PLANT SCIENCE TODAY
Vol 13(sp1): 1-12
https://doi.org/10.14719/pst.13172

eISSN 2348-1900

RESEARCH ARTICLE

Evaluation of fertigation uniformity under a drip irrigation system and its effects on irrigation water management in garlic (*Allium sativum* L.)

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Received: 11 December 2025; Accepted: 03 February 2026; Available online: Version 1.0: 11 March 2026

Cite this article: Kabyasree C, Chinmoy KS, Barsri B, Pankaj B, Bipul D, Pranjit B, Boishali D, Arunjyoti S, Dimpi D. Evaluation of fertigation uniformity under a drip irrigation system and its effects on irrigation water management in garlic (*Allium sativum* L.). Plant Science Today. 2026; 13(sp1): 1-12. https://doi.org/10.14719/pst.13172

Abstract

Drip irrigation can save 30–60 % of water and enables the simultaneous application of water and fertilisers through fertigation. A field experiment was conducted for three consecutive rabi seasons (2021–22, 2022–23 and 2023–24) to evaluate the effect of different injector and emitter types on fertigation uniformity in garlic (*Allium sativum* L.) Three types of emitters and two types of fertiliser injectors were tested to determine their influence on the coefficient of variation (Cv) of water and nutrient application. Results showed that both injector type and emitter manufacturing variability significantly affected fertigation and irrigation uniformity. Across the years, the lowest Cv for fertigation was obtained with the combination of a pressure-compensating emitter (2 lph) and a venturi manifold device, whereas the highest Cv resulted from the combination of drip tape emitter (4 lph) with a hydro-pneumatic pressure pump vessel. Fertigation uniformity improved as Cv decreased. The study also revealed noticeable differences between the Cv of irrigation water and the Cv of fertiliser application, indicating that a system performing well in water distribution does not necessarily ensure uniform fertiliser distribution. Based on the findings, the use of 2 lph pressure-compensating emitters with a venturi manifold device is recommended for achieving higher fertigation uniformity in drip irrigation systems.

Keywords: drip irrigation; fertigation uniformity; garlic; irrigation water management; nutrient distribution

Introduction

India is an agriculture-based country. Most of the rural population depends on agriculture for its livelihood. In an increasingly volatile global economy, efficient management of water and nutrient resources in agriculture has become essential for sustaining productivity and profitability (1). In the Indian context, this sector remains vital, contributing nearly 17 % to the national gross domestic product (GDP) and providing employment to more than 60 % of the population (2). Agriculture is the largest (81 %) consumer of water in India and hence more efficient use of water in agriculture needs to be topmost priority (3). With rapidly increasing population and urbanization, India is heading towards acute water scarcity resulting from an ever-increasing gap between supply and demand of freshwater (4). Water is deeply connected to every part of society and having secure and reliable water is key to reaching the sustainable development goals (5). The irrigation sector is the main consumer of freshwater and more than 90 % of groundwater draft in India (6). Earlier, farmers used traditional method of irrigation for watering their fields which is known as flood irrigation. In flood irrigation method, water is simply conveyed to the field either directly or through pipe systems. But, through this flood irrigation method, it is not possible to save water as only half of the water is utilized by the crops and the rest of the water is lost through evaporation, percolation into the soil and runoff. The use of flood irrigation can result in a low potential irrigation water use efficiency and inefficient use of nitrogen. It can also cause crusting of the soil surface following irrigation and can contribute to the degradation of some soil properties (7). Climate change makes the situation even more complicated by altering rainfall patterns, causing temperature shifts and increasing extreme events like droughts and floods, which in turn makes managing natural resources much harder (8). Drip irrigation is important in the context of climate change because it uses water efficiently, reduces wastage and helps crops withstand increasing water stress. Drip irrigation can save about 30–60 % of water and with saved water more area can be brought under irrigation (9). A study was conducted to assess the drip and flood irrigation on water and fertiliser use efficiencies for sugar beets. The study concluded that the amount of applied irrigation water with the drip system was lower than that for flood irrigation. Also, agronomic water use efficiency (WUE) and fertiliser use efficiency (FUE) for drip irrigation were always higher than those for flood irrigation (10). Drip irrigation has become widely adopted because it minimises water loss and boosts WUE, ultimately helping to increase crop yields (11). One important advantage of drip irrigation is that fertiliser and nutrients can be applied through drip irrigation which is called fertigation process. Fertigation enables the application of soluble fertilisers and other chemicals along with irrigation water, uniformly and more efficiently (12). In recent years, drip fertigation has gained popularity in arid and semi-arid areas facing water scarcity. It helps cut down irrigation needs while improving water-use efficiency and the effective use of fertilisers (13). An experiment was conducted for 2 years with 3 and 5 levels of nitrogen during 1995 and 1996, respectively, in drip and furrow irrigation to assess efficiency of fertiliser use, water use efficiency and the magnitude of moisture stress on the yield of tomato crops at Research Farm of Mahatma Phule Agricultural University, Rahuri (Maharashtra). The study revealed that drip fertigation economized irrigation water upto 37 % and increased fruit yield upto 12.5 % as compared to furrow irrigation system. Water use efficiency of drip irrigation system was also higher by about 72 % as compared to furrow irrigation (14). Comparison of various methods of irrigation suggests that drip irrigation achieves highest application efficiency of 90 % with overall efficiency ranging between 80–90 %. There are several advantages of using fertigation over conventional dry application of fertilisers. Broadcasting methods of chemical fertilisers can cause significant loss of fertilisers. In fertigation system, nutrients are already in soluble form when applied and are thus potentially more available for uptake by crops and trees than dry materials (15). A field experiment was conducted at Jorhat, Assam for 3 consecutive years to evaluate the economic feasibility of fertigation and mulching on 4-year-old Assam lemon. The study revealed that fertigation played a positive role in increasing the productivity of Assam lemon with additional benefit by saving fertiliser and labor cost (16). Water and fertiliser distribution uniformity are important considerations for the design and operation of drip fertigation systems because non-uniform applications of water and fertiliser may reduce crop yield (17). Application uniformity of fertilisers is critical for crop uniformity but can be difficult to determine when a fertiliser or chemical is applied through drip irrigation (18). Garlic being a shallow rooted crop needs an even supply of water and nutrients, especially during bulb formation. Uniform fertigation through drip irrigation system ensures balanced growth of all plants, resulting in better bulb development and higher yield (19).

There are various factors that can affect the fertigation uniformity through drip irrigation system. Variation in operating pressure in a field system is the main reason causing a nonuniform water distribution (20). In addition to flow variations due to pressure, variations between emitters of the same type also occur due to manufacturing variations in the tiny plastic components. The manufacturing variability of emitter flow rate variation coefficient (Cv) is an important index to evaluate the hydraulic performances of emitter (21).

To minimize the loss of nutrients during application to the crop field, a liquid-jet nozzle was developed for injection of liquid fertiliser in paddy fields. The liquid-jet nozzle was modelled to examine the mass flow rates and velocities as affected by the critical design parameters of the nozzle. The study found that the liquid-jet nozzle, a non-traditional injection method, has high potential to become a cost-effective and low soil-disturbance practice for rice production (22). Injectors and emitters act as the key to fertigation uniformity in a drip irrigation system. Several factors such as injector types, injection rate and flow rate affect uniformity (23).

Garlic (*Allium sativum* L.) is the second important bulb crops grown in India after onion and contributes 14.0 % of world area and 5 % production (24). Although, garlic has various medicinal properties, but the productivity is low in India as compared to other countries. This might be due to unawareness of farmers about the improved varieties, crop diseases, irrigation and fertiliser requirement and post-harvest processing as well as management.

Hence, this study was taken with the objective to evaluate fertigation uniformity of drip irrigation system and its effects on irrigation water management in garlic crop for various injectors and emitters, to establish relationship between fertigation and water application uniformity for various injectors and emitters and to provide recommendation to farmers and end users for optimal design and operation of drip fertigation system.

Materials and Methods

A field experiment was designed and performed to evaluate the influence of injector types and emitter types on fertigation uniformity. The field experiment was conducted for three consecutive rabi seasons during October-March of the year 2021–22, 2022–23 and 2023–24 at the Instructional-cum-Research Farm of Assam Agricultural University, Jorhat, Assam, India. The experimental soil was sandy loam in texture with an acidic reaction (pH 5.2). The soil had a medium organic carbon content (0.71 %). Available nitrogen, phosphorus (P_2O_5) and potassium (K_2O) contents were 220.7, 28.7 and 108.6 kg ha^{-1}, respectively, indicating medium fertility status. The experiment was laid out each year at the same location following the same experimental design and treatment structure to ensure continuity. Data recorded over the 3 years were subjected to pooled and statistically analyzed. The study area experiences a tropical monsoon climate with distinct seasonal variations in rainfall and temperature. During the experimental periods, the climatic conditions were monitored and the averages were recorded. From October to December 2021, the area received an average daily rainfall of 1.38 mm and a weekly mean temperature of 23.1 °C. In 2022, the January–March period had an average daily rainfall of 1.22 mm and a weekly mean temperature of 19 °C, while October–December showed higher rainfall of 2.57 mm/day and cooler temperatures averaging 11.84 °C. In 2023, January–March recorded 1.41 mm/day of average daily rainfall and a mean temperature of 18.7 °C, whereas October–December had 2.02 mm/day with a mean temperature of 22.5 °C. For January–March 2024, the average daily rainfall and weekly mean temperature were 0.90 mm/day and 18.9 °C, respectively. These data reflect the temporal variability in both rainfall and temperature during the experimental periods. The chosen experimental plot size was 260 sq m in total. The experimental design selected was factorial randomized complete block design

(FRCBD). The experiment was designed with two factors. The first factor included 3 types of emitters: drip tape emitters with discharge rates of 2 L h^{-1}(lph) and 4 lph and a pressure-compensating emitter with a discharge rate of 2 lph. The second factor consisted of two types of injectors: a hydro-pneumatic pressure pump vessel and a venturi manifold device. Together, these factors resulted in 6 treatment combinations, each replicated 4 times. Each replication served as a block and all 6 treatments were randomly assigned within each block. Thus, the experiment consisted of four blocks, each containing 6 plots, resulting in a total of 24 experimental plots. Each individual plot was of size 3 × 2 m. It is important to select an appropriate injection method that best suits the irrigation system and the crop to be grown. Inappropriate selection will affect the crop yield and will reduce the efficiency of the fertigation system. Hydro- pneumatic pressure pump vessel are tanks that delivers water at a preset pressure range and prevents a pump from starting up every time during when the distribution system receives a request for water. They are extremely efficient for distributing water and fertiliser as they maintain a constant water level. Venturi manifold device is a commonly used device for fertiliser application through drip irrigation (20). It is a complete assembly of valve, pressure gauge and venturi injector which can be installed directly in the irrigation system. An experiment was conducted to study the effect of system pressure and solution concentration on fertiliser injection rate of a venturi device. The study revealed that, for the venturi injector, the discharge rate increased proportionally with the system pressure (25). It works on the principle of reduced fluid pressure that results in constant flow velocity.

The fertigation unit set up was installed near the plot along with water filtration system. The schematic of the fertigation unit setup is shown in Fig. 1. The water supplied to the experiment was pressurised using a centrifugal pump of 1491.40 watt from a local shallow tube well. Polyvinyl chloride (PVC) pipes having diameter of 50.8 mm were used as the mainline of the drip irrigation system and PVC pipes having 38.1 mm were used as the sub-main of the same drip irrigation system. Lateral pipes of 12 mm were used on which emitters were attached at a spacing of 6 cm. The lateral pipes were installed at a spacing of 15 cm apart. Three types of filtering processes sand separator, sand filter and screen filter were used in the drip irrigation system setup along with the hydro pneumatic pressure pump vessel and venturi manifold device to filter out any sediments or foreign particles present in the irrigation water. A fertiliser tank was fixed along the filtration systems to apply fertiliser through the hydro pneumatic pressure pump vessel for fertiliser distribution. One pressure gauge was installed in the system to monitor the increase or decrease in pressure during the operation of the drip irrigation system. The operating pressure was kept constant for the whole experiment at 0.07 MPa to ensure proper working of the emitters at appropriate pressure. A pressure switch was also installed in the fertigation system set-up to automate the starting of the pump while operating the fertigation through hydro pneumatic pressure pump vessel.

Soil sample from 15 cm depth of soil was collected at the beginning of the experiment to examine the various physio-chemical properties of the soil. The soil texture of the experimental area was sandy loam with uniform topography, well drained and moderately fertile. Sandy loam soils in this region generally have a slightly acidic to neutral pH and moderate organic matter content. After land preparation of the experimental area was completed, garlic cloves of the cultivar 'Yamuna Safed' were dibbled at 6×15 cm (plant to plant × row to row) spacing. Irrigation was applied to the crop from October to March based on crop evapotranspiration (ETc), which was estimated using the FAO-56 Penman-Monteith method. Reference evapotranspiration (ETo) was computed from daily meteorological data and ETc was obtained by multiplying ETo with appropriate crop coefficient (Kc) values for garlic (26). In this study, a fixed irrigation interval of two days interval was adopted. The irrigation was stopped 10 days before the harvesting date. The bulb yield of garlic was recorded immediately after harvesting using standard procedures.

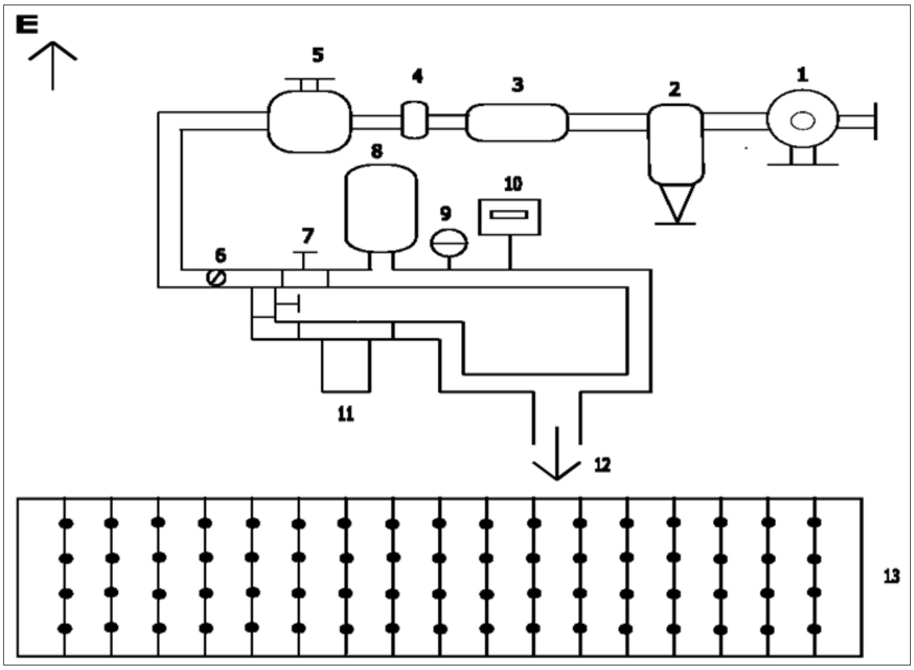
Data collection and analysis

All drip lines were conditioned for 20 min before the start of the experiment to avoid any traces of foreign particles inside the drip pipes. The NPK 19-19-19 was used as supply of fertiliser to the garlic crop; however, as it could not meet the entire nitrogen requirement through fertigation due to the risk of excess phosphorous and potassium application. Therefore, at 30 days after sowing (DAS), fertigation was carried out using a limited quantity of NPK 19:19:19 was applied through fertigation and remaining nitrogen requirement was met through urea to maintain nitrogen balance. Based on plot size (6 m^2), 31.8 g of NPK 19:19:19 and 52.2 g of urea were applied per plot. Accordingly, 0.76 kg of NPK 19:19:19 and 1.25 kg of urea were dissolved in the fertiliser tank and applied per irrigation to all plots. Nitrogen was applied in two splits to synchronise nutrient availability with crop demand and minimise losses. Half of nitrogen was applied as basal to support early crop establishment, while the remaining half was fertigated at 30 DAS coinciding with the peak vegetative growth stage. The plastic containers for collecting discharges were placed just below the emitters for about 10 min during the irrigation process. A total of 12 sampling points were selected for each 3 × 2 m plot. A small hole was dug below each emitter to allow the plastic container to be fixed properly. The collected discharge water was measured for each can by a 100 mL measuring cylinder. The experiment was run 2 times each time using different injector types. Same amount of irrigation water along with fertilisers were applied during each run of the experiment using 2 different injector types.

For applying fertiliser through hydro-pneumatic pressure pump vessel, the fertiliser was placed at the fertiliser tank which was attached along the filtration system. The electrical conductivity of the fertiliser solution was measured for the same collected discharge samples using a conductivity meter. The fertiliser concentration was calculated by converting the electrical conductivity with the help of pre-calibrated relationship between electrical conductivity and solution concentration. The amount of fertiliser applied through each emitter was calculated by multiplying the fertiliser concentration with the volume of sample collected.

Statistical analysis

Statistical analysis was performed based on the 6 treatment combinations to evaluate their effect on fertigation uniformity. The *p*-value less than 0.05 was considered significant. Coefficient of variation (Cv) was estimated from the data collected for each emitter from the following equation:



1. Pump
2. Sand separator
3. Sand/Media filter
4. Screen filter
5. Fertiliser tank
6. Non-returning valve
7. Valve
8. Hydro pneumatic pressure pump vessel
9. Pressure gauge
10. Pressure switch
11. Venturi manifold
12. Irrigation inlet
13. Emitters setup along the drip laterals

Fig. 1. Schematic of the fertigation unit setup along with arrangement of emitters along drip laterals.

$$C_v = \frac{S_q}{q} \qquad \text{(Eqn. 1)}$$

Where, S_q is the standard deviation of the emitter discharge of the sample, q is the mean emitter discharge of the sample.

Similarly, to find out the Cv for fertiliser application, Cv was calculated by considering the calculated fertiliser amount of the samples which gave the fertigation uniformity for all the treatment combinations. Interaction effect on garlic yields as well as individual effect of emitters and injectors on garlic yield was analysed by using the statistical software Statistics 10.

Results

Evaluation of irrigation and fertiliser distribution uniformity under various combination

The coefficient of variation (Cv) of irrigation water and fertiliser distribution for different combinations of injector types-hydro-pneumatic pressure pump vessel and venturi manifold device- and emitters, namely drip tape emitters with discharge rates of 2 (lph) and 4 lph and pressure-compensating emitters of 2 lph, for 3 years 2021–22, 2022–23 and 2023–24 is presented in Table 1.

For fertiliser application, a consistent trend was observed over the 3 years of study. The lowest Cv was recorded with the

Table 1. Coefficients of variation, Cv for irrigation, solution concentration and fertiliser applied for 3 different emitter types with two different injector types for the year 2021–22 and 2022–23

	Venturi manifold device	Hydro pneumatic pressure pump vessel	Venturi manifold device	Hydro pneumatic pressure pump vessel	Venturi manifold device	Hydro pneumatic pressure pump vessel
	Year 2021–22		Year 2022–23		Year 2023–24	
Cv for irrigation						
Pressure compensating emitter (Discharge rate at 2 lph)	0.10	0.33	0.11	0.38	0.24	0.23
Drip tape emitter (Discharge rate at 2 lph)	0.37	0.28	0.41	0.29	0.41	0.29
Drip tape emitter (Discharge rate at 4 lph)	0.20	0.43	0.20	0.46	0.31	0.41
Cv for solution concentration						
Pressure compensating emitter (Discharge rate at 2 lph)	0.23	0.33	0.22	0.33	0.20	0.14
Drip tape emitter (Discharge rate at 2 lph)	0.31	0.23	0.35	0.25	0.17	0.09
Drip tape emitter (Discharge rate at 4 lph)	0.34	0.48	0.39	0.54	0.14	0.06
Cv for fertiliser						
Pressure compensating emitter (Discharge rate at 2 lph)	0.24	0.55	0.23	0.69	0.20	0.27
Drip tape emitter (Discharge rate at 2 lph)	0.44	0.41	0.45	0.40	0.46	0.27
Drip tape emitter (Discharge rate at 4 lph)	0.42	0.70	0.48	0.78	0.40	0.44

pressure-compensating emitter (2 lph) used in combination with the venturi manifold device, while the highest Cv was associated with the drip tape emitter (4 lph) combined with the hydro-pneumatic pressure pump vessel.

The measured discharges for irrigation water and fertiliser applied for the drip irrigation system for the year 2021–2022, 2022–2023 and 2023–2024 are illustrated in Fig. 2–4, respectively for the 6 combinations of emitters along with injectors.

For irrigation water and fertiliser applied, lowest Cv was obtained by the combination of pressure compensating emitter (discharge rate at 2 lph) with venturi manifold device and highest Cv was obtained by the combination of drip tape emitter (discharge rate at 4 lph) with hydro pneumatic pressure pump vessel.

However, there are vast differences in Cv among all the different combinations of emitters and injectors. Hence, it can be suggested that the uniformity in fertiliser application is highly dependent on the method of fertiliser injector and type of emitter used. Therefore, the suitable injector and emitter type should be selected while designing a fertigation system to obtain uniformity in fertiliser application.

Effect of irrigation and fertigation combinations on garlic yield

The yield of garlic cultivated under different combinations of emitters and injectors pooled for the years 2021–2024 is represented in Table 2. Considering emitter type, the pressure-compensating emitter (2 lph) produced the highest garlic yield (19.68 q/ha), while the drip tape emitter (4 lph) resulted in the lowest yield (13.62 q/ha) across the study period. These differences were statistically significant ($p \leq 0.05$) as determined by analysis of variance (ANOVA). In the year 2023–24, however, the yield was higher as compared to the years 2021–2022 and 2022–2023 and followed the trend of yield value as pressure compensating emitter (2 lph)> drip tape emitter (2 lph)> drip tape emitter (4 lph).

In case of type of injectors, the pooled data of 3 years indicated that the yield was higher when venturi manifold device (17.79 q/ha) was used in comparison to hydro pneumatic pressure pump vessel (14.93 q/ha). Individual year data also showed higher yield under the venturi manifold type of injector.

When interaction effect of the combined type of emitters and type of injectors were studied, the yield of garlic was recorded to vary as shown in Table 3. The yield of garlic in 2021–2024 was found to be highest (22.6 q/ha) under fertigation application using the combination of pressure compensating emitter (2 lph) type of emitter with venturi manifold device injector. Whereas it was lowest for the combination of drip tape emitter (4 lph) type of emitter with hydro-pneumatic pressure pump vessel injector. The highest yield individually for the years 2021–22 (21.25 q/ha), 2022–23 (19.87 q/ha) and 2023–24 (26.7 q/ha) was also obtained in the combination of pressure compensating emitter (2 lph) type of emitter with venturi manifold device injector.

Effect of application of irrigation and fertiliser distribution combinations on water use efficiency (WUE)

The effect of different combinations of emitters and injectors on water use efficiency (WUE) values for the years 2021–2024 are represented in Table 4. Among different types of emitters, irrespective of the type of injector, the pressure compensating emitter (2 lph) recorded highest WUE % in all the years studied. In case of type of injectors, the venturi manifold device showed the highest WUE % when combined with pressure compensating emitter (2 lph) and drip tape emitter (4 lph) than hydro pneumatic pressure pump vessel injector for all the years. The combination of pressure compensating emitter (2 lph) with venturi manifold device type of injector recorded highest WUE (%) value in all the years. Whereas it was lowest for the combination of drip tape emitter (4 lph) with hydro pneumatic pressure pump vessel injector. The WUE was higher for the year 2023–2024 as compared to the previous years.

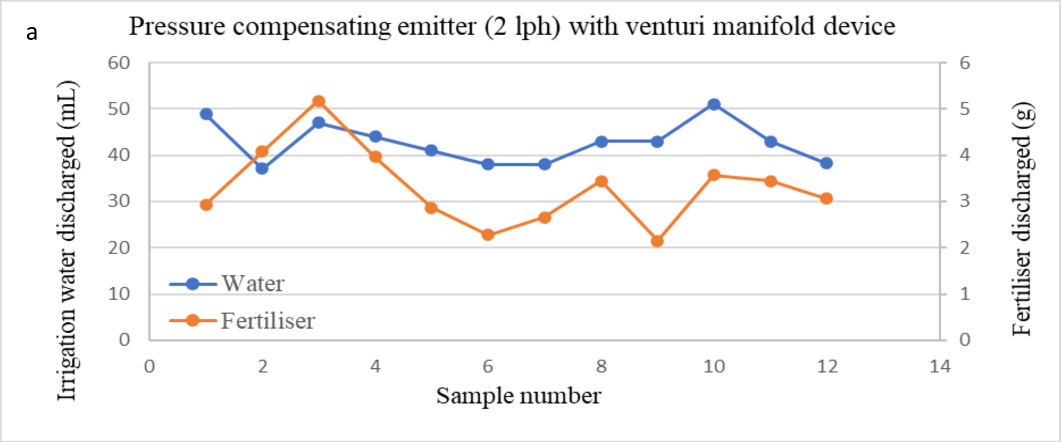
Effect of application of irrigation and fertiliser distribution combinations on economics of garlic cultivation

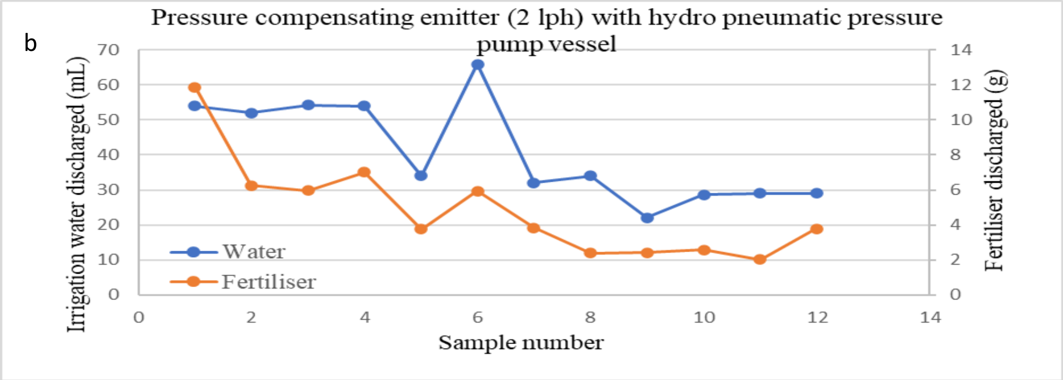
Economic analysis of combined effect of emitters and injectors in garlic (pooled data of 2021–24) is presented in the Table 5. The affectability of any system largely depends on its economic return. In this study, the cultivation of garlic using venture devices required lowest cost for cultivation irrespective of the types of emitters and gave higher returns than pressure compensating tank when used in combination with pressure compensating emitter and drip tape emitter (4 lph). The B: C ratio of all the combinations was higher than one indicating overall benefit, however, the highest (3.6) was obtained when venture device type of injector was used in combination with pressure compensating emitter and the lowest (1.7) was in case of pressure compensating tank type of injector with drip tape emitter (4 lph).

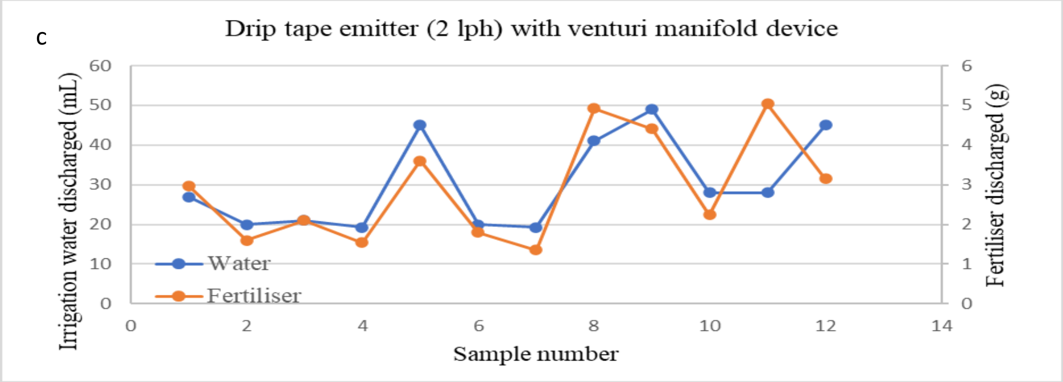
Discussion

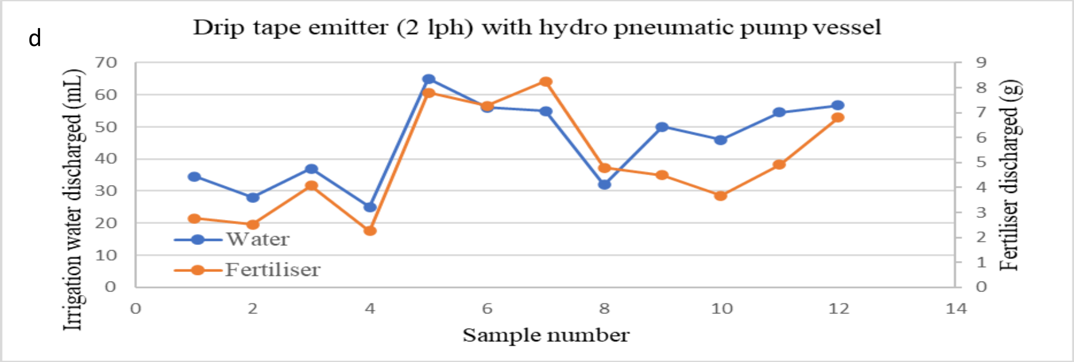
The present study highlights the effect of emitter and injector types on fertigation uniformity, garlic yield, WUE and economic returns under a drip irrigation system, as uniform discharge rates and stable operating pressure enhanced nutrient distribution and crop response. The findings provide valuable information on optimization of irrigation water management along with fertiliser application for enhancing garlic production under the agro-climatic conditions of Assam. The findings provide valuable insights on optimization of irrigation water management and fertiliser application for enhancing garlic production under the agro-climatic conditions of Assam.

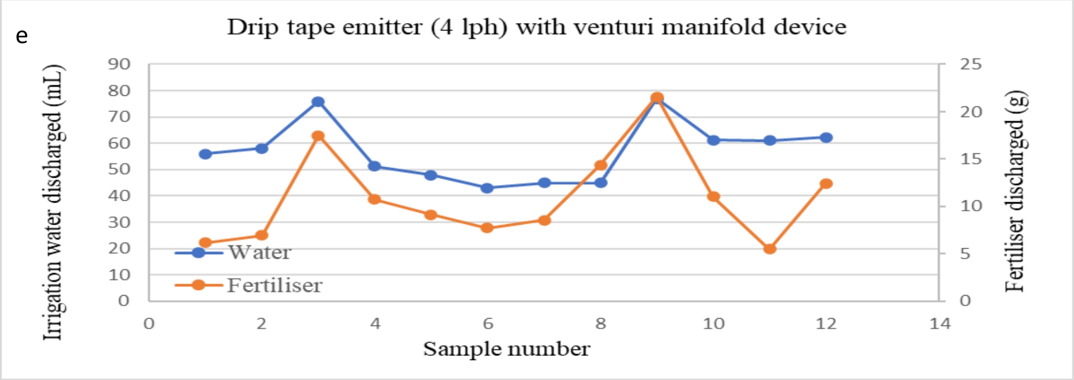
The results indicated that the type of emitter and injector plays a crucial role in determining the production of garlic. Among different emitters, the use of pressure compensating emitter (2 lph) consistently recorded significantly higher yield (19.68 q/ha pooled), while the drip tape emitter (4 lph) produced the lowest yield (13.62 q/ha pooled). Similarly, in case of the venturi manifold device injector also, it outperformed the hydro pneumatic pressure pump vessel injector, with pooled yields of 17.79 q/ha and 14.93 q/ha, respectively. The interaction between emitter and injector types revealed that the combination of pressure compensating emitter (2 lph) with venturi manifold device injector achieved the highest yield (22.6 q/ha pooled), while the combination of drip tape emitter (4 lph) with hydro pneumatic pressure pump vessel injector resulted in a significant reduction in yield. These results emphasize the importance of selecting emitters and injectors with low coefficient of variation to ensure uniform fertigation and maximise the crop yield which agrees with the findings of earlier studies (27, 28). The highest WUE was recorded with the combination of pressure compensating emitter (2 lph) and venturi manifold device across all


a
Pressure compensating emitter (2 lph) with venturi manifold device
Irrigation water discharged (mL)
0
10
20
30
40
50
60
Fertiliser discharged (g)
0
1
2
3
4
5
6
Sample number
0
2
4
6
8
10
12
14
Water
Fertiliser


b
Pressure compensating emitter (2 lph) with hydro pneumatic pressure pump vessel
Irrigation water discharged (mL)
0
10
20
30
40
50
60
70
Fertiliser discharged (g)
0
2
4
6
8
10
12
14
Sample number
0
2
4
6
8
10
12
14
Water
Fertiliser


c
Drip tape emitter (2 lph) with venturi manifold device
Irrigation water discharged (mL)
0
10
20
30
40
50
60
Fertiliser discharged (g)
0
1
2
3
4
5
6
Sample number
0
2
4
6
8
10
12
14
Water
Fertiliser


d
Drip tape emitter (2 lph) with hydro pneumatic pump vessel
Irrigation water discharged (mL)
0
10
20
30
40
50
60
70
Fertiliser discharged (g)
0
1
2
3
4
5
6
7
8
9
Sample number
0
2
4
6
8
10
12
14
Water
Fertiliser


e
Drip tape emitter (4 lph) with venturi manifold device
Irrigation water discharged (mL)
0
10
20
30
40
50
60
70
80
90
Fertiliser discharged (g)
0
5
10
15
20
25
Sample number
0
2
4
6
8
10
12
14
Water
Fertiliser

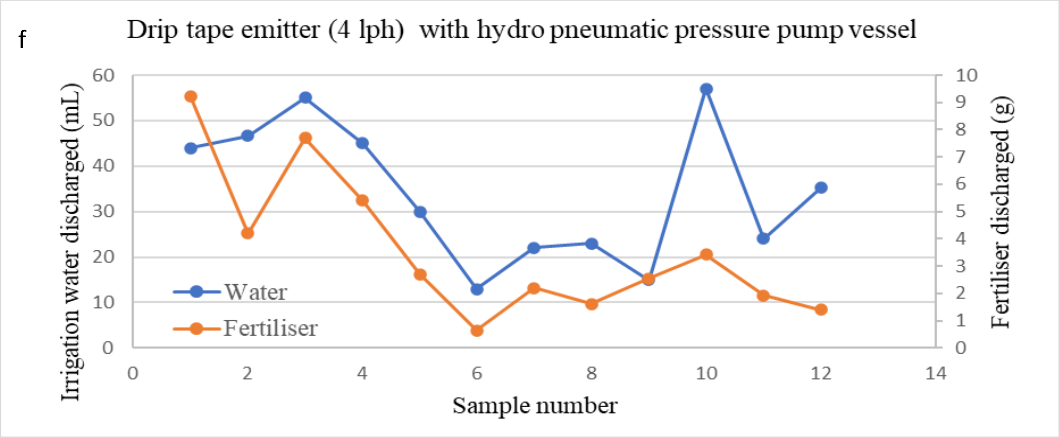
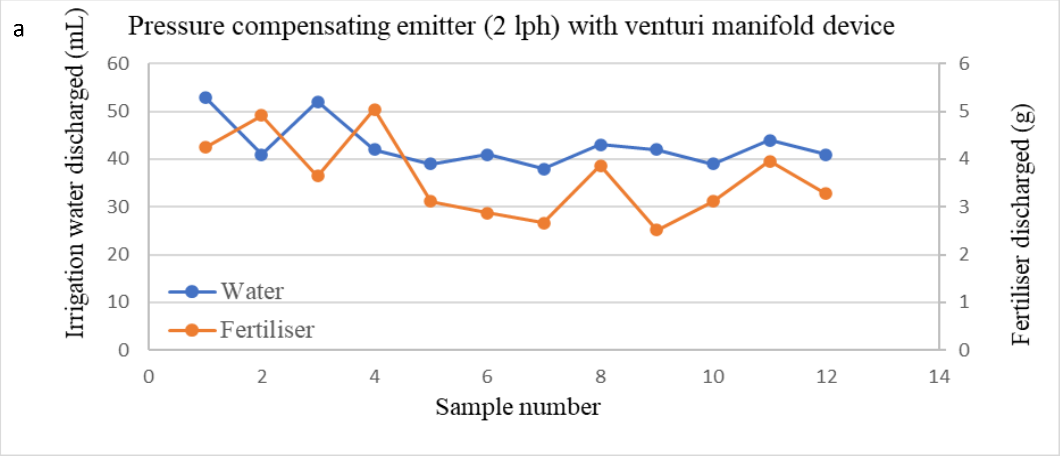
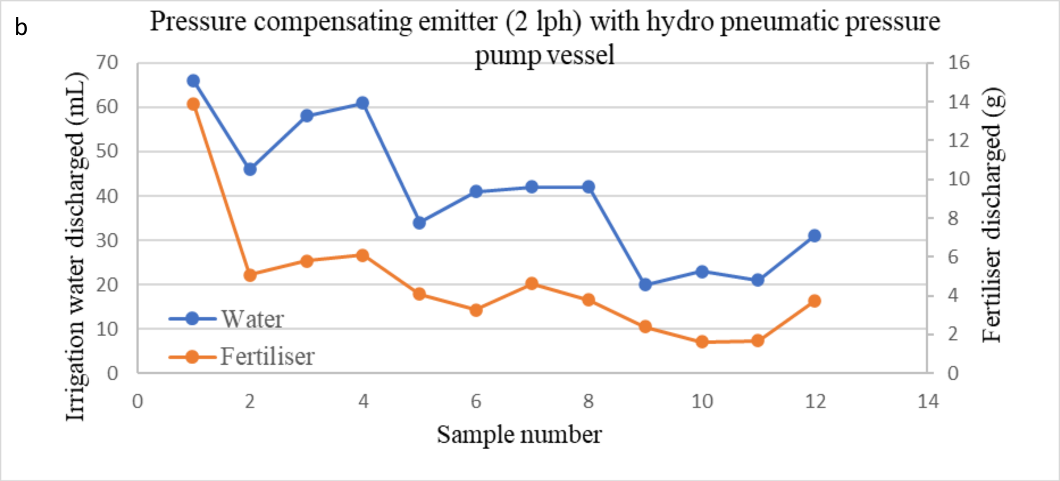
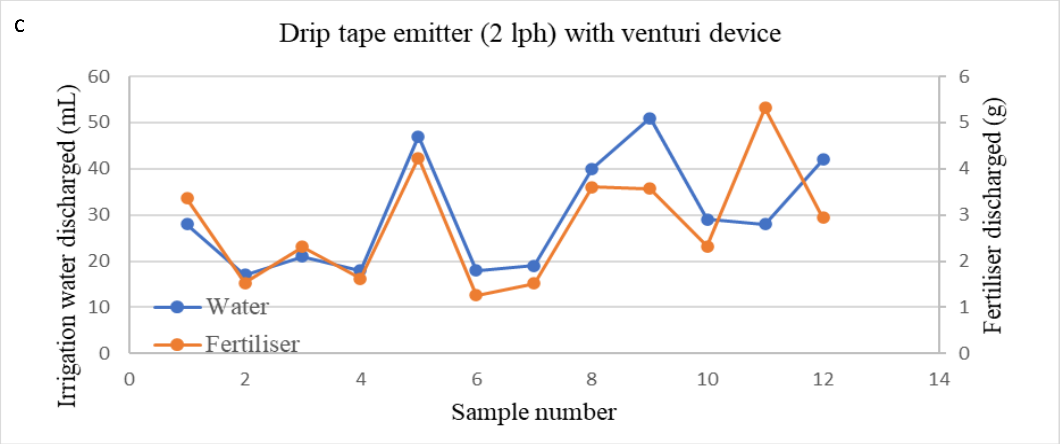


Fig. 2. Variations of measured discharges of irrigated water and fertiliser for various combinations of emitters and injectors for the year 2021–2022. a- Pressure compensating emitter (2 lph) with venturi manifold device; b- Pressure compensating emitter (2 lph) with hydro pneumatic pressure pump vessel; c- Drip tape emitter (2 lph) with venturi manifold device; d- Drip tape emitter (2 lph) with hydro pneumatic pump vessel; e- Drip tape emitter (4 lph) with venturi manifold device; f- Drip tape emitter (4 lph) with hydro pneumatic pressure pump vessel.







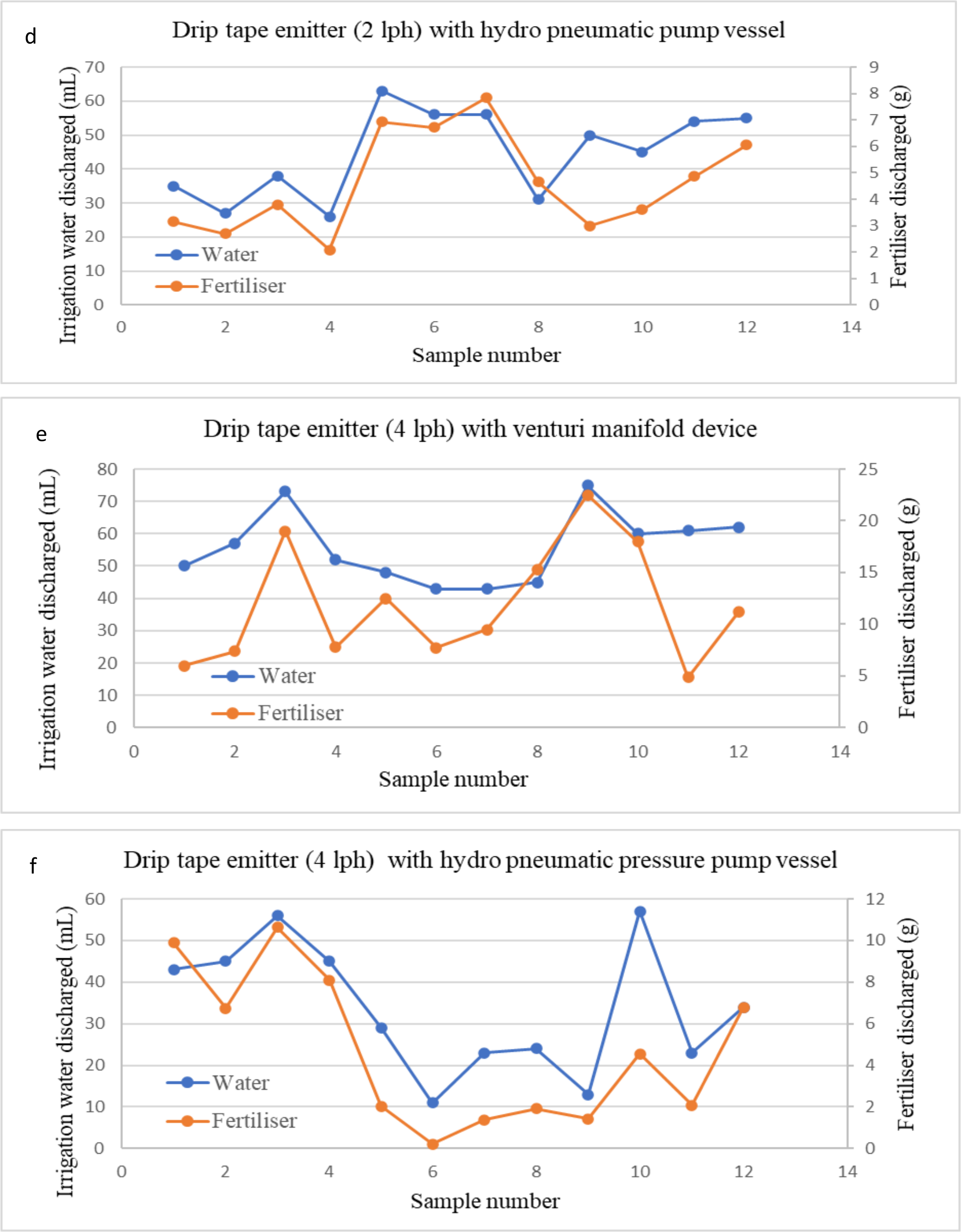
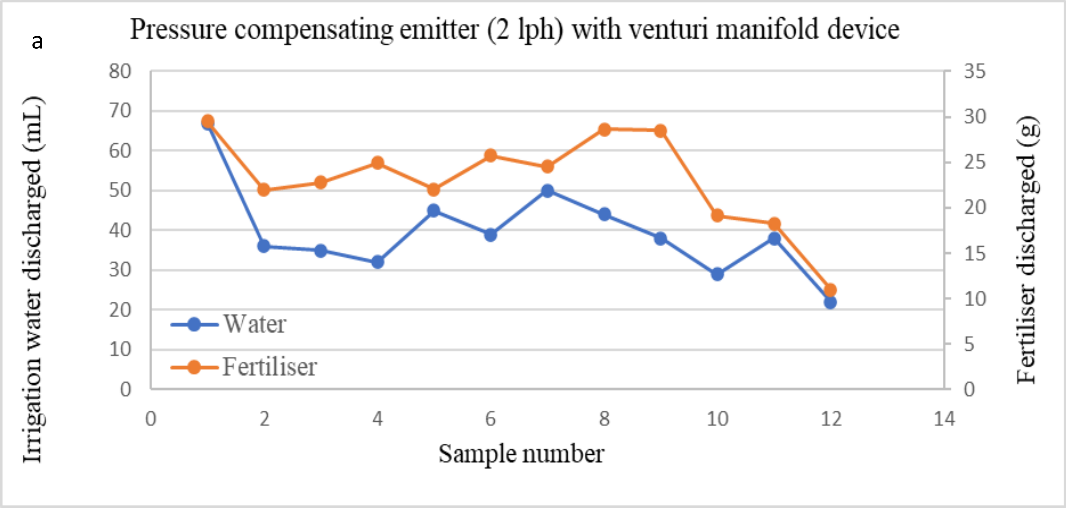
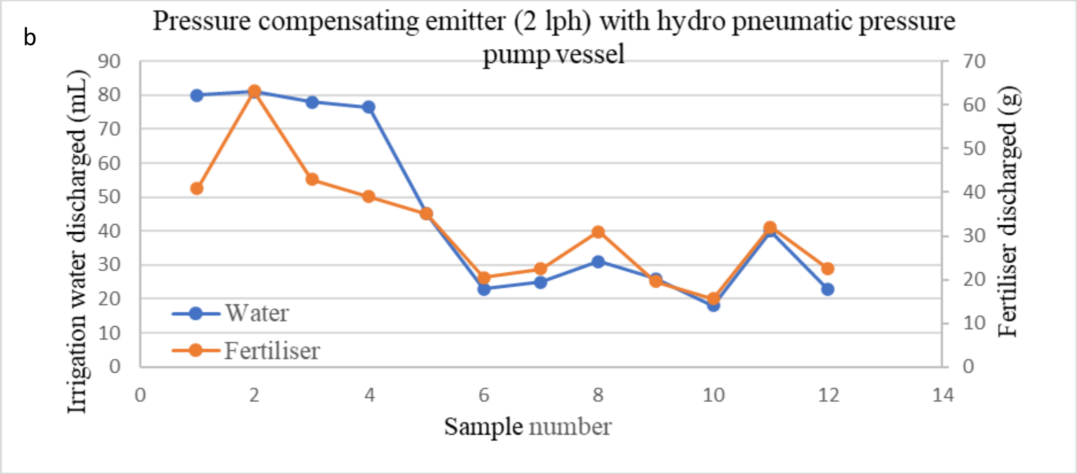
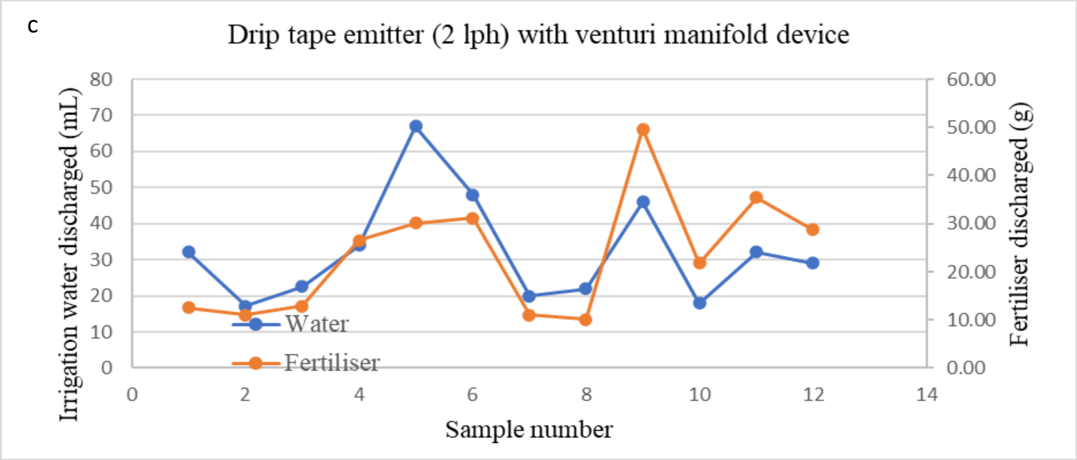
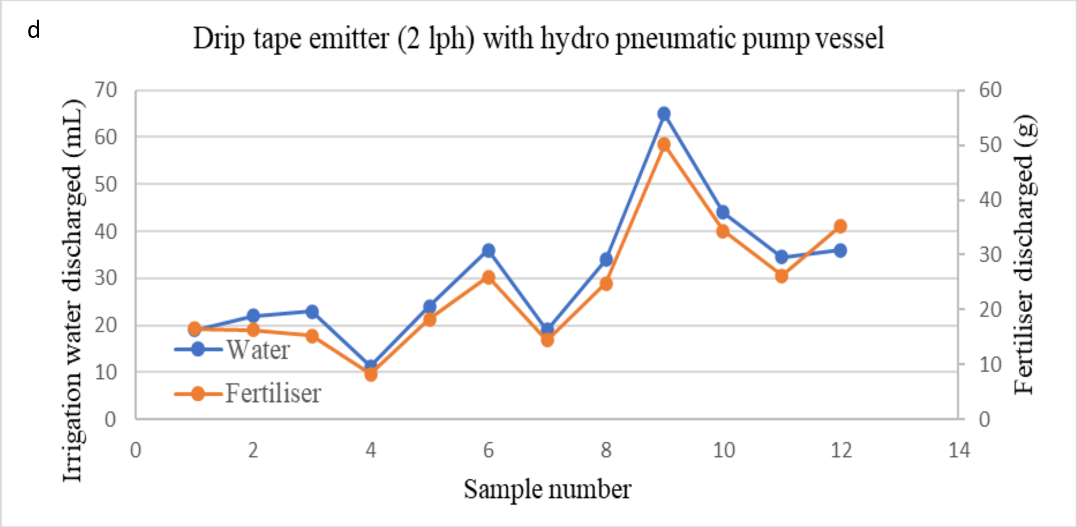


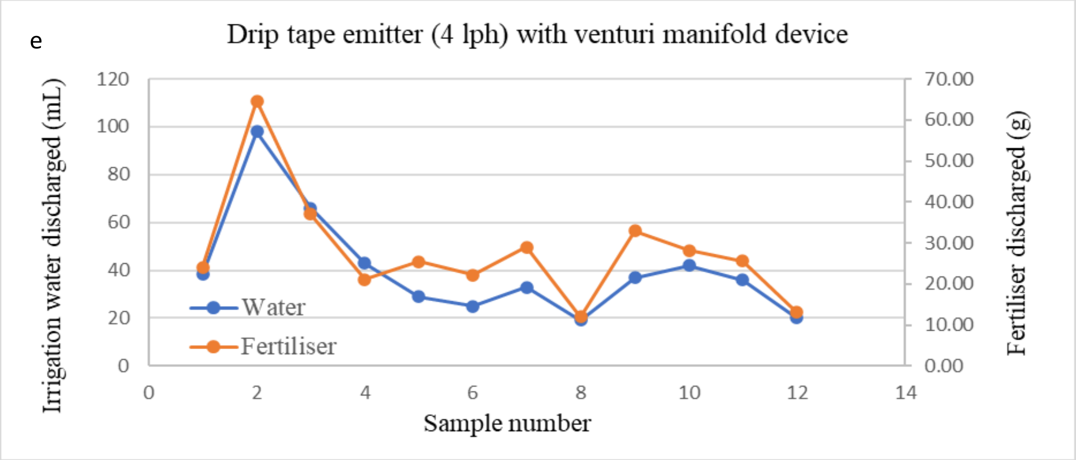
Fig. 3. Variations of measured discharges of irrigated water and fertiliser for various combinations of emitters and injectors for the year 2022–23. a- Pressure compensating emitter (2 lph) with venturi manifold device; b- Pressure compensating emitter (2 lph) with hydro pneumatic pressure pump vessel; c- Drip tape emitter (2 lph) with venturi manifold device; d- Drip tape emitter (2 lph) with hydro pneumatic pump vessel; e- Drip tape emitter (4 lph) with venturi manifold device; f- Drip tape emitter (4 lph) with hydro pneumatic pressure pump vessel.




b
Pressure compensating emitter (2 lph) with hydro pneumatic pressure pump vessel
Irrigation water discharged (mL)
0
10
20
30
40
50
60
70
80
90
Fertiliser discharged (g)
0
10
20
30
40
50
60
70
Sample number
0
2
4
6
8
10
12
14
Water
Fertiliser


c
Drip tape emitter (2 lph) with venturi manifold device
Irrigation water discharged (mL)
0
10
20
30
40
50
60
70
80
Fertiliser discharged (g)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Sample number
0
2
4
6
8
10
12
14
Water
Fertiliser


d
Drip tape emitter (2 lph) with hydro pneumatic pump vessel
Irrigation water discharged (mL)
0
10
20
30
40
50
60
70
Fertiliser discharged (g)
0
10
20
30
40
50
60
Sample number
0
2
4
6
8
10
12
14
Water
Fertiliser


e
Drip tape emitter (4 lph) with venturi manifold device
Irrigation water discharged (mL)
0
20
40
60
80
100
120
Fertiliser discharged (g)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Sample number
0
2
4
6
8
10
12
14
Water
Fertiliser

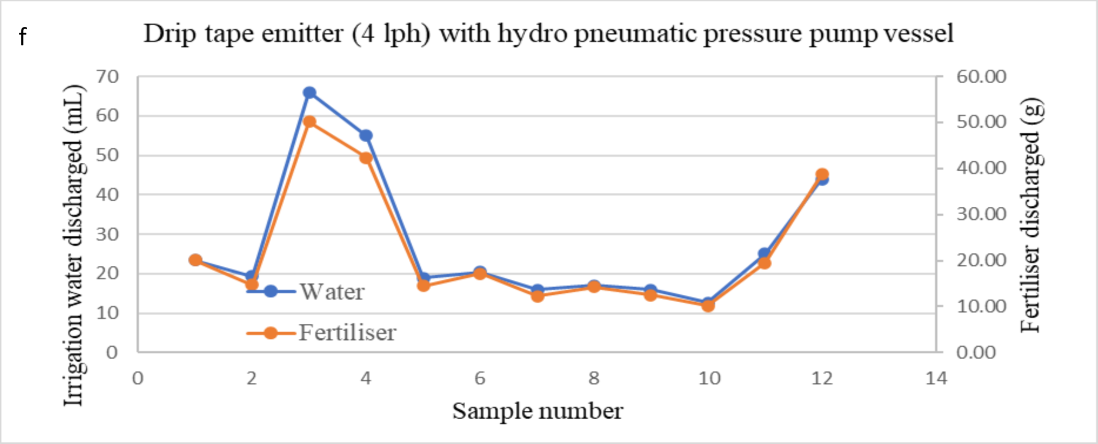


Fig. 4. Variations of measured discharges of irrigated water and fertiliser for various combinations of emitters and injectors for the year 2023–24. a- Pressure compensating emitter (2 lph) with venturi manifold device; b- Pressure compensating emitter (2 lph) with hydro pneumatic pressure pump vessel; c- Drip tape emitter (2 lph) with venturi manifold device; d- Drip tape emitter (2 lph) with hydro pneumatic pump vessel; e- Drip tape emitter (4 lph) with venturi manifold device; f- Drip tape emitter (4 lph) with hydro pneumatic pressure pump vessel.

Table 2. Yield (q/ha) of garlic as influenced by different emitters and injectors for the year 2021–24 (pooled)

Treatments	2021–22	2022–23	2023–24	Pooled
Emitters				
Pressure compensating emitter (2 lph)	18.51a	17.80a	22.9a	19.68a
Drip tape emitter (2 lph)	14.36bc	14.60ab	18.5bc	15.78ab
Drip tape emitter (4 lph)	11.71c	12.00b	17.2c	13.62b
SEm (±)			1.85	
CD			4.02	
Injectors				
Venturi manifold device	16.58a	16.20a	20.6a	17.79a
Hydro pneumatic pressure pump vessel	13.14b	13.10b	18.5a	14.93a
SEm (±)			1.51	
CD			3.05	

The data are presented as mean value and the different letters indicates the significant difference at *p* (0.05) according to DMRT.

Table 3. The interaction effect on crop yield (q/ha) of garlic during the year 2021–24

Treatments	2021–22		2022–23		2023–24		Pooled	
	Venturi manifold device	Hydro pneumatic pressure pump vessel	Venturi manifold device	Hydro pneumatic pressure pump vessel	Venturi manifold device	Hydro pneumatic pressure pump vessel	Venturi manifold device	Hydro pneumatic pressure pump vessel
Pressure compensating emitter (2 lph)	21.25a	15.78a	19.87a	15.25ab	26.7a	19.2ab	22.6a	16.7a
Drip tape emitter (2 lph)	12.04b	16.68a	11.93b	16.98a	15.7c	21.4a	13.2b	18.3a
Drip tape emitter (4 lph)	16.45ab	6.98b	16.85ab	7.09b	19.4bc	15.0b	17.6ab	9.7b
SEm (±)					2.62			
CD					5.68			

The data are presented as mean value and the different letters indicates the significant difference at *p* (0.05) according to DMRT.

Table 4. Irrigation water use efficiency (%) for the year 2021–24

Treatments	2021–22		2022–23		2023–24	
	Venturi manifold device	Hydro pneumatic pressure pump vessel	Venturi manifold device	Hydro pneumatic pressure pump vessel	Venturi manifold device	Hydro pneumatic pressure pump vessel
Pressure compensating emitter (2 lph)	17.08	13.40	15.97	13.64	21.48	17.18
Drip tape emitter (2 lph)	12.68	13.22	12.26	13.54	15.44	15.57
Drip tape emitter (4 lph)	9.68	5.61	9.58	5.70	12.62	12.08

Table 5. Economic analysis of combined effect of emitters and injectors in garlic (pooled data of 2021–24)

Treatments	**Cost of cultivation (Rs./ha)**		**Gross return (Rs./ha)**		**BC ratio**	
	Venturi device	**Pressure compensating tank**	**Venturi device**	**Pressure compensating tank**	**Venturi device**	**Pressure compensating tank**
Pressure compensating emitter (2 lph)	201874	203540	723680	535786	3.6	2.6
Drip tape emitter (2 lph)	185206	186874	423125	586944	2.3	3.1
Drip tape emitter (4 lph)	180207	181874	561834	310320	3.1	1.7

years, as pressure compensating emitters ensured uniform discharge along the laterals while the venturi manifold device provided consistent fertigation under varying operating pressures, thereby reducing water and nutrient losses and improving crop water productivity; the maximum WUE was observed during 2023–2024 (29). This combination consistently shows superior performance over others, indicating its superior ability to optimize water and fertiliser use. Conversely, the combination of drip tape emitter (4 lph) with hydro pneumatic pressure pump vessel injector recorded the lowest values of water use efficiency, highlighting the inefficiency of this setup in utilising water resources effectively. This study reveals that to obtain fertigation uniformity in a drip irrigation system, it would be recommended to use pressure compensating emitter (2 lph) along with venturi manifold device.These results are consistent with findings reported by other researchers under similar agro-climatic and management conditions (30, 31).

Economic analysis revealed that the venturi manifold device injector required the lowest cost of cultivation, while, providing higher gross returns compared to the hydro pneumatic pressure pump vessel. The highest benefit-cost (B:C) ratio (3.6) was achieved with the combination of pressure compensating emitter (2 lph) and venturi manifold device injector, while the lowest B:C ratio (1.7) was observed for the combination of drip tape emitter (4 lph) and hydro pneumatic pressure pump vessel. This underscores the economic advantage of using efficient emitter and injector combinations for garlic cultivation.

Conclusion

It can be concluded that coefficient of variation of emitters and injector types had a significant influence fertigation uniformity in drip irrigation systems. Emitters and injectors with a lower coefficient of variation ensured more uniform irrigation and fertiliser application, which result in higher yield of garlic as compared to one with more coefficient of variation. In contrast, the emitters and injectors having high coefficient of variation were non-uniform and resulted in lower yield of garlic. An injector that can release fertiliser more uniformly is recommended for obtaining fertigation uniformity of drip irrigation system. It was observed that there were some differences of values of coefficient of variation between irrigation water application and fertigation application. This means that drip irrigation producing uniform application of irrigated water does not mean a uniform fertiliser application. Therefore, if fertiliser application is considered in a drip irrigation system, it is utmost necessity to consider proper injector methods. Future studies may focus on integrating sensor-based and automated fertigation systems to further improve water and nutrient use efficiency under drip irrigation. More detailed research on how nutrients move in the soil, their possible leaching losses and their interaction with the crop is needed to ensure environmental sustainability. Long-term assessment of system performance, including emitter clogging and hydraulic stability under different fertiliser sources, will help improve reliability. Developing crop-specific fertigation schedules by considering soil and climatic factors could optimise resource use. Testing the recommended system across different agro-climatic regions and crops would support it wider adoption.

Acknowledgements

This work was financially supported by the All India Coordinated Research Project on Irrigation Water Management (AICRP-IWM) under Indian Council of Agricultural Research (ICAR).

Authors' contributions

KC conceptualised the study and prepared the original draft. CKS developed the methodology. Software-related work was carried out by BB and PB^1. Validation was performed by BD^1. Writing-review and editing was completed by PB^2. Data curation was done by DD. Writing-original draft preparation was carried out by BD^2. Supervision was provided by AS. All authors read and approved the final manuscript. [PB^1- Pankaj Barua, PB^2- Pranjit Bharali; BD^1- Bipul Deka, BD^2- Boishali Dutta].

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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