodder without soil, with or without nutrient solution under environmentally controlled structures, devices, houses or machines (Naik and Singh, 2013; Naik *et al.,* 2015). The fodder grown hydroponically is known as hydroponic fodder or sprouted grains or sprouted fodder (Dung *et al*., 2010). Al-Karaki and Al-Hashimi (2012) evaluated barley, cowpea, sorghum and wheat for green fodder production under temperature-controlled hydroponic conditions (24 ± 10 ^{0}C) and natural window illumination at growth room of soilless culture laboratory, Arabian Gulf University, Manama, Bahrain. The highest yields of hydroponic fodder after 8 days for cowpea, barley and alfalfa were 217, 200, and 194 tons/ha, respectively. Maize is considered an important dual purpose crop for human food as well as animal feed (Gupta *et al*., 2019). Kumar *et al.* (2020) concluded that fodder maize sown with higher seed rate of 100 kg/ha in open field was economical. In India, hydroponic fodder maize is preferred because of the easy availability of seed, good biomass production and fast-growing habit. Girma and Gebremariam (2018) recorded dry matter content of 11-14%, yield of 5-6 folds on fresh basis for hydroponics maize and 8-13% increase in milk production. Naik *et al.* (2012) observed the highest values of crude protein (13.57%) for hydroponics fodder maize on 7th day of growth which was higher than the conventional green fodder maize (10.67%). The crude fiber content of the maize seed was 2.50% which increased to 14.07% on 7th day of growth in hydroponics system but was lower than the fodder maize grown under conventional practices (25.92%).

There are many organizations working on development of low-cost hydroponic devices made from locally available materials like bamboo, wood, greenhouse net etc. These local structures are not suitable for the regions of hot and dry climate where the relative humidity stays to lower side during 7-8 months in a year. Also, these structures are not strong enough to use for longer periods, there are chances of growth of fungi because of unhygienic environment and there is no scientific data available in terms of literature on thermal variation under these structures. Temperature variation under the solar drying structure has been reported earlier (Singh et *al.,* 2017). But evaporative cooling technique is effective in overcoming this problem upto some extent. In a hot and dry climate ‘evaporative cooling’ refers to the cooling obtained solely by evaporation of water in air. Air surrounding the structure gives up its heat energy to evaporate water and gets cool (Bokade *et al.,* 2017). This eco-friendly technology could reduce temperature by 10-15 ^{o}C. However, in mild climatic conditions, the evaporative cooling is not very much effective. Maximum temperature drop under fan pad cooled greenhouse in Bangalore, Karnataka (India) during peak summer and overall cooling efficiency of 7.3^{0}C and 53.6% were observed earlier (Singh *et al.,* 2005). Several studies on the zero-energy cool chamber using evaporative cooling technique showed its importance with reference to its low cost, eco-friendly and energy saving (Islam *et al.,* 2012; Singh and Satapathy, 2006; Rajeswari *et al.,* 2011). However, there was paucity of information on environmentally controlled small and medium size evaporative cool hydroponic system for fodder production that could operate in hot and dry regions. Therefore, it was realized to develop a suitable evaporative cool hydroponic fodder production chamber specially designed for small and marginal farmers who can easily adopt this technology for fodder production. When dry air passes over water, the air absorbs water and evaporative cooling occurs. The evaporative cooling system cools the inner space by evaporating water from the wet walls containing wet fillers. Keeping the above in view, the present investigation was aimed to develop evaporative cool hydroponic fodder production chamber and study cooling and humidifying performance, temperature and relative humidity variations, and qualitative evaluation of hydroponic maize.

Materials and Methods

Experimental setup: An experimental setup of evaporative cool hydroponic chamber (ECHC) of the dimension 1.5m x 1.5m x 1.2m (Fig 1) consisting of a double wall (inner and outer wall), a filler (evaporating medium) inside the double-wall, fogging system to increase the humidity, drip system for watering the filler and a shading curtain was developed. The outer and inner walls of the ECHC were made of solid clay bricks. The gap between the outside and inside wall was 5 cm packed with filler consisting of a mixture of 80% sand and 20% gravel (Islam and Morimoto, 2014). Sand was used to increase the water retention capacity and gravel stone was used to enhance the evapo-transpiration rate. The tap water from tank was supplied to the filler material through low pressure drippers placed on the walls and to the fogger having solid cone nozzle (capacity: 10.0 l/h with 0.8 m spray dia) inside the chamber. The operating time of pump to supply water for filling materials of the walls was 6 h/day (10 am to 4 pm). The bottom of the cool chamber was covered with gunny bags. A shading curtain that reduces solar radiation by 80% (Bokade *et al.,* 2017) was also used to cover the entire structure including the water tank.

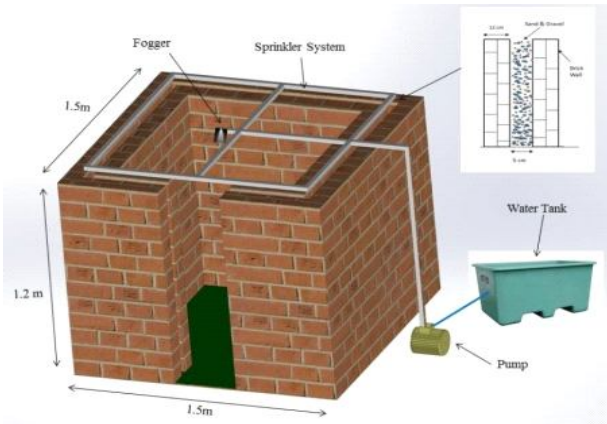

Fig 1. Experimental setup

Covering materials of structure: Before start of actual experimentation, a trial was made to record the effect of covering material (polycarbonate sheet) and without covering the chamber on the temperature and humidity variations under the chamber. It was observed that minimum and maximum temperature and relative humidity levels with cover were 22-30 ^{0}C and 82-98%, and without cover were 25-35 ^{0}C and 55-81%, respectively

(Fig 2). The humidity level with polycarbonate sheet as covering material went up to a maximum 98% and without cover, the lower level of relative humidity decreased to 55%. As both of these cases were not desirable conditions for hydroponic fodder production, a shade net (80%) was used as covering material to maintain the temperature and humidity level.

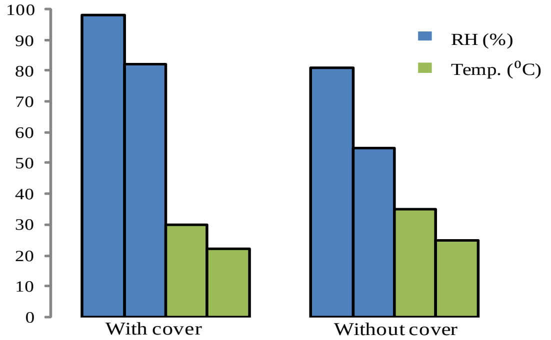

Fig 2. Variations of maximum and minimum temperature and RH under the ECHC

Testing of ECHC: Testing of ECHC was done continuously from 15th to 21st June 2020 during summer. The maize (variety: maize hybrid seed 'ASC-555', Ajanta Seed Corporation) seeds were cleaned and soaked in water for 24h and then packed tightly in gunny bag for 12h to sprout the seeds. The sprouted seeds were spread in three hydroponic trays each of size 35.6 cm x 26.10 cm, at the seed rate of 300 g/ft^2 and the trays were placed in the ECHC on 15th June 2020. Spraying of water was done only in day time at an interval of 2 h. Inside the ECHC, the seedlings were allowed to grow for seven days and harvested at the end of the seventh day. The growth behaviour of maize fodder grown under ECHC was recorded (Fig 3).

1-day plant (sprouted seed) 3-days plant

5-days plant 7-days plant (harvested maize fodder)

Fig 3. Growth behaviour of maize fodder grown under ECHC

Cooling performance and thermal variation: During experiment under ECHC, hourly data such as time, temperature and RH were recorded for 24 hours and the data were analysed. The cooling efficiency was calculated using the following equation as used earlier (Singh *et al*., 2007; Sabeh *et al.*, 2006; *Oz et al*., 2009); $\eta = (T_o - T_i) \times 100 / (T_o - T_{wb})$. Where, T_o = Ambient air temperature, ^{0}C; T_i = Temperature inside the chamber, ^{0}C and T_{wb} = Ambient wet bulb temperature, ^{0}C.

Qualitative analysis: The hydroponic fodder after 7 days of growth was chopped into small pieces and kept in hot air oven for drying to find out dry matter and moisture content. Nutritional quality (proximate analysis) of green fodder produced in the developed hydroponic structure was carried out. The composition like moisture content, dry matter (DM), organic matter (OM), crude protein (CP), crude fibre (CF), ether extract (EE), total ash (TA) and acid insoluble ash (AIA) were determined following standard methods (AOAC, 2000).

***Statistical analysis*:** Statistical analysis in terms of maximum, minimum, average values, standard deviation and standard error of mean of various responses/ attributes was done using MS-EXCEL software as per the method described by Gomez and Gomez (1984). The variation of environment data was analyzed graphically.

Results and Discussion

Thermal performance of ECHC: The thermal performance in terms of daily average, daily maximum and daily minimum temperature (T) and relative humidity (RH) and the variations of temperature (T) and relative humidity (RH) at different timings of day and night during hydroponic maize production were recorded (Table 1). These are based on hourly observations of day and night temperature and relative humidity for 7 days during experimentation. The average T in the morning (8 am), afternoon (1 pm), evening (5 pm) and midnight (2 am) were 29 °C, 33 °C, 29.8 °C and 29.4 °C, respectively and average values of RH at respective times were 76%, 58.7%, 67% and 71.6%, respectively. Maximum T and minimum RH of 34.3 °C and 52% at 1 pm and minimum T and maximum RH of 26 °C and 87% at 2 am (midnight) were recorded. To bring down the temperature, evaporative cooling system through application of water on walls and to increase the humidity level, fogging system were operated in day time during 8 am to 5 pm. The variation of T from morning to evening (8 am to 5 pm) was 3 °C. Minimum variation of T of 1.9 °C was observed in the morning (8 am) and maximum variation of 3.2 °C was observed in the midnight (2 am). This was due to absence of sunshine at the night and non-operation of evaporative cooling. It was also observed that during this period, the variations of RH were 32%. The excessive build-up of T could be avoided due to evaporative cooling. The average RH value of 71.6% from morning (8 am) to evening (5 pm) was achieved due to fogging system and ventilation through the shade net. The hourly T and RH ranged from 26.8 °C to 33.0 °C and 58.7% to 82.7%, respectively (Fig 4) along with average T and RH of 29.3 °C and 72% respectively.

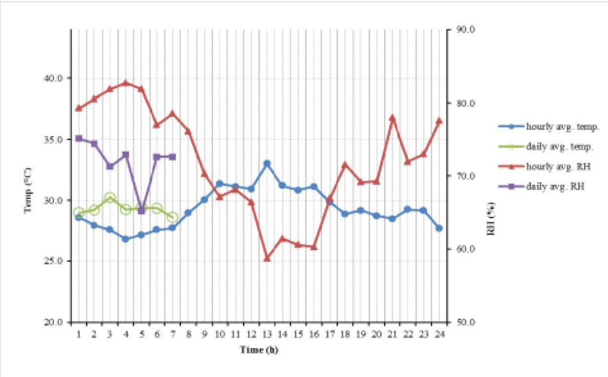

Fig 4. Variation temperature and RH during 7 days growth

Similarly, the variation of maximum and minimum T and RH was recorded (Fig 5). The average daily T and RH ranged from 28.6 - 30.2 °C and 65.2 - 75.1%, respectively. The daily maximum and minimum T range achieved under ECHC was 25.4 to 34.3 °C. These ranges of T and RH were indeed suitable environmental conditions for hydroponic fodder production except few highest levels of temperature. The optimum temperature required for hydroponic crops is around 22 °C and the maximum temperature that the crop can tolerate is usually around 30-32 °C (Sinsinwar and Krishna, 2012). Dirpan *et al.* (2017) also observed zero-energy cool chamber suitable for decreasing temperature and increasing relative humidity. Similarly, the daily maximum and minimum RH values ranged between 52 to 88%. These extreme limits of 52% and 88% were not desirable, but overall average RH ranged between 65.2-75.1% and the evaporative cooled structure resulted in healthy crop, so extreme limits of RH (52% and 85%) could also be tolerated by the plants.

Cooling performance of ECHC: Daily dry bulb temperature (DBT), wet bulb temperature (WBT), RH of ambient condition and DBT, temperature decrease (ΔT) and cooling efficiency under ECHC during the period of experimentation were recorded (Table 2). The highest T and lowest RH of the ambient were observed at 2 PM. The wet bulb depression (WBD), which represented the cooling potential, varied from minimum of 7.2 °C to maximum of 9.2 °C.

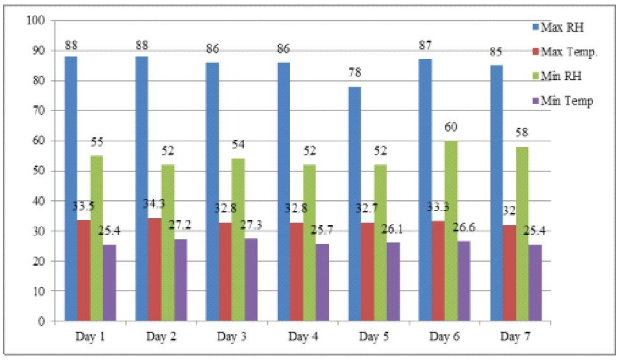

Fig 5. Variation of maximum and minimum T and RH during 7 days growth under ECHC

Table 1. Variation of T and RH at different timing during 7 days of hydroponic production

Description	Temperature (°C)			Humidity (%)		
	Max	Min	Avg	Max	Min	Avg
Day 1	33.5	25.4	29.1	88	55	75.1
Day 2	34.3	27.2	29.2	88	52	74.4
Day 3	32.8	27.3	30.2	86	54	71.3
Day 4	32.8	25.7	29.2	86	52	72.9
Day 5	32.7	26.1	29.4	78	52	65.2
Day 6	33.3	26.6	29.4	87	60	72.6
Day 7	32	25.4	28.6	85	58	72.6
Variation in the morning (8 am)	30	28.1	29	81	67	76.1
Variation in the afternoon (1 pm)	34.3	32	33	63	52	58.7
Variation in the evening (5 pm)	31.1	28.4	29.8	86	54	67
Variation from morning to evening (8 am to 5 pm)	31.1	28.1	29.4	86	54	71.6
Variation in the midnight (2 am)	29.2	26	27.9	87	73	80.6
Variation in the hourly average	33	26.8	29.3	82.7	58.7	72

Max: Maximum; Min: Minimum; Avg: Average

Table 2. Daily DBT, WBT, RH of ambient condition and DBT, temperature decrease and cooling efficiency under ECHC during the period of experimentation

Day	Ambient condition									Inside condition		
	DBT (°C)			WBT (°C)			WBD (°C)	RH (%)		DBT (°C)	ΔT (°C)	η (%)
	Min	Max	Avg	Min	Max	Avg		Min	Max			
1st	30.6	38.8	34.7	25.6	29.2	27.4	7.3	47	66	29.1	5.6	76.71
2nd	28.5	40.5	34.5	25.0	25.6	25.3	9.2	40	77	29.2	5.3	57.61
3rd	30.0	40.0	35.0	26.4	28.8	27.6	7.4	41	74	30.2	4.8	64.86
4th	30.4	40.6	35.5	26.8	28.8	27.8	7.7	39	74	29.2	6.3	81.81
5th	30.8	41.4	36.1	26.4	29.0	27.7	8.4	37	69	29.4	6.7	79.76
6th	30.0	40.4	35.2	26.0	28.8	27.4	7.8	40	71	29.4	5.8	74.35
7th	30.4	38.8	34.6	26.0	28.8	27.4	7.2	45	69	28.6	6.0	83.33

DBT: Dry bulb temperature; WBT: Wet bulb temperature; WBD: Wet bulb depression; RH: Relative humidity; ΔT: Decrease in temperature

Table 3. Biomass yield and nutrient content in hydroponic maize at the end of 7th day

Attributes	R1	R2	R3	Mean	SD	SEM
BMY (kg/sq. ft tray)	1.165	1.240	1.192	1.20	0.038	0.022
BMY (kg/kg of seed)	3.883	4.133	3.973	4.00	0.127	0.073
DM (%)	13.38	13.51	13.47	13.45	0.067	0.038
OM (%)	96.62	96.53	96.59	96.58	0.046	0.026
CP (%)	13.08	13.16	13.06	13.10	0.053	0.031
CF (%)	15.28	15.35	15.30	15.31	0.036	0.021
EE (%)	3.17	3.18	3.22	3.19	0.026	0.150
TA (%)	3.38	3.47	3.41	3.42	0.046	0.026
AIA (%)	0.29	0.32	0.26	0.29	0.030	0.017

BMY: Biomass yield; R: Replication; SD: Standard deviation; SEM: Standard error of mean

Maximum 6.7 °C decrease in T inside the ECHC was observed as compared to ambient conditions. Watering lowered the inside T to 25.4 °C and increased the RH from 52 to 88% under an ambient T of 28.5 °C to 41.4 °C. The cooling efficiency (s) of the evaporative cooling system varied from 57.61% to 83.33% with an average value of 74.06%. Evaporative cooling decreases the inside temperature of the ECHC below the dry bulb temperature. The cooling below DBT inside ECHC was due to combined moist wall of the ECHC and mist used for irrigation and to increase the humidity level of the ECHC. Islam and Morimoto (2014) also observed reduction of inside temperature of zero energy cool chamber to 12.07 °C as compared to average outside T of 31.5 °C. On the other hand, the solar radiations were blocked at the tune of 80% by shade net, which also contributed to lower the temperature (Islam *et al.,* 2013). On an average, the ambient T was higher than T inside the ECHC, particularly in daylight. The ambient highest T and minimum RH at peak sunshine hour (2 PM) were 41.4 °C and 37%, respectively and the corresponding values for inside ECHC were 34.3 °C and 52%, respectively. This result was also in agreement with a study of Islam and Morimoto (2012) in which the temperature of zero energy cool chamber was lower than the outside one. Higher evaporative cooling was also observed under fan-pad cooled greenhouses in summer months as compared to winter season and cloudy days (Singh *et al.,* 2005).

Biomass yield and quality of hydroponic maize: The results of biomass yield and nutrient composition on percent dry matter basis were recorded (Table 3). The range of shoot length varied from 26 to 33 cm and the maximum number of leaves per plant was three. Fresh biomass yields were observed as 1.2 kg/ sq. ft tray area and 4.00 kg/kg of seed which indicated an increase in fresh green fodder biomass four times as compared to seed biomass. However, varieties of maize and seed rate also influenced the hydroponic maize biomass yield (Getachew *et al.,* 2020). Yields of 4-5 folds on fresh basis and dry matter (DM) content of 11-14% are common for hydroponic maize fodder. Sometimes dry matter up to 18% was also observed (Naik *et al.,* 2013). The average DM and moisture contents were found as 13.45% and 86.55%, respectively for harvested hydroponic maize fodder. The high moisture content was due to crop grown in water and harvested at very early stage. The crude protein (CP) an important nutrient required in the ruminant diet was found higher (13.10%). Low crude fibre (15.30%)

in hydroponic fodder was also due to harvesting of plants at early stage before the development of fibrous tissues. Higher CP and lower fibre content (FC) in hydroponic maize fodder make it nutritious and easily digestible for livestock.

The values of CP, CF, EE and TA for commercially available maize fodder grown conventionally in the field condition were 10.59, 28.40, 2.28, and 2.15%, respectively (Naik *et al.,* 2012). The comparatively high fibre content in conventionally grown maize fodder was due to harvesting at mature fibrous stage. The earlier worker also supported that the hydroponic fodder is more nutritious and palatable than conventional fodder (Naik *et al.,* 2014). Increase in milk yield of 9.3 to 13.7% with feeding of hydroponic green fodder to the livestock was reported earlier (Reddy *et al.,* 1988; Naik *et al.,* 2014). Thus, hydroponic fodder provides diets with high nutrients, but we need regular sowing of seeds at 7-10 days intervals. The growth of seven days of fodder maize validates its biomass which was enough to feed the livestock. Although, hydroponic and conventional systems of fodder productions have their own advantages and limitations. Rachel *et al. (*2020) reported in similar line as described above that hydroponic method of fodder production yields fodder with better nutritional quality than conventional method.

Conclusion

In evaporative cool hydroponic chamber (ECHC), developed using low-cost locally available materials, the cooling efficiency varied from 57.61 to 83.33% with an average value of 74.06%. Fresh biomass yields for fodder maize were 1.2 kg/ sq. ft tray area and 4.00 kg/kg of seed. Biomass was also rich in protein (13.10%), but low in crude fibre (15.30%) when compared to conventionally grown fodder maize. Thus, the developed low-cost energy efficient evaporative cooling based hydroponic fodder production unit could be exploited to provide green fodder during the period of scarcity and to sustain livestock production.

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