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Developing and standardization of pneumatic automatic solution dispenser for fertigation of crops on daily basis

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Abstract
The research paper outlines the development and laboratory standardization of pneumatic automatic solution dispenser that works based on the principle of thermal expansion of air driven by diurnal temperature variation, for fertigation to crops on daily basis. The dispenser consists of air chamber and solution dispenser. In order to standardize the output efficiency of this solution dispenser, entire set up was maintained in an incubator set with simulated temperature variation of 5 and 10°C. The temperature ranges as follows; T_1: 20-25°C, T_2: 25-30°C, T_3: 30-35°C, T_4: 35-40°C, T_5: 20-30°C, T_6: 25-35°C, T_7: 30-40°C. Each treatment was replicated 4 times (cycles) of measurement at one hour interval. The results revealed that low temperature range of 20-25°C recorded no dispensing of fertilizer solution at all hours of measurement. On contrary, other ranges of temperature at 5°C variation recorded increasing rate of solution dispensed *viz.,* 1.98, 2.30 and 3.41 ml/°C at 25-30°C, 30-35°C and 35-40°C respectively depicting a positive linear relationship between the volumes of solution dispensed (ml/°C) with rise in temperature range. Similarly, temperature range at 10°C recorded a dispensing rate of 5.47, 4.97 and 4.37 ml/°C at 20-30°C, 25-35°C and 30-40°C respectively. On contrary to 5°C variation, simulated variation at 10°C could able to reduce the effect of increase in humidity in air chamber at every contraction cycle. Finally, the results indicated the feasibility of this pneumatic automatic solution dispenser to be used for fertigation to crops on daily basis under tropical climate having a minimum temperature above 25°C with diurnal variation of 5-10°C. It is beneficial in term of automatic delivery, portability, cost effectiveness, easy handling and no power requirement. This kind of dispensers will help to deliver fertilizer solution to crops automatically to match the nutrient requirement on daily basis, either in soil, growing media or in drip lines. While designing for commercial use all components will be integrated into a single unit.

Keywords: Coefficient of volume dispensing, diurnal temperature variation, pneumatic automatic solution dispenser, rate of dispensing, thermal expansion

1. Introduction

Horticultural crops have now attained a status parallel to field crops and stake a strong claim of offering nutritional security, thereby share a part of load on consumption of cereals. Raising the productivity of horticultural crops is perhaps still a constraint. For most horticultural crops *viz.,* fruits, flowers, vegetables and ornamental plants, the economic concern are that much of fertilizer cost to be incurred within production cost for obtaining desirable yield and quality. Therefore, growers are most concerned about effective methods to improve fertilizer use efficiency.

Conventional practice of nutrient management is based on nutrient schedule. At periodical intervals, broadcast applications of fertilizers are distributed in bulk in the field. Bulk distribution of fertilizers results in wastage and creates imbalance in ion concentration in soil. So, to address such issues, recently fertigation and foliar spray are found to be the most advanced and efficient methods (Pawar and Dingre, 2013) [2]. These methods of fertilization in horticultural crops makes use of liquid fertilizers or water soluble fertilizers to meet nutritional demand of crop at critical growth stages with higher fertilizer use efficiency. It has been reported that use of fertigation in horticultural crops could save 30-50% of fertilizer (Shirgure *et al.*, 2003; Shirgure and Srivastava, 2014) [4, 5]. of different fertilizers formulations, water soluble fertilizers are a special class of fertilizers, which hold very strong promise in protected cultivation, hydroponic or aeroponic or even open field conditions (Liu *et al.*, 2012) [1]. There is more scope for the water soluble fertilizers to increase the production of horticultural crops, as the demand is increasing in India in multifold every year.

Several commercially developed fertilizer injectors are being used for applying liquid fertilizers either through the irrigation systems or foliar spray. There are two main techniques: ordinary closed tank and injector pump (Thomas *et al.*, 2010) [6]. The injector pumps are mainly either venturi type or piston pump. Both the systems are operated by the water pressure. Though such fertilizer injectors are advantageous in term of easy and fast application, it is not promising with regard to cost, handling skills, clogging problems, unequal distribution in soil and manufacturing repairment.

Further, fertigation systems have been designed to large scale distribution of nutrient solution in field. There are no suitable dispensers available to apply nutrient solution per plant basis. In protected cultivation system vegetable or flower crops are grown in poly-houses, and each plant has a commercial value. Hence, each plant has to be given with required quantity of nutrient, matching to the growth stages of crops. If nutrient dispensers are available, that can be used to fertilize high value commercial crops which are grown in raised bed or grow bags or pots.

In order to address such situation associated with the use of fertilizer application per plant basis, the present study has been taken up to develop and standardize a pneumatic automatic solution dispenser that uses air pressure as a driving force for its functioning. Unlike commercially available injectors, it is beneficial in terms of automatic delivery, portability, cost effectiveness and easy handling.

2. Materials and Methods

A laboratory experiment was conducted in the Department Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University (TNAU), Coimbatore with an aim to develop and standardize a pneumatic solution dispenser in order to aid automatic delivery of fertilizer solution to individual plants. The empirical laboratory model of pneumatic solution dispenser and the methodology adopted to evaluate its performance are furnished below.

2.1 Design of pneumatic solution dispenser

2.1.1 Structural component

The experimental set up of pneumatic solution dispenser consists of 3 structural components *viz.*, 1) Air Chamber made with reagent bottle (thin walled glass) 1 lit capacity, 2) Nutrient Solution Container made with plastic bottle of 350 ml capacity, 3) Nutrient Solution Receiver Container made with conical flask / beaker with plastic lid (250 ml). All the three components are interconnected through polythene tubes. Both air chamber and nutrient solution container are sealed air tight so as to prevent leak of air between inside and outside (Fig 1).

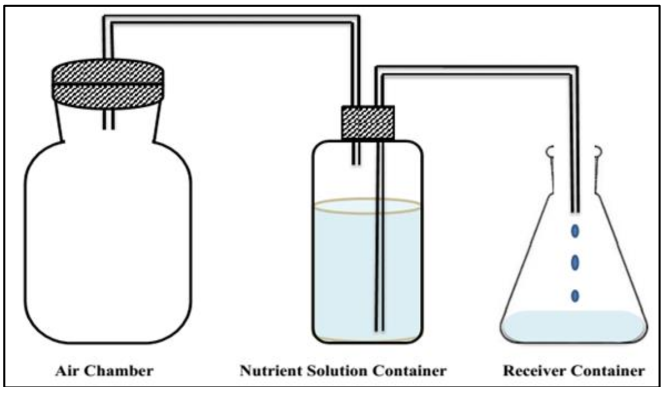

Fig 1: Outline of pneumatic solution dispenser

2.1.2 Working Principle

The working principle of pneumatic solution dispenser is based on the thermal expansion of air. The increasing temperature of air increases the average speed (and therefore the kinetic energy) of movement of the gaseous molecules. This causes the molecules to 'spread out' - a phenomenon called thermal expansion. The thermal expansion coefficient of air changes with its temperature. At normal standard conditions of 25°C (298 °K), thermal expansion coefficient of air is said to be around 0.0034/K or (0.34 ml/L/°C) (Scott Post, 2011).

Every day there is a diurnal variation in air temperature, which represents the difference between maximum temperature during day and minimum temperature during night. The newly designed dispenser makes use of this diurnal temperature variation as a driving force that triggers displacement of fertilizer solution to external environment. The flow mechanism lies with, as the temperature of air inside the air chamber increases upon warming during day time, it undergoes thermal expansion and air pressure spreads out. This expanding air moves via interconnected tube and tries to occupy the space inside the solution chamber. This in turn causes an expulsion of equivalent volume of fertilizer solution. The expelled solution is collected in receiver container (Fig 2).

Fig 2: Empirical Model of Pneumatic Solution Dispenser for automatic application of nutrient solution to plant

Again during night time, the air inside the air chamber gets cooled down. Hence, contraction of volume of air occurs in air chamber, which takes in external air inside. This occurs as bubbling in the solution from the long tube dipped in solution. Such differential air expansion and contraction inside air chamber mediated by diurnal temperature variation continues on daily basis during entire crop growth period to aid automatic application of fertilizer solution to plant.

2.2 Methodology of experimentation

In order to standardize the output efficiency of solution dispenser by measuring volume of fertilizer solution dispensed (ml/°C), laboratory experiment was conducted. For simulating nutrient solution, 10g of AR grade of NaCl was dissolved in 300 ml of distilled water and filled in nutrient solution chamber.

The entire dispenser set up was kept in a temperature regulated incubator and maintained for an observation period of 1 hour alternatively at 2 temperature intervals (5°C and 10 °C) at varying temperature ranges. The details of temperature ranges and intervals maintained are furnished in Table 1. The basis for formulated treatments is that regions in a tropical climate have air temperature with diurnal variation of approximately 5 to 10 °C. The concept behind maintaining these 2 temperature intervals in treatments lies with simulating the diurnal temperature variation that prevails during crop growth period.

Table 1: Treatments details of temperature intervals and range (°C)

T. No	Temperature Interval (°C)	Temperature Range (°C)
T_1	5	20-25
T_2	5	25-30
T_3	5	30-35
T_4	5	35-40
T_5	10	20-30
T_6	10	25-35
T_7	10	30-40

The initial empty weight of receiver flask (W_i) was recorded. Subsequently, after the expulsion of nutrient solution, the final total weight of nutrient solution collected plus weight of receiver flask (W_f) was recorded for each temperature range treatments at the end of every cooling cycle. Then, the actual quantity of fertilizer solution dispensed (W_f -W_i) was computed gravimetrically. Thus, each treatment was replicated 4 times (cycles) of measurement. Each time of recording of weight was done at one hour difference, in order to allow the set up to equilibrate with heat imposed in the incubation chamber. Finally, the mean volume of fertilizer solution dispensed (ml) was computed.

Based on volume, derived parameters *viz.*, rate of dispensing (ml/°C) and coefficient of volume dispensing (ml/°C/ml_i) were quantified for each temperature treatments using the following formula (Scott Post, 2011)

Coefficient of volume dispensing (cvd) = [(Vf-Vi)/(Tf-Ti)]/Vi

Where,
VF= Final volume of solution (ml)
Vi = Initial volume of solution (ml)
Tf = Final temperature (°C)
Ti = Initial temperature (°C)

3. Results and Discussion

3.1 Effect of simulated diurnal temperature variation of 5°C on volume of solution dispensed

The volume of fertilizer solution dispensed (ml/°C) at the set simulated diurnal temperature variation of 5 °C, varied widely at four range of temperature (20-25, 25-30, 30-35 and 35-40°C), imposed in treatment T_1 to T_4.

The results on volume of fertilizer solution dispensed (Table 2) showed that among all range of temperature, low temperature range of 20-25°C recorded no collection of fertilizer solution at all hours of measurement. This might be due to the fact that such temperature range (20-25°C) may have failed to provide sufficient amount of heat energy for expansion of air inside the air chamber which in turn caused no expulsion of fertilizer solution. This finding coincided to the principle of air expansion stating that volume temperature expansion of air is not linear with temperature.

On contrary, other 3 levels of temperature range *viz.*, 25-30, 30-35 and 35-40 °C recorded increasing rate (ml/°C) of fertilizer solution dispensed of 1.98, 2.30 and 3.41 respectively. Such observation depicted a positive linear relationship between the volumes of solution dispensed (ml/°C) with rise in incubation temperature range (Fig 3). Such finding confirmed with the basic principle of thermal expansion of air as per Charles law which depicts that thermal expansion of air increases with rise in temperature at constant atmospheric pressure.

Table 2: Rate of solution dispensed (ml/°C) at different temperature ranges with a simulated variation of 5 °C

T. No	Hours after Start (HAS)	Time (Hours)	Temperature Maintained (°C)	Volume of Solution Dispensed (ml)	Rate of dispensing (ml/°C)		Coefficient of volume Dispensing (ml/°C/ml_i)	
					at hours after start	mean	at hours after start	mean
T_1	1	9:30 am	20	-	0.00	0.00	0.00	0.00
	2	10:30 am	25	0				
	3	11:30 am	20	-				
	4	12:30 pm	25	0				
	5	1:30 pm	20	-				
	6	2:30 pm	25	0				
	7	3:30 pm	20	-				
	8	4:30 pm	25	0				
T_2	1	9:30 am	25	-	4.50	1.98	0.015	0.007
	2	10:30 am	30	22.51				
	3	11:30 am	25	-	1.85		0.006	
	4	12:30 pm	30	9.26				
	5	1:30 pm	25	-	1.10		0.004	
	6	2:30 pm	30	5.50				
	7	3:30 pm	25	-	0.45		0.001	
	8	4:30 pm	30	2.24				
T_3	1	9:30 am	30	-	5.02	2.30	0.017	0.008
	2	10:30 am	35	25.08				
	3	11:30 am	30	-	2.07		0.007	
	4	12:30 pm	35	10.36				
	5	1:30 pm	30	-	1.42		0.005	
	6	2:30 pm	35	7.10				
	7	3:30 pm	30	-	0.70		0.002	
	8	4:30 pm	35	3.51				
T_4	1	9:30 am	35	-	5.15	3.41	0.017	0.011
	2	10:30 am	40	25.76				
	3	11:30 am	35	-	3.44		0.011	
	4	12:30 pm	40	17.21				

	5	1:30 pm	35	-	2.78		0.009	
	6	2:30 pm	40	13.90				
	7	3:30 pm	35	-	2.25		0.007	
	8	4:30 pm	40	11.23				

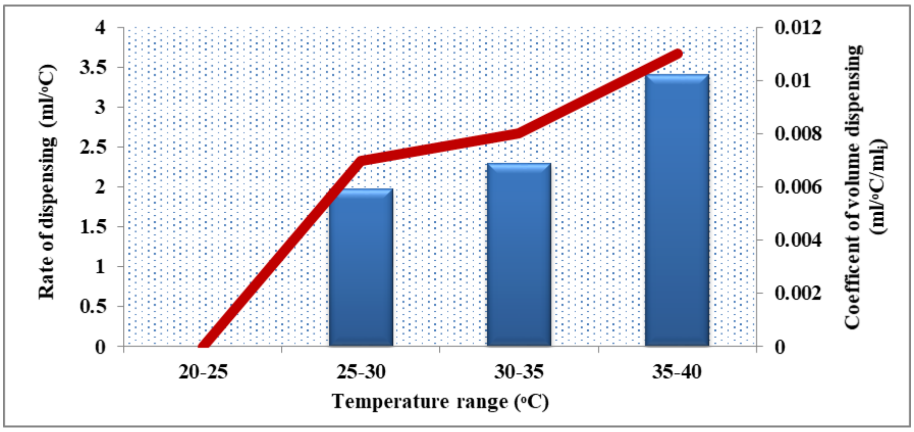

Fig 3: Relationship between Rate of dispensing (ml/°C) and Coefficient of volume dispensing (ml/°C/ml$_i$) with temperature range (°C) at simulated variation of 5 °C

With alternative cycles of volume measurement at one hour intervals at each temperature range of 25-30, 30-35 and 35-40°C, the quantity of fertilizer solution dispensed followed a decreasing trend as hours after start (HAS) proceeded. This was well evidenced by dispensing of 22.51 ml of fertilizer solution at 2 HAS of incubation followed by 9.26, 5.50 and 2.24 ml at 4, 6 and 8 HAS respectively at a temperature range of 25-30°C. Similar trend was also observed with other temperature interval (30-35 and 35-40°C) each set at 5°C variation (Fig 4).

This might be due to the humidifying effect of contraction cycle in air chamber. With expansion cycle initially atmospheric air contained in air chamber which could have had low humidity might have expanded greater extent, and hence pushed more solution into receiver flask. In subsequent contraction cycle, air chamber would have taken in atmospheric air from outside through the solution chamber by bubbling process. Thus bubbles would have taken humidity from solution and transferred into air chamber. Thus, in every contraction cycle more and more humidity would have accumulated in air chamber. As the coefficient of expansion of water vapour (humidity) is much lesser than air, expansion of air in air chamber would have been reduced substantially at each subsequent cycle. Decrease in the volume of fertilizer solution resulted in the present study, would have been thus the effect of increase in humidity in air chamber at every contraction cycle.

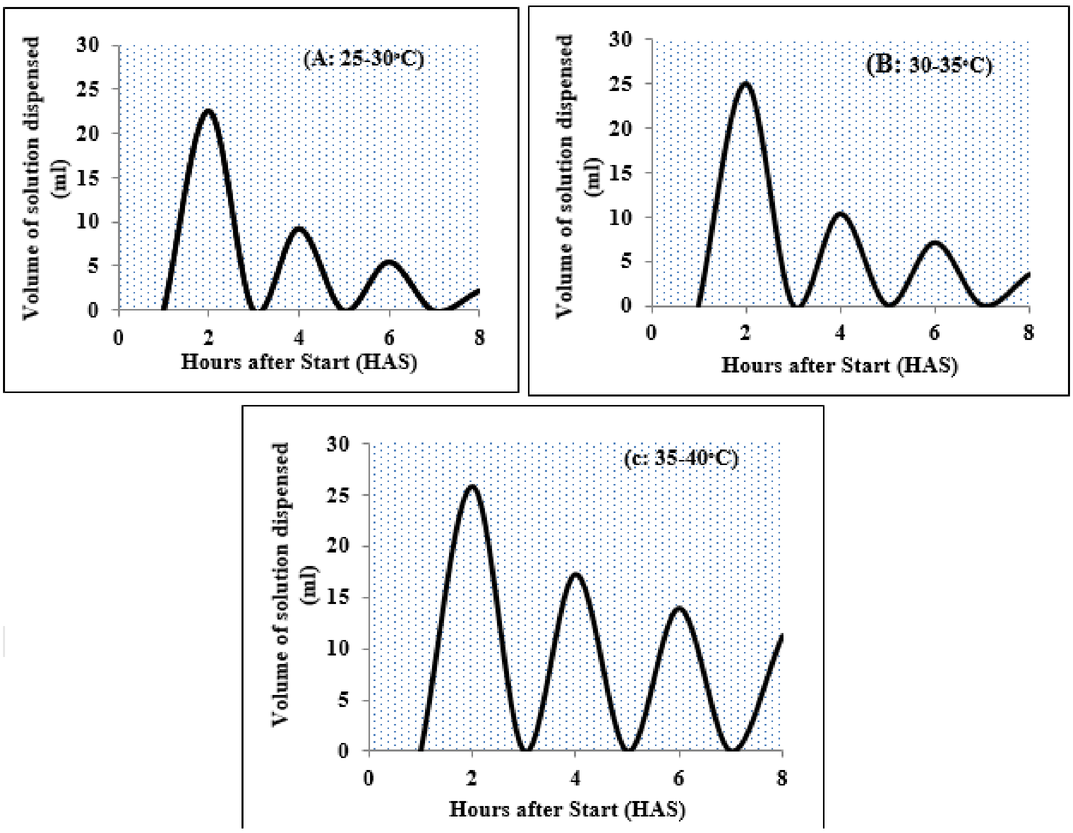

Fig 4: Relationship between Volume of solution dispensed (ml) and Temperature range (°C) at hours after start (HAS) [a,b,c]

The change in rate and coefficient of volume dispensing in alternative cycles of volume measurement at one hour intervals recorded a declining trend at each temperature range of 25-30, 30-35 and 35-40ºC simulated at a diurnal temperature variation of 5ºC (Fig 5). At temperature range of 25-30ºC, the rate of dispensing was found to be 4.50, 1.85, 1.10 and 0.45 ml/ºC at 2, 4, 6 and 8 HAS respectively. Similarly, coefficient of volume dispensing also followed a declining trend which was well evidenced by 0.015, 0.006. 0.004 And 0.001 ml/ºC/ml$_i$ at 2, 4, 6 and 8 HAS. Hence, rate and coefficient of volume dispensing followed an increasing trend with rise in temperature wherein it attained a declining trend as hours after start proceeded.

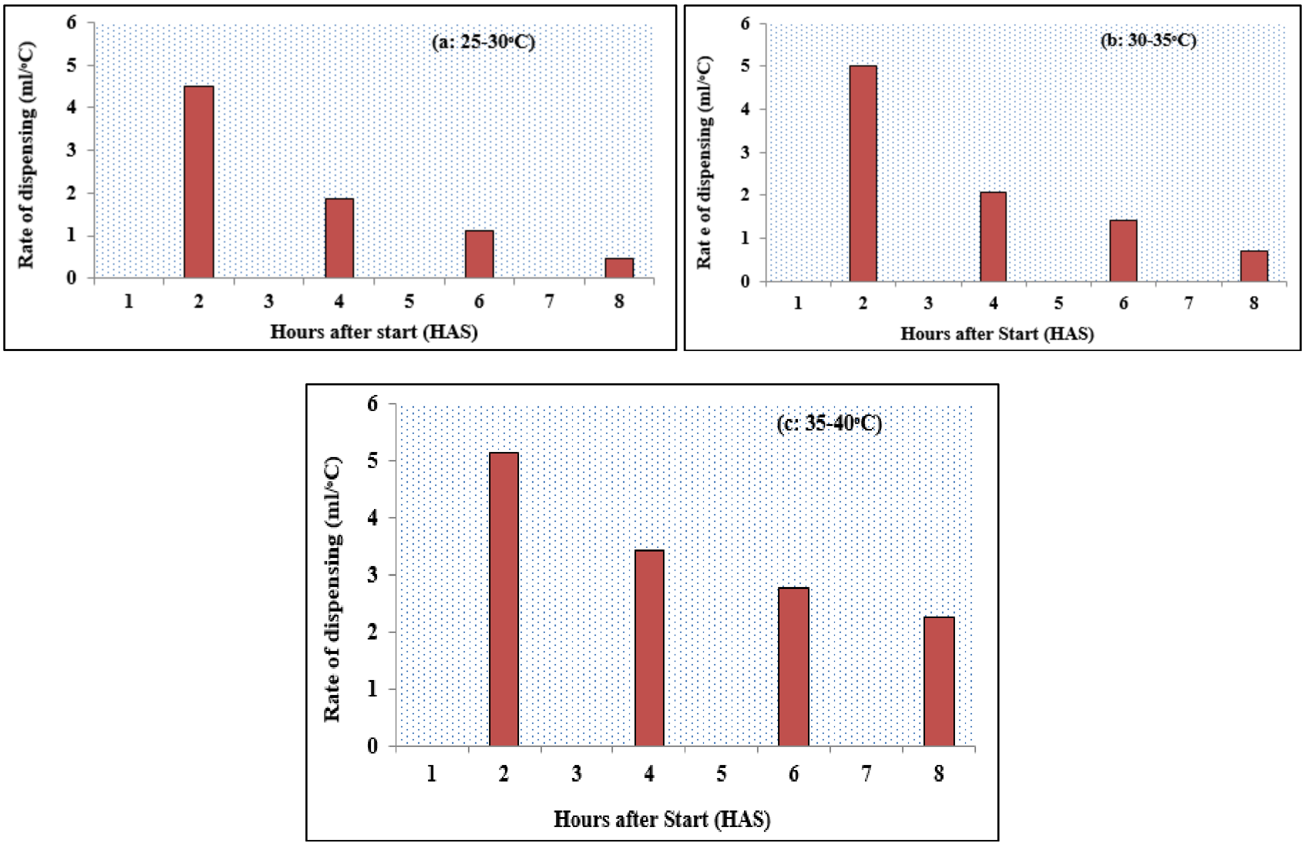

Fig 5: Relationship between Rate of dispensing (ml/ºC) and temperature range (ºC) at hours after start (HAS) [a,b,c]

3.2 Effect of simulated 10ºC diurnal temperature variation on volume of solution dispensed

To standardize the rate of fertilizer solution dispensed (ml/ºC) at simulated diurnal temperature variation of 10ºC, the entire solution dispenser system was maintained at three ranges of temperature (20-30, 25-35 and 30-40 ºC) imposed in treatment T5 to T$_7$. The results on rate of fertilizer solution dispensed (Table 3) showed that at three levels of set temperature ranges *viz.*, 20-30, 25-35 and 30-40ºC recorded a mean rate of fertilizer solution dispensed of 5.47, 4.97 and 4.37 ml/ºC respectively. Unlike simulated variation of 5ºC, there is a linear drop in rate and coefficient of volume dispensing with the rise in temperature ranges from 20-30 to 30-40ºC simulated each at a variation of 10ºC (Fig 6).

Table 3: Rate of solution dispensed (ml/ºC) at different temperature ranges with a simulated variation of 10 ºC

T. No	Hours after Start (HAS)	Time (Hours)	Temperature Maintained (ºC)	Volume of Solution Dispensed (ml)	Rate of dispensing (ml/ºC)		Coefficient of volume dispensing (ml/ºC/ml$_i$)	
					at hours after start	mean	at hours after start	mean
T$_5$	1	9:30 am	20	-	5.88	5.47	0.020	0.019
	2	10:30 am	30	29.41				
	3	11:30 am	20	-	5.57		0.019	
	4	12:30 pm	30	27.87				
	5	1:30 pm	20	-	5.44		0.018	
	6	2:30 pm	30	27.19				
	7	3:30 pm	20	-	4.97		0.017	
	8	4:30 pm	30	24.87				
T$_6$	1	9:30 am	25	-	4.75	4.97	0.016	0.017
	2	10:30 am	35	23.75				
	3	11:30 am	25	-	5.30		0.018	
	4	12:30 pm	35	26.49				
	5	1:30 pm	25	-	5.68		0.019	
	6	2:30 pm	35	28.40				
	7	3:30 pm	25	-	4.14		0.014	
	8	4:30 pm	35	20.69				

T_7	1	9:30 am	30	-	4.63	4.37	0.015	0.015
	2	10:30 am	40	23.14				
	3	11:30 am	30	-	4.77		0.016	
	4	12:30 pm	40	23.84				
	5	1:30 pm	30	-	4.17		0.014	
	6	2:30 pm	40	20.84				
	7	3:30 pm	30	-	3.91		0.013	
	8	4:30 pm	40	19.56				

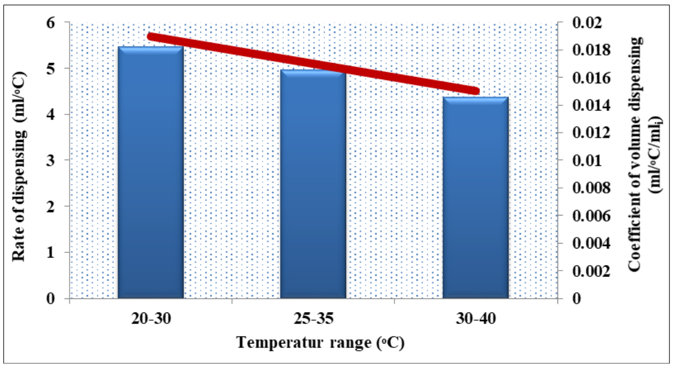

Fig 6: Relationship between Rate of dispensing (ml/°C) and Coefficient of volume dispensing (ml/°C/ml$_i$) with temperature range (°C) at simulated variation of 10 °C

With alternative cycles of volume measurement at one hour intervals at each temperature range of 20-30, 25-35 and 30-40°C, the quantity of fertilizer solution dispensed followed a decreasing trend as hours after start (HAS) proceeded. This was well evidenced by dispensing of 29.41 ml of fertilizer solution at 2 HAS of incubation followed by 27.87, 27.19 and 24.87 ml at 4, 6 and 8 HAS respectively at a temperature range of 20-30°C. Similar trend was also observed with other temperature interval (25-35 and 30-40°C) each set at 10°C variation
(Table 3).

The change in rate and coefficient of volume dispensing in alternative cycles of volume measurement at one hour intervals recorded a declining trend at each temperature range of 20-30, 25-35 and 30-40°C at simulated diurnal temperature variation of 10°C (Fig 7). At temperature range of 20-30°C, the rate of dispensing was found to be 5.88, 5.57, 5.44 and 4.97 ml/°C at 2, 4, 6 and 8 HAS respectively. Similarly, coefficient of volume dispensing also followed a declining trend which was well evidenced by 0.020, 0.019. 0.018 and 0.017 ml/°C/ml$_i$ at 2, 4, 6 and 8 HAS. Decrease in the rate of nutrient solution dispensed, resulted in the present study would have been thus due to the humidifying effect at each contraction cycle. However, on contrary to 5°C variation, simulated variation at 10°C could able to reduce the effect of increase in humidity in air chamber at every contraction cycle. Hence, rate and coefficient of volume dispensing followed an increasing trend with rise in temperature wherein it attained a declining trend as hours after start proceeded.

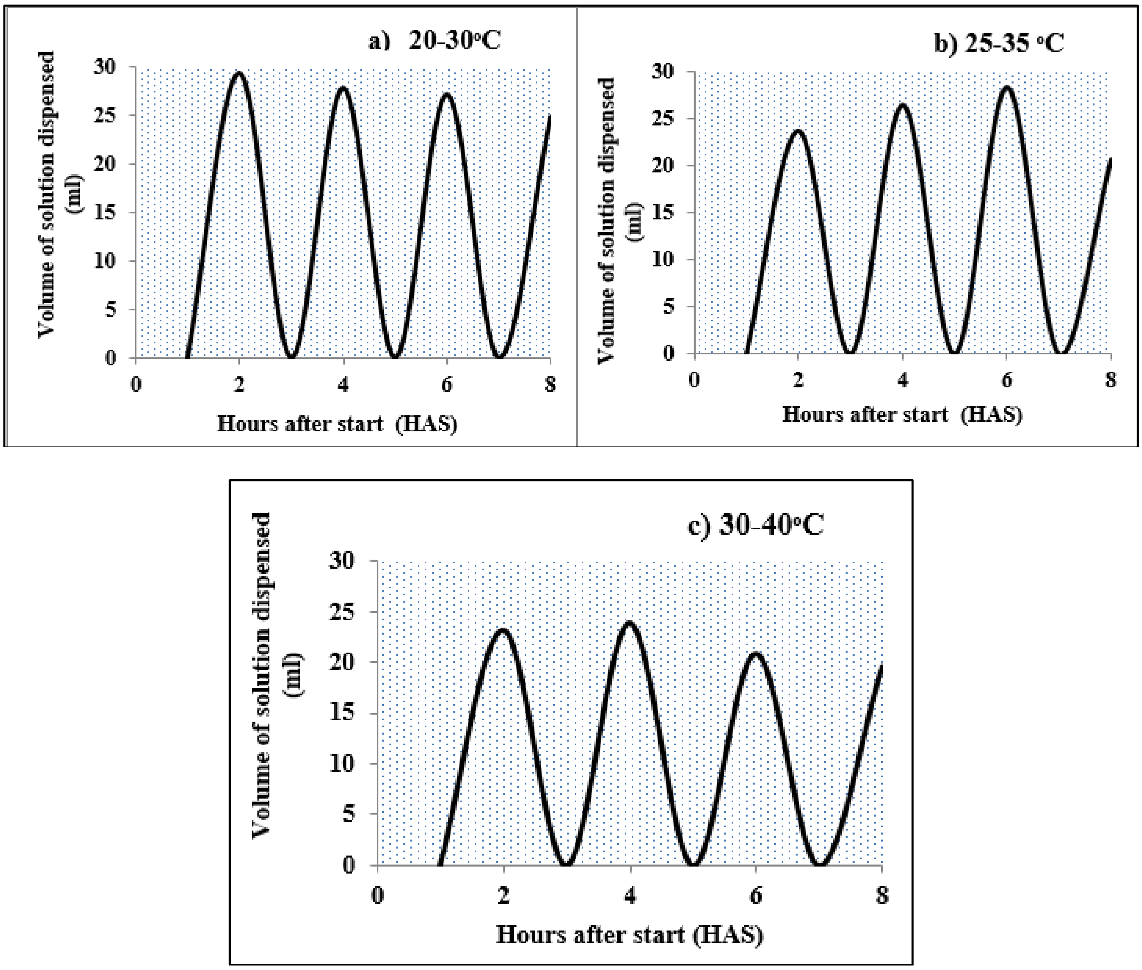

Fig 7: Relationship between Volume of solution dispensed (ml) and Temperature range (°C) at hours after start (HAS) [a, b, c]

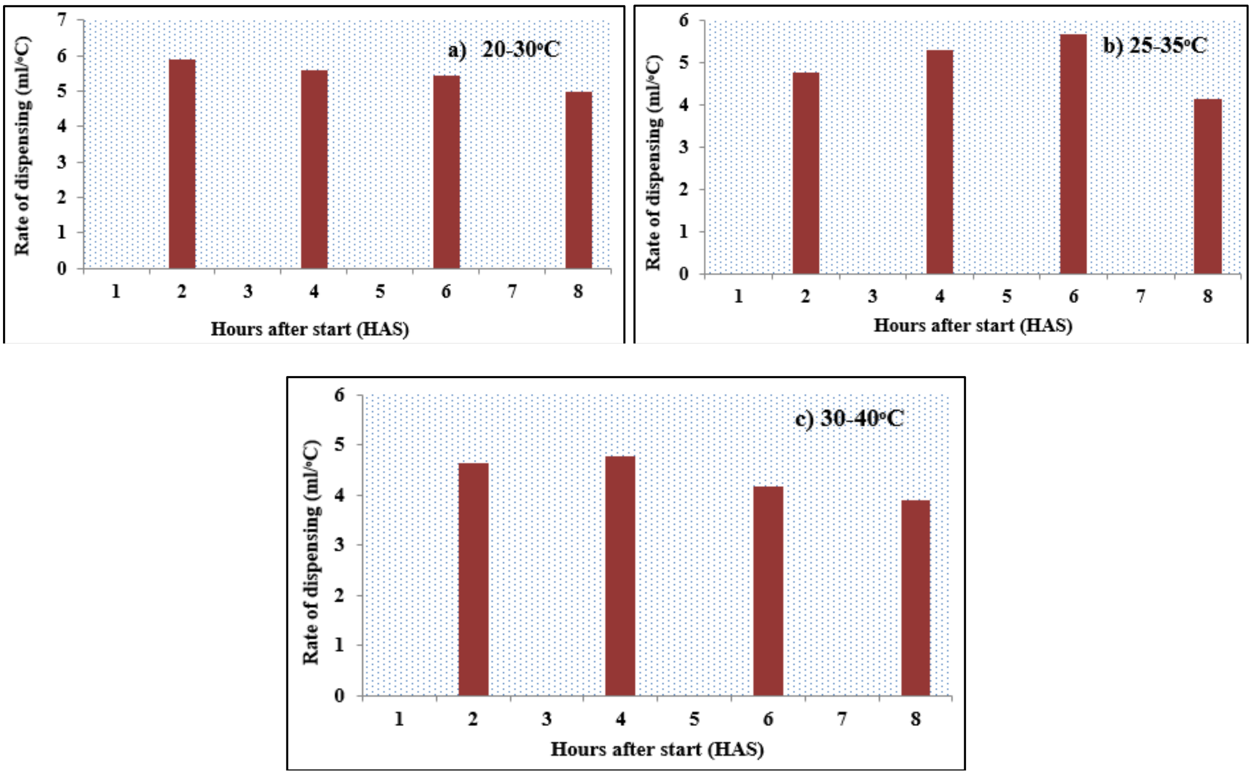

Fig 8: Relationship between Rate of dispensing (ml/°C) and temperature range (°C) at Hours after start [a,b,c]

3.3 Correlation studies

3.3.1 Correlation between Rate of dispensing (ml/°C), Coefficient of volume dispensing (ml/°C/ml$_i$) and temperature range (°C) at simulated variation of 5 and 10 °C

The correlation studies between rate of dispensing and temperature range (Table 4) revealed a highly positive correlation (r = 0.91) with each other in all temperature ranges simulated at 5°C and 10°C**.** Coefficient of volume dispensing was also found to be positively correlated with the simulated temperature ranges (r = 0.93). Coefficient of volume dispensing also showed a positive correlation with the rate of dispensing at all temperature ranges (r = 0.99) there by indicating a linear pattern in volume expansion thereby an increase in rate of dispensing.

Table 4: Correlation matrix between Rate of dispensing (ml/°C), Coefficient of volume dispensing (ml/°C/ml$_i$) and temperature range (°C) at simulated variation of 5°C and 10°C

Parameters	Temperature (°C)	Rate of dispensing (ml/°C)	Coefficient of volume dispensing (ml/°C/ml$_i$)
Temperature (°C)	1		
Rate of dispensing (ml/°C)	0.91**	1	
Coefficient of volume dispensing (ml/°C/ml$_i$)	0.93**	0.99**	1

*and ** denote significant at 5% and 1% level, respectively.

3.3.2 Correlation between Rate of dispensing (ml/°C), Coefficient of volume dispensing (ml/°C/ml$_i$) and hours after start (HAS) at simulated variation of 5°C and 10 °C

There was a strong negative correlation between the rate and coefficient of volume dispensing, with hours after start (Table 5). At simulated variation of 5°C with temperature range 25-30°C had a strong negative correlation with the rate of dispensing (r = -0.93) and coefficient of volume dispensing (r = -0.94). Similar trend of correlation was also found in other temperature ranges viz., 30-35, 35-40 °C. On contrary, temperature range of 20-30°C only showed a strong negative correlation wherein, other ranges of temperature 25-35°C and 30-40°C had a poor negative correlation between hours after start and rate of dispensing with a r value of -0.27 and -0.89 respectively.

Table 5: Correlation matrix between Rate of dispensing (ml/°C), Coefficient of volume dispensing (ml/°C/ml$_i$) and Hours after start (HAS) at simulated variation of 5 and 10 °C

Parameters	Temperature (°C)					
	25-30°C	30-35°C	35-40°C	20-30°C	25-35°C	30-40°C
Hours after start (HAS) × Rate of dispensing (ml/°C)	-0.93**	-0.92**	-0.95**	-0.97*	-0.27*	-0.89*
Hours after start (HAS) × Coefficient of volume dispensing (ml/°C/ml$_i$)	-0.94**	-0.93**	-0.96**	-1**	-0.29*	-0.80*
Rate of dispensing (ml/°C) × Coefficient of volume dispensing (ml/°C/ml$_i$)	0.99**	0.98**	0.99**	0.97**	0.99**	0.98**

*and ** denote significant at 5% and 1% level, respectively.

4. Conclusion

The research study revealed that the newly designed pneumatic solution dispenser could reduce the humidifying effect during contraction cycle, thereby depicting a linear increase in rate of dispensing with rise in temperature above 25°C set at simulated diurnal variation of both 5 and 10°C. However, it failed to dispense fertilizer solution at low temperature range of 20-25°C. Hence, it is concluded that, this pneumatic dispenser is feasible to be used for fertigation to crops matching the nutrient requirement on daily basis either in soil or grow bag media or in drip lines. It is highly suitable for tropical areas having a minimum temperature above $25^{o}C$ with diurnal variation of $5\text{-}10^{o}C$. It is also beneficial in term of automatic delivery, portability, cost effectiveness, easy handling and no power requirement. While designing for commercial use all components will be integrated into a single unit. Based on the coefficient of volume dispensing, the volume of air chamber can be modified so as to regulate rate dispensing thereby matching the crop requirement under large scale cultivation.

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