Growth and yield of cauliflower under surface and subsurface drip irrigation with primarily treated municipal wastewater in a semi-arid peri-urban area

Deepak Singh[1,*], Neelam Patel[2], Sridhar Patra[1] and Nisha Singh[3]

[1]Hydrology and Engineering Division, ICAR-Indian Institute of Soil and Water Conservation, Dehradun 248 195, India
[2]Department of Agricultural Engineering, ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India
[3]Department of Biochemistry, H.N.B. Garhwal University (A Central University), Srinagar (Garhwal) 246 174, India

This study reports the effect of surface and subsurface drip irrigation with municipal wastewater and groundwater on growth and yield of cauliflower. Eight treatments were evaluated: surface drip (T1), subsurface drip (non-pressure compensating) (T2), bioline subsurface drip (T3) and bioline (pressure-compensating) surface drip (T4) using groundwater, and the same drip systems using primarily treated municipal wastewater (i.e. T5–T8). Results showed maximum leaf area index and root length density (5.64 and 5.25 cm/cm^3 respectively) of cauliflower in subsurface drip system having pressure-compensating lateral applying wastewater and minimum (4.48 and 4.05 cm/cm^3 respectively) in surface drip system having inline lateral applying groundwater. The highest curd yield (79.67 tonne/ha) was found with subsurface pressure-compensating drip with wastewater application, whereas lowest (59.01 tonne/ha) was recorded in case of inline surface drip with groundwater. The cauliflower curd yield increased by 7.58% and 8.49% under surface and subsurface pressure-compensating drip laterals with wastewater application, with a saving of 30.1% nitrogen, 14.14% phosphorus and 33.7% potassium, compared to groundwater-irrigated treatments.

Keywords: Cauliflower, crop growth, drip irrigation, municipal wastewater, peri-urban area, yield.

WATER resources in many arid and semi-arid regions around the world are becoming scarce[1] and the water managers are forced to consider alternate sources for developmental activities[2–4]. At the same time, there is a need for increased food production for feeding the rapidly growing population[5]. It is estimated that 450 million tonnes (mt) of food grain will be required in 2050 to feed the growing population in India compared to the present scenario[6]. Thus, the requirement of water for irrigation purposes is likely to further exert pressure on freshwater resources of the country in the future[7]. Irrigation is an important requirement to raise both living standards of rural society and agricultural productivity[8]. Irrigation with wastewater is a good alternative for crop production in water-scarce situation[9–11]. Due to this, irrigation with wastewater has gained importance in recent years[1]. Wastewater use in agriculture protects the freshwater bodies and increases crop production by utilizing the available nutrients in it[6,12,13].

In India, the direct use of wastewater for irrigating crops is around 6 hectares per million litres per day, whereas indirect use is around 39 hectare per million litres per day[10,12]. In most of the peri-urban areas of the country, wastewater finds direct use in irrigating vegetable crops. Potentially irrigable land estimated for class-I cities and class-II towns is around 1.1 m ha[10,12,14]. Many more countries/cities worldwide are using wastewater either in treated or untreated form. In Mexico, about 260,000 ha is irrigated with untreated wastewater. In Ghana, wastewater is being utilized for irrigating 11,500 ha by conjunctively diluting wastewater with freshwater from rivers and streams[15]. About 80% of the total vegetable produced is irrigated by wastewater in Hanoi Vietnam[16]. The urban and peri-urban farmers mostly use wastewater in untreated or moderately treated form for irrigating their crops[17,18].

Given the importance of wastewater utilization in crop production, the present study aimed to evaluate the potential benefits of wastewater irrigation through water-saving irrigation techniques such as surface and subsurface drip irrigation. Cauliflower was chosen as an experimental crop in the study. This is an important vegetable crop widely grown in peri-urban areas with wastewater using inefficient surface irrigation methods. The annual production of cauliflower in India is 5.4 mt with a share of around 28.9% of the global production[12,18,19]. The objective of this study was to comparatively assess the effects of irrigation with primarily treated wastewater and groundwater through surface and subsurface bioline and inline drip laterals on crop growth parameters such as root length density (RLD), leaf area index (LAI) and yield of cauliflower. Bioline is a low-volume pressure-compensating inline drip system specifically designed for wastewater application with mechanisms to reduce clogging of drip emitters[20].

The experimental site is located at the Indian Agricultural Research Institute (IARI), Delhi (28°38′11″N lat. and 77°09′54″E long.). The climate of the experimental site is subtropical, semi-arid. The mean annual temperature is 24°C with the hottest temperature (45°C) in June and the coldest (7°C) in January. The mean annual rainfall is 790 mm. The water table in the farm area is about 5–7 m deep. Figure 1 shows the ombrothermic diagram indicating monthly variation in temperature and rainfall.

An experimental field plot of 53 m × 30 m dimensions was selected for conducting the field experiments. The

*For correspondence. (e-mail: dpk905@gmail.com)

experimental unit was divided into two plots of 25 × 30 m each, with a buffer strip of 1 m for separating them from each other. In this study, eight treatments were evaluated. Table 1 and Figure 2 give description of the treatments and the experimental set-up are shown respectively. Drip systems were separately installed for municipal wastewater and groundwater in the experimental field. Lateral lines were placed at 60 cm interval and the plant spacing was 40 cm. Bioline and inline laterals with drip emitter discharges of 2 l h^{-1} were used.

The Penman–Monteith equation was used to estimate crop water requirement. The necessary climatic data were obtained from the automatic weather station installed near the experimental field[21]. The growth stage of cauliflower crop was divided into four phases, viz. initial: 35 days, development stage: 30 days, mid-season stage: 40 days and late-season stage: 15 days. The crop coefficients of cauliflower for different phases were adopted as 0.7 for initial, 0.88 for development, 1.05 for mid-season and 0.95 for late season[12]. The irrigation water required for the cauliflower field throughout the crop period was 347 mm (ref. 12). Figure 3 shows the estimated crop water requirement during the crop growth period of cauliflower.

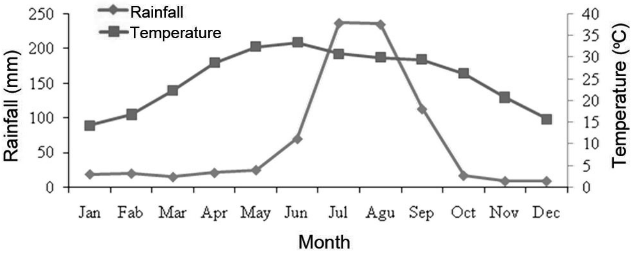

Figure 1. Ombrothermic diagram of the study area showing monthly variation in rainfall and temperature.

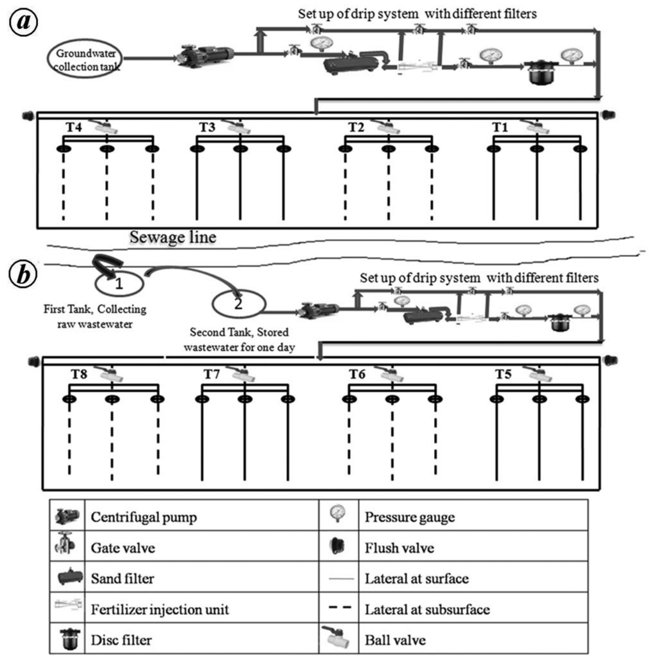

Figure 2. Layout of the experiment under different treatments. ***a***, Groundwater applied for treatments T1 to T4. ***b***, Wastewater applied for treatments T5–T8. Two separate set-ups of drip irrigation system were installed for groundwater and wastewater application.

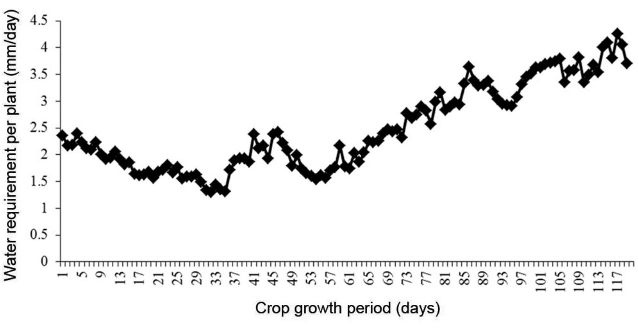

Figure 3. Water requirement (mm/day/plant) of cauliflower crop during 120 days of the growing period.

Seeds of cauliflower (variety: Indame 9803) were treated with Bavistin fungicide @ 2 g kg^{-1} of seed. The seeds were sown in the first week of October. Groundwater was applied by hand sprayer to germinating seedlings in the nursery. Twenty-five-day-old seedlings were transplanted at a row-to-row spacing of 60 cm and plant-to-plant spacing of 40 cm in the experimental field[22].

Wastewater samples were collected from the wastewater drainage channels passing through IARI (near the experimental plot). Groundwater samples were collected from a 40 m deep tube well. Various chemical and biological parameters of water samples such as pH, electrical conductivity (EC), total nitrogen (TN), phosphate (P), potassium (K), biological oxygen demand (BOD) and chemical oxygen demand (COD) were estimated following standard methods[23].

A standard recommended amount of nutrients (180 kg ha^{-1} N, 120 kg ha^{-1} P_2O_5 and 150 kg ha^{-1} K_2O) were applied in the groundwater-irrigated plots[18], whereas in wastewater irrigated plots only 133.38 kg ha^{-1} N, 98.70 kg ha^{-1} P_2O_5 and 96.56 kg ha^{-1} K_2O were applied

Table 1. Details of treatments (surface means: drip laterals placed on the soil surface; subsurface means: drip lateral placed 15 cm below the soil surface; inline: non-pressure compensating and bio-line: pressure compensating)

Treatment	Details
T1	Groundwater application using inline surface drip
T2	Groundwater application using inline subsurface drip
T3	Groundwater application using bioline surface drip
T4	Groundwater application using bioline subsurface drip
T5	Wastewater application using inline surface drip
T6	Wastewater application using inline subsurface drip
T7	Wastewater application using bioline surface drip
T8	Wastewater application using bioline subsurface drip

deducting the available nutrients in waste water (average N, P_2O_5 and K_2O contents in wastewater were found to be 30.1, 14.4 and 33.7 mg l^{-1} respectively)[12]. For the supply of NPK, a selective water-soluble fertilizer, including urea phosphate and muriate of potash was used[22]. Fertilizer application was initiated after two weeks of transplantation of crop and stopped two weeks before maturity of the crop.

The biometric observation of cauliflower crop was taken from centre rows of the treatments to avoid edge effects. The biometric properties such as LAI and RLD were observed for the entire crop duration starting from initial to maturity stage at an interval of 25 days. Hollow auger was used to collect root samples from a depth of 0–45 cm. Water with 0.25% of sodium hexametaphosphate was used to soak the root samples overnight. Root scanner was used to measure RLD, whereas LAI was measured by using canopy analyzer[24].

Analysis of the data was done by ANOVA using full factorial following procedures of SPSS (16) software[12,25]. A *P*-value less than the critical level indicated significant difference between the corresponding two groups and when significant, the means were compared by the Tukey test at $P = 0.05$.

Average values of the physico-chemical characteristics of irrigation water observed during the experimental period are presented in Table 2 along with the maximum allowable concentrations according to WHO standards[26,27].

EC and pH values of wastewater were less than that of the groundwater. EC values for groundwater ranged from 1.92 to 2.43 dS m^{-1} with a mean of 2.17 dS m^{-1}, whereas for wastewater it varied from 1.48 to 1.88 dS m^{-1} with an average of 1.70 dS m^{-1}. The pH values varied from 7.21 to 7.60 for groundwater with an average of 7.40 which was higher than that of wastewater (mean value 6.89). The turbidity of wastewater was higher than that of groundwater, with a mean value of 44 NTU. The concentrations of COD and BOD in wastewater were found much higher than those in the groundwater. Measurements were taken before the study to establish the initial conditions. Measurement of pH was important for this study since nutrients mobilization depends on it. Similarly, salt content in wastewater may lead to salinization and impact crop growth for which EC was also measured. It may be explained in light of the fact that BOD and COD values regulate the availability of oxygen for respiration of roots.

The system performance of drip irrigation was assessed by computing coefficient of variation (CV) of dripper discharge for all the eight treatments (Table 1). Figure 4 shows the mean values based on two years of pooled data. Similar CV values and trends were observed during both the years. Maximum value of CV, i.e. 11.57% was found in subsurface non-pressure-compensating (inline) drip lateral dispersing wastewater (T6) and minimum value of 4.52% in surface (bioline) drip lateral dispersing groundwater (T3). Subsurface placed laterals showed poor performance compared to surface placement (Figure 4). In most of the treatments the CV value was less than 10%, which is within the recommended limit (10.0%) by ASABE[28], except treatment T6 (11.57%). Results revealed that the bioline drip laterals performed better with a lower CV within the prescribed limit compared to inline drip laterals. This indicates that the performance of laterals may be rated as good.

Figure 5 shows the mean values of LAI based on two years of pooled data. Similar LAI values and trends were observed during both the years. During the initial and development stages, LAI for surface drip lateral was slightly higher than that of subsurface drip lateral. The highest values of LAI, i.e. 0.87 and 1.14 were observed in treatment T7, whereas treatment T2 was found to have the lowest LAI values, i.e. 0.64 and 0.99 at the initial and development stages respectively. However, no significant differences were observed among the treatments at $P < 0.05$ during both the stages (initial and development). At the middle crop stage, the rate of increase in LAI values under treatments T2, T4, T6, T8 (subsurface laterals) was higher in comparison to T1, T3, T5, T7 (surface laterals). At the same time, the rate of increase of LAI for the treatments with bioline drip laterals was higher in comparison to those with inline drip laterals.

Table 2. Physio-chemical and biological properties of water used for irrigation

Parameters	Wastewater (mean ± SD)	Groundwater (Mean ± SD)	Maximum allowable concentration*
pH	6.89 ± 0.16	7.4 ± 0.19	6.5–8.0
EC (dS m^{-1})	1.70 ± 0.18	2.17 ± 0.26	0.7–3.0
N (mg l^{-1})	30.1 ± 6.32	8.2 ± 0.57	5.0–30.0
P (mg l^{-1})	14.4 ± 2.44	0.35 ± 0.02	NA
K (mg l^{-1})	33.7 ± 4.04	10.3 ± 0.61	NA
Turbidity (NTU)	44.0 ± 10.12	1.50 ± 0.13	NA
COD (mg l^{-1})	163 ± 34.23	16.67 ± 1.50	NA
BOD5 (mg l^{-1})	126 ± 30.24	0.725 ± 0.10	NA

NA, Not available; *From: De Jusus *et al.*[26].

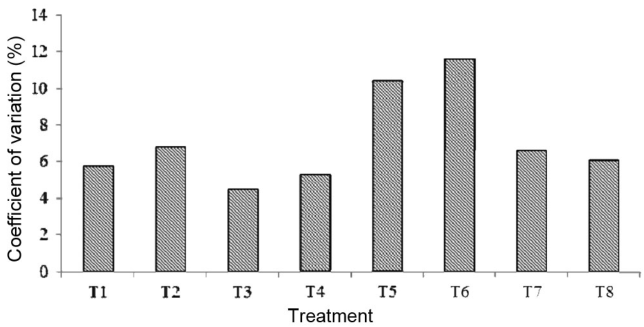

Figure 4. Coefficient of variation of dripper discharge under different treatments.

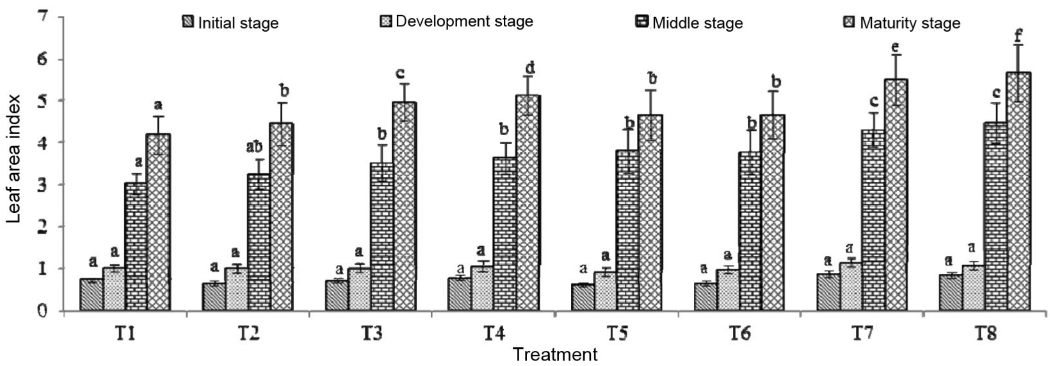

Figure 5. Temporal variation of leaf area index of cauliflower under different treatments. Different letters indicate statistical significance at $P < 0.05$ within a particular growth stage.

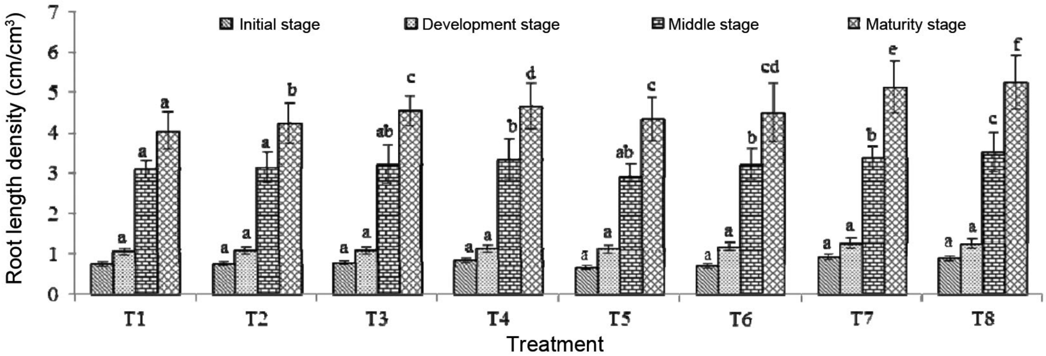

Figure 6. Temporal variation of root length density of cauliflower crop under different treatments. Different letters indicate statistical significance at $P < 0.05$ within a particular growth stage.

At the maturity stage, maximum values of LAI (5.64) were found in treatment T8 (subsurface bioline drip lateral dispersing wastewater), whereas minimum value (4.18) was observed for treatment T1 (surface inline drip lateral dispersing groundwater). A statistically significant ($P < 0.05$) difference in LAI was observed between subsurface and surface laterals placement both for bioline and inline laterals at the maturity stage of the crop. Higher LAI was observed under municipal wastewater in bioline drip lateral than groundwater. This may be attributed to the fact that the municipal wastewater containing essential major and micronutrients for plant growth is effectively delivered to the crop root zone by bioline lateral with greater efficiency and less clogging of the drip emitters. Subsurface placement of drip laterals reduces evaporation loss and leaching of nutrients, thereby increasing nutrient use efficiency of the crop and resulting in higher leaf area.

Figure 6 presents the mean values of RLD based on two years of pooled data. Results revealed that RLD increased successively until the maturity stage of the crop and similar trends were noted for both the years. During the initial and development stages, RLD for surface-placed drip lateral (treatments T1, T3, T4 and T7) was higher than the subsurface-placed lateral (treatments T2, T4, T6 and T8). The placement of drip laterals did not affect RLD significantly during the initial and crop development stages. Treatment T7 had the highest RLD values, i.e. 0.93 and 1.27 cm/cm^3; whereas treatment T2 had the lowest values of 0.73 and 1.04 cm/cm^3 at the initial and development stages respectively. This shows that the plants irrigated with wastewater have a higher root growth rate compared to those irrigated with groundwater. After the development stage, the growth rate of root length was found to be faster in the subsurface compared with surface-placed drip laterals. It was observed that there were no significant difference at $P < 0.05$ among the treatments at both stages. In the middle stage, the increment in RLD in subsurface-placed laterals was higher compared to the treatments of surface-placed laterals. A similar pattern was also observed at the maturity stage; the maximum value of RLD was found to be 5.25 cm/cm^3 for treatment T8 and the minimum value of 4.05 cm/cm^3 for treatment T1 (Figure 6).

The higher RLD value observed under subsurface laterals may be attributed to better soil water availability to the crop roots and more volume of soil being under wet condition compared to surface-placed drip laterals. This could help in the reduction of loss due to water evaporation and improved physiological growth of the crop. Subsurface drip laterals also permit better utilization of nutrients under frequent and controlled irrigation water. Rooijen *et al.*[9] found that the availability of soil moisture is one of the main constraints affecting the growth and development of biometric properties such as leaves and roots. Moreover, water stress is also responsible for physiological changes in plants and therefore in photochemical content[29,30].

Figure 7 presents the pooled mean value of curd yield (CY). The maximum average CY (79.67 tonne/ha) was found in T8, whereas the minimum average CY (59.01 tonne/ha) was observed in T1. Wastewater irrigation with bioline subsurface drip resulted in significantly ($P < 0.05$) higher CY than the inline surface drip with groundwater (Figure 7). Results revealed that there was 7.58% and 8.49% higher yield observed in surface and subsurface placement of bioline drip laterals respectively, using wastewater than groundwater. During the experimentation, CY among inline drip lateral treatments such as T2, T5 and T6 had no significant differences ($P > 0.05$), except T1. However, bioline drip lateral treatments such as T3, T4, T7 and T8 showed significant differences ($P < 0.05$) among themselves. Moreover, subsurface drip lateral placement treatments T2, T4, T6 and T8 were significantly higher ($P < 0.05$) than the surface drip lateral placement treatments (T1, T3, T5 and T7).

The reason for higher yield may be attributed to the fact that subsurface placement of drip laterals will directly apply water to the root zone at low flow rates and high frequency compared to surface-placed drip lateral. This could help in the reduction of loss due to water evaporation and improve the physiological growth of the crop with a more stable soil water and nutrient environment for optimal crop growth. Subsurface placement of drip laterals may also maintain the uniformity of soil moisture in the root zone, which could lead to better availability of nutrients and moisture at a lower and uniform rate[31]. Yao *et al.*[32] observed that the subsurface drip plays a vital role in maintaining constant soil moisture to the root zone, which helps improve the physiological growth of plants leading to higher production. Scarpare *et al.*[33] reported that subsurface drip has a better potential for water and nutrients utilization as well as yield intensification.

Figure 8 shows the pooled mean value of dry matter content in curd (DMCC). The average maximum DMCC (13.18%) was observed in T8 whereas minimum average DMCC (9.69%) was observed in T1 with groundwater. Wastewater irrigation with subsurface drip treatments (T6 and T8) resulted in significantly ($P < 0.05$) higher DMCC than the surface drip treatments (T5 and T7). Results revealed that the bioline drip laterals with surface and subsurface placement showed significantly higher DMCC at $P < 0.05$ using wastewater compared to groundwater. During the experimentation, DMCC among inline drip lateral treatments such as T1, T2, T5 and T6 had no significant difference. The bioline drip lateral treatments such as T3, T4, T7 and T8 showed significant differences ($P < 0.05$) among themselves. The subsurface drip lateral placement treatments T2, T4, T6 and T8 were significantly higher ($P < 0.05$) than the surface drip lateral placement treatments (T1, T3, T5 and T7). Wastewater-irrigated plots (T5, T6, T7 and T8) had significantly higher ($P < 0.05$) DMCC in all the treatments compared to groundwater-irrigated plots (T1, T2, T3 and T4; Figure 8).

Factorial randomized block design was applied to analyse the statistical effects on CY and DMCC (Table 3). For CY, the coefficient of determination (R^2) was found to be 0.85 and for DMCC, it was 0.84 ($P < 0.05$). The effects of water type on CY were significantly different ($P = 0.041$), whereas a similar trend was also observed for DMCC ($P = 0.046$). Placement of laterals played a significant ($P < 0.05$) role in CY and DMCC. Results showed that the effect of type of laterals was significant on CY at $P < 0.01$ and curd yield at $P < 0.05$.

The interaction effect of type of irrigation water (wastewater or groundwater) and placement of laterals (surface or subsurface) on CY was highly significantly

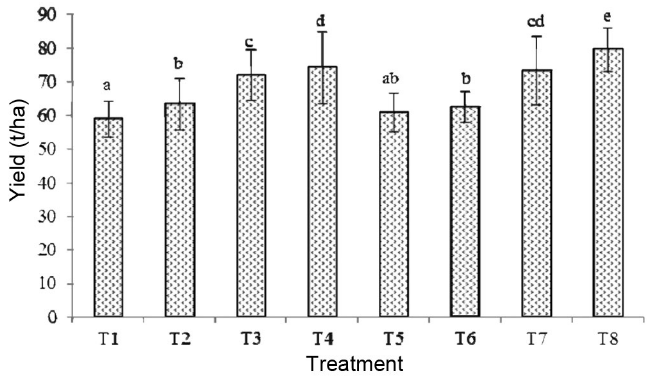

Figure 7. Impact of different treatments on cauliflower curd yield. Different letters indicate statistical significance at $P < 0.05$.

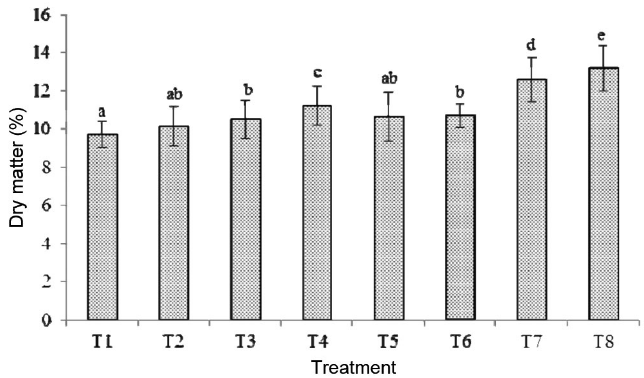

Figure 8. Impact of different treatments on dry matter content of cauliflower curd. Different letters indicate statistical significance at $P < 0.05$.

Table 3. Statistical analysis of dry matter content and yield of cauliflower using factorial randomized block design with three factors (water, placement of laterals and type of laterals) with two levels each (wastewater–groundwater, surface–subsurface and bioline–inline)

		Main and interaction effect						
Parameters	Model	W	Pol	Tol	W × Pol	W × Tol	Tol × Pol	W × Tol × Pol
Yield	$R^2 = 0.85$*	0.041*	0.025*	0.008**	0.011*	0.006**	0.020*	0.005**
Dry matter	$R^2 = 0.88$*	0.046*	0.034*	**0.180**	0.032*	0.025*	0.029*	0.009**

Bold figure, Not significant at $P > 0.05$; other figures, Significant at $P < 0.05$*, $P < 0.01$**. W, Water; Pol, Placement of drip laterals and Tol, Type of drip laterals.

different at $P < 0.01$ but for DMCC, it was only significantly different at $P < 0.05$. The effect of irrigation water and lateral types (inline or bioline) was significantly different at $P < 0.01$ and $P < 0.05$ for CY and DMCC. Results showed that the interaction effect of placement and type of laterals was significantly different at $P = 0.020$ and $P = 0.029$ for both CY and DMCC. However, the interaction effect of the type of irrigation water, type and placement of laterals was highly significant at $P < 0.01$ for both the parameters.

This study aimed to assess the impact of water quality, type, and depth of the laterals installed on growth and yield of cauliflower. Results showed that the growth parameters and yield of cauliflower crop were affected by water quality, type and depth of laterals. Higher RLD (5.25 cm/cm^3) and LAI (5.64) values were observed under subsurface pressure-compensating drip laterals. Maximum cauliflower CY was also found in the subsurface pressure-compensating drip laterals. The effect of irrigation water (groundwater or municipal wastewater) and placement of laterals (surface or subsurface) on growth and yield parameters of cauliflower was significantly different at $P < 0.05$, whereas the effect of type of drip laterals on CY and dry matter content was significantly different at $P < 0.01$. These parameters were significantly higher in wastewater-irrigated treatments compared to groundwater. In developing countries like India, the major problem with wastewater reuse in agriculture is the lack of technology and awareness. Thus, it is a challenge to find such a user-friendly technology which on the one hand maintains agricultural production with less input and on the other hand protects our valuable natural resources from degradation. The drip irrigation system is now being recognized as an efficient technology for the utilization of wastewater. Utilization of municipal wastewater with drip irrigation provides saving of inorganic fertilizers along with a reasonable increase in cauliflower yield and also averts weed germination. Therefore, the present study recommends the use of wastewater through subsurface placement with pressure-compensating drip laterals which increase plant growth, yield and quality of produce by less consumption of inorganic fertilizers and water. This system not only saves inorganic fertilizers and increases production, but also protects our valuable natural resources from degradation.

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Postmortem attentive behaviour in Indian Ocean humpback dolphins (*Sousa plumbea*)

Ketki Jog[1,*,#], Mihir Sule[1,2,#], Himanshu Damle[1,3], Isha Bopardikar[1,4] and Dipani Sutaria[1,5]

[1]The Konkan Cetacean Research Team, 9/A Balaji Apartments, D R Marg, Dadar, Mumbai 400 028, India
[2]Centre for Ecological Sciences, Indian Institute of Science, Bengaluru 560 012, India
[3]Department of Veterinary Surgery and Radiology, Dr G. C. Negi College of Veterinary and Animal Sciences, Palampur 176 062, India
[4]Indian Institute of Science Education and Research, Tirupati, Karakambadi Road, Tirupati 517 507, India
[5]College of Science and Engineering, James Cook University Townsville, 1 James Cook Drive, Queensland 4811, Australia

Postmortem attentive behaviour (PAB) has been recorded across several mammalian species. Here, we document two instances of PAB in the Indian Ocean humpback dolphin (*Sousa plumbea*) along the Sindhudurg coast in Maharashtra, India. We describe the subsequent behaviours displayed by the care-giving individuals and other group members. In both cases, an adult 'postmortem attender', was observed to support and erratically move around a dead calf. In the second case, the adult–calf pair was escorted by a second adult individual. An examination of the carcass in the first instance revealed blunt force trauma under the right flipper of the calf. These findings suggest that closely associated group members may be distressed by injury to or death of an offspring and stress the importance of long-term behavioural studies. We also discuss the evolutionary significance of PAB in the larger context of social behaviour across mammalian groups and the importance of cataloguing these incidents.

Keywords: Epimeletic care, mammalian species, postmortem attentive behaviour, social behaviour, *Sousa plumbea*.

SEVERAL species of animals, other than humans, exhibit complex, often ritualistic responses towards dead or dying conspecifics[1]. These responses range from aggression, sexual display and play (in pilot whales[2] and chimpanzees[3]), to curiosity and exploration (in chimpanzees[3]), removal of the carcasses (in rats[4]), group distress (in chimpanzees[5,6]), cannibalism (in orangutans[7]), and epimeletic care (in chimpanzees[3,6,8] and marmosets[9]). Epimeletic behaviour, is defined as the care or attention directed towards an enfeebled or a dead conspecific[10]. It has been recorded across a range of terrestrial and marine mammalian species, including non-human primates[6,11], giraffes[12], elephants[13], canids[14], otters[15], manatees[16] and

*For correspondence. (e-mail: ketki.jog@my.jcu.edu.au)
[#]Contributed equally.