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Research Article

Design and performance of subirrigation system in maize (*Zea mays*) in Kumulur farm, Trichy district, Tamil Nadu, India

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Abstract

Subirrigation system can furnish water to plants. The upward flux and the discharge rate must satisfy the plant's lifesaving irrigation needs during summer. The experiment was laid out in A-block of Eastern farm, Agricultural Engineering College and Research Institute, Kumulur, Trichy, Tamil Nadu. Subirrigation system spacing was arrived using Moody's equation calculated as 10 m. The experiment was laid out in spilt plot design with three replications. Four drain spacing levels (7.5, 10, 12.5 and 15 m) were the main plot treatments and two levels of depth and diameter of drain pipes (75 cm, 60 cm & 75 mm, 63 mm) were the sub plot treatments. The highest volumetric water content was recorded in 7.5 m spacing + 45 cm soil depth + lower reach ($S_1T_3T_1$). Capillary rise on water table management system under subirrigation mode was fixed as 33.5 cm and the average deep percolation loss was obtained in 0.3 cm/d at development stage of crop period. The highest maize yield (4.30 t/ha) was obtained in 7.5 m spacing + 60 cm drain depth + 75 mm diameter (S_1D_3). The highest water use efficiency of (0.86 kg/m^3) was recorded in 7.5 m spacing + 60 cm drain depth + 75 mm drain diameter (S_1D_3). This subirrigation system could furnish water to plants due to upward flux and the same system also functioned efficiently under drainage modes and removed the waterlogging during wet periods.

Keywords: Capillary rise, Deep percolation, Subirrigation, Volumetric water content, Water Use efficiency

INTRODUCTION

Subirrigation is not often used in arid or semi-arid irrigated areas where irrigation is often needed to germinate crops. It is typically used in conjunction with subsurface drainage or controlled drainage. The subsurface drainage lowers the water table and removes excess water through open ditches or perforated pipe. The water table depth can be controlled by installing a weir on the drainage system. This water table is lowered in wet periods so that the root zone remains unsaturated. The water is pumped into the drainage system to raise the water table and provide additional water for plant growth in dry periods. In some conditions, drained water is stored for use when irrigating (Bjorneberg, 2013).

Gautham *et al.* (2019) showed that water could be supplied to root zone at a rate more than sufficient to satisfy plant needs for 7.5 m and15 m drain spacing's. However their response was too low for the 30 m tile lines and he concluded that both subirrigation and drainage requirements could be satisfied with 15 m drain spacing.

Subirrigation system effectiveness depends on several soil physical characteristics such as hydraulic conductivity and moisture holding capacity. The method can be used on soils having relatively low water holding capacities and high intake rates. Subirrigation systems do work satisfactorily in some areas, and it is stated that this system of irrigation, if properly designed and operated, might be the best method available for many areas. Hence the objective of the study was to design and performance of subirrigation system in maize *(Zea mays)* from May 2016 to August 2016 at farm Kumulur, Trichy, Tamil Nadu.

MATERIALS AND METHODS

The subirrigation experiment was conducted during May 2016 in A-block of Eastern farm, Agricultural Engineering College and Research Institute, Kumulur, Trichy, Tamil Nadu. Maize COHM6 (*Z. mays*)) was used as a test crop. Sandy loam soil is the soil type of the experimental area. The soil is sodic in reaction with a pH of 9.1 and electrical conductivity of 0.14 dS m^{-1}. Maize COHM6 Hybrid medium duration variety of 118 days duration was used as a test variety for studying the subirrigation experiment. This system functions efficiently with both subirrigation and drainage modes and fulfilling both the needs. Subirrrigation system can furnish water to plants, the upward flux and the discharge rate must satisfy the plant's life, saving irrigation is needed during summer. The same system operates the traditional drainage system during wet periods. Inevitably, if the system is efficient in subirrigation mode, it will satisfy the needs of the drainage also since the spacing requirement is less for subirrigation mode.

Design consideration of subirrigation

The hydraulic conductivity appears to decrease and become stable at a particular depth, indicating the depth of the impervious layer about 3.5 to 4.0 m. The designing of the subirrigation system Moody (1966) equation was used.

Evapotranspiration rate (ER) recorded at Agricultural Engineering College and Research Institute, Kumulur, during summer, usually less than 5.0 mm/d as per weather records, was considered design value for 'e' in Moody's equation. The water table depth to be maintained at the above drain points depends on the root zone depth and crop tolerance for wet conditions. For using this equation, the water table should be maintained to the depth of 0.4 m by considering the expected average root zone depth of 0.25 m and the midpoint water table should be held to the depth, not greater than 0.5 m from the surface.

Generally, in the study location, a water table depth of 0.45 m was observed. Hence the effective root zone depth was assumed as 0.3 m for sandy loam soil. The same Moody equation was used for finding out the drain spacing in subirrigation system as follows.

$$L^2 = \frac{4K(h_0^2-h_1^2)}{e} \quad \text{...............(1)}$$

Where,

L = Spacing of drain (m)

e = Evapotranspiration rate, i.e. 5 mm/d

K = Hydraulic conductivity (m/d)

h_0 = Difference between depth to impervious layer to effective root zone of the crop (m)

h_1 = Difference between depth to impervious layer to height of water table above the water level in the drain (m)

$h_0 = 4.0 – 0.3$

$h_0 = 3.7$ m

$h_1 = 4.0 – 0.5$

$h_1 = 3.5$ m

Substitute the value in Eq. 1

$$L^2 = \frac{4x0.35(3.7^2 - 3.5^2)}{0.005}$$

L = 20.7 m

Equivalent depth under subirrigation mode

$$d_e = \frac{D}{1+\frac{D}{L}(\frac{8}{\pi}ln\frac{D}{r_e}-3.4)} \quad \text{............(2)}$$

Substituting this L value by considering effective radius of drains (r_e) as 0.036 m in Eq. 2

d_e = 0.39 m

$m = h_0-h_1$

m= 3.7 – 3.5

m = 0.2

By taking suitable corrections for convergence, the final equation for spacing reduces to

$$L^2 = \frac{4km(2h_0'-\frac{h_0'}{h_0}m)}{e} \quad \text{................(3)}$$

h_0' **=** d_e+h

= 0.39 +0.5

h_0' = 0.89 m

$$L^2 = \frac{4x0.35x0.2(2x0.89 - \frac{0.89}{3.7}x0.2)}{0.005}$$

Drain Spacing for subirrigation (L) = 10 m

Design diameter of drain pipes

Wessling's equation (1964) for uniform flow in smooth pipes and corrugated pipes derived from manning's equation was used to calculate the size of the lateral drain pipes. Size of the lateral pipe required to carry the design flow rate is given as

$Q = 89 (d_l)^{2.716} x(i)^{-0.572}$................(4)

Where

d_l = Diameter of lateral pipe (m)
i = Slope of lateral pipe fraction 0.3 per cent as 0.003

Q = L x W x I ………………(5)

Where
Q = Discharge (m^3/d)
L = Length of the field (m)
I = Initial drainage coefficient (m/d)

Substituting the drain spacing 7.5 m in Eq. 4.5

Q = 0.003x7.5x50

Q= 1.125 m^3/d

$$1.125 = 89(d_l)^{2.716} x(0.003)^{-0.572}$$

d_l = 58 mm

The commercial available pipe diameter of 63 mm and 75 mm was used for all the spacing.

The experiment was laid out in split plot design with three replications. For field practical sensitivity analysis 7.5, 10, 12.5 and 15 m spacing are main plot treatments and two levels of depth and diameter of drain pipes (75 cm, 60 cm &75 mm, 63 mm) are the sub plot treatments. Less water requirement crop (maize) was cultivated during summer as a test crop for finding out the suitability of subirrigation system.

Performance and evaluation of subirrigation system

The initial moisture at different depths in the near, middle and farther end midway between the laterals were observed. After the pumping operation, the soil moisture content depletion was recorded at a frequent interval of 24 hours for the period of 4 days from the date of irrigation at midway between the laterals at lower (T_1) middle (T_2) and farther ends (T_3) at three different depths of 15 cm (t_1), 30 cm (t_2) and 45 cm (t_3). Similarly, the subirrigation treatments during summer were taken for performance evaluation by reversibly pumping water in to the system.

Design considerations of capillary zone thickness

During subirrigation water is transmitted from the water table through the capillary zone to the plant's root system. Peck *et al.* (1974) proposed an empirical relationship to relate the height of capillary rise to an inverse function of the product of void ratio (e) and grain size distribution of soil particle as

H_c = C/(e x d) …………..(6)

where
H_c = Height of the capillary rise (mm)
d = Grain size distribution of soil particle (mm)
e = Void ratio
C = Constant depending varying between 10 to 50 mm^2 on surface impurities and grain shape

Deep percolation loss in subirrigation system

Deep percolation is estimated using the water balance equation (Upreti *et al.*2015). The water balance equation for the field can be expressed as

$\Delta S = P + I - ET - DP - HS - R$ …………(7)

Where
ΔS = Change is storage in the root zone
P = Precipitation (mm)
I = Irrigation water (mm)
ET = Actual Evapotranspiration (mm)
DP = Deep percolation (mm)
R = Surface Runoff (mm)

As the experiment in the study area, the horizontal seepage is zero and surface runoff is negligible. So that water balance equation becomes,

$\Delta S = P + I - ET - DP$ ……………..(8)

Rearranging equation (7) and knowing all the variable, deep percolation is estimated using,

$DP = P + I - ET - \Delta S$ ……………(9)

Change in storage (ΔS) using the initial and final moisture content reading over required time duration.

Determination of water use efficiency

Water Use Efficiency (WUE) was calculated for each treatment, which is the ratio of yield of the crop in kg/ha and total water applied in mm.

$$WUE = \frac{Y}{W} \quad …………….(10)$$

Where,
WUE - Water Use Efficiency, (kg/m^3)
Y - Yield of the crops, (kg/ha)
W - Total water applied, (mm)

RESULTS AND DISCUSSION

Soil moisture distribution pattern under subirrigation system:

Horizontal direction of soil moisture distribution at 60 cm depth

The highest volumetric water content (32 per cent) was recorded in 7.5 m spacing + 45 cm soil depth + lower reach ($S_1t_3T_1$), whereas the lowest value (14.2 per cent) in 15 m spacing + 15 cm soil depth + farther reach ($S_4t_1T_3$) on 1st day of observation in horizontal direction of drain pipes at 60 cm drain depth. Similar trend was obtained in all other days of observation viz., one day after irrigation, two day after irrigation and third day after irrigation.

Horizontal direction of soil moisture distribution at 75 cm depth

The highest volumetric water content (29.9 per cent) was recorded in 7.5 m spacing + 45 cm soil depth + lower reach ($S_1t_3T_1$). In contrast, the lowest value (11.9 per cent) in 15 m spacing + 15 cm soil depth + farther reach ($S_4t_1T_3$) on 1st day of observation in horizontal direction of drain pipes at 75 cm drain depth.

Similar trend was obtained in all three days of observation *viz.,* one day after irrigation, two days after irrigation and third day after irrigation.

There was a gradual decline in the volumetric water content toward farther ends within the effective area midway between drains. Increase in volumetric water content at both horizontal and vertical direction of drain spacing within the profile. i.e. through 15, 30, and 45 cm soil depth. More volumetric water content reading was noticed in 60 cm drain depth than 75 cm drain depth. This might be due to the less opportunity time and limited capillary rise for the water to rise from drain level. It was observed that near the collector, i.e. lower reaches, higher soil volumetric water content was found because the pressure build up near the valves made the water rise up and oozing to the surface, causing surface inundation. The variation of average soil moisture distribution at different spacing and depth is presented in Fig.1 to 2. Similar results found by Prabhakar *et al.* (1991) reported that the moisture content gradually decreased while the increased distance from the emitter. Skaggs *et al.* (1972) showed that 7.5 m and 15 m spacing were adequate to fulfill the crop water use, while the 30 m spacing was inadequate to maintain the targeted water table level. Chakraborty *et al.* (2008) also reported that the soil water content was relatively higher by volume near the emitter and it was decreasing as the distance from the emitting point increased. Gowtham *et al.* (2019) concluded that 80 cm drain depth had lower gravimetric moisture content than the drain depth of 60 cm and reported that the soil water content was relatively higher by volume near the emitter and it was decreasing as the distance from the emitting point increased.

Capillary rise and deep percolation losses on subirrigation system

The capillary rise was calculated by using the formula (H_c = C / e x d), considering the average size of the sandy loam soil particles (d) is 0.50 mm, considering the same value for surface impurities and grain shape (C) and void ratio (e) (0.48). Hence the capillary rise on water table management system under subirrigation mode is fixed as 33.5 cm. similar result found by Liu *et al.* (2014) concluded that natural sand actually gave a capillary rise of 62.5 cm. The average deep percolation losses were obtained at development stage, mid stage and maturity stage are 0.3, 0.2 & 0.15 cm d^{-1}. Similar results found by Upreti*et al.* (2015) reported that deep percolation was calculated using the water balance approach and also concluded that at initial stage, development stage, mid stage and late stage of deep percolation, losses were observed in 10, 22, 18 and 12 mm/d.

Maize yield under subirrigation system

The maize was raised in 75 cm and 60 cm drain depth for all the spacing to test the water table management system's performance under subirrigation mode. The

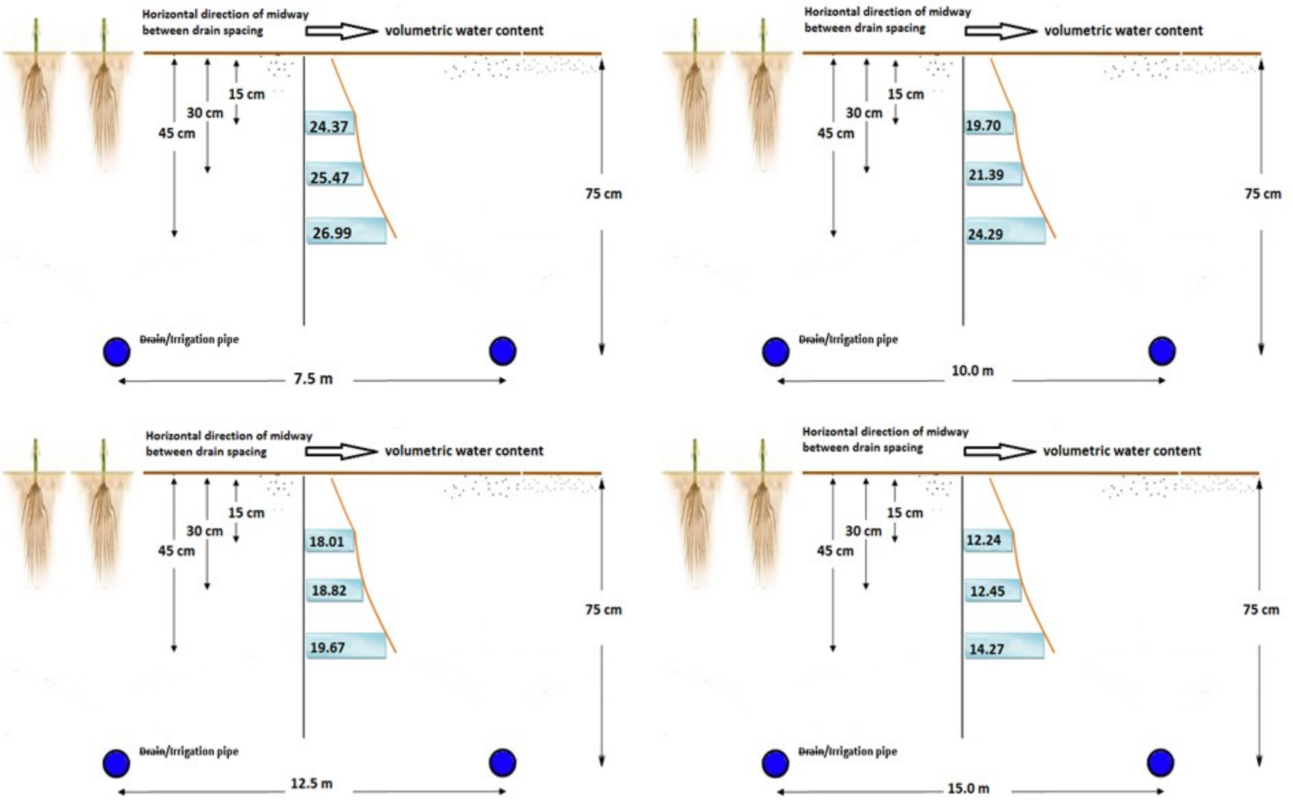

Fig. 1. *Horizontal direction of soil moisture distribution pattern at 75 cm depth under different spacing.*

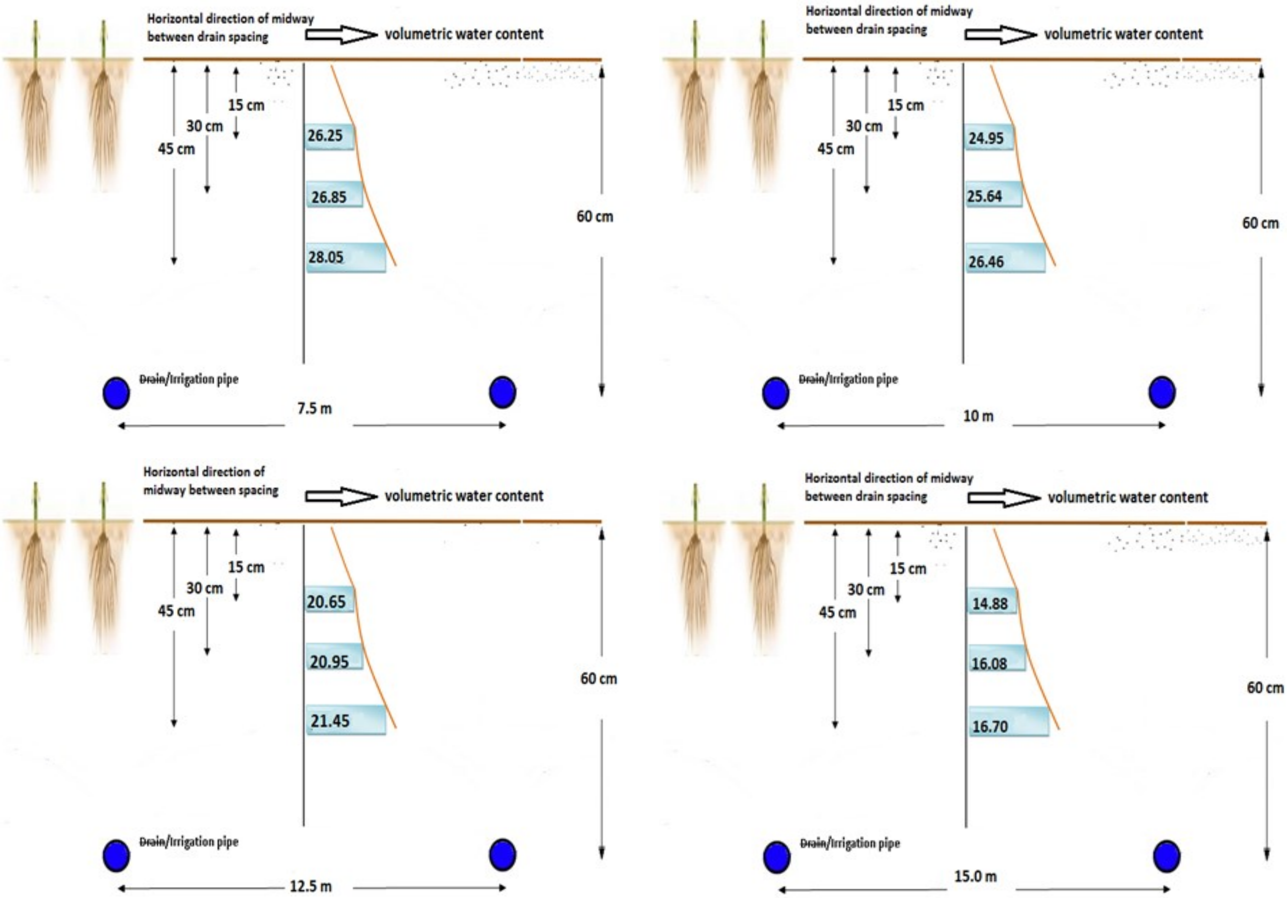

Fig. 2. *Horizontal direction of soil moisture distribution pattern at 60 cm depth under different spacing.*

highest maize yield (4.30 t/ha) was obtained in 7.5 m spacing + 60 cm drain depth + 75 mm diameter (S_1D_3) whereas the lowest value (3.40 t/ha) in 15 m drain spacing + 75 cm drain depth + 75 mm drain diameter (S_4D_1). The yield data of maize recorded at 60cm and 75cm drain depth is presented in Fig. 3. Fisher *et al.* (1999) reported that Maize crop had higher yield with subirrigation with more effectiveness in subirrigation . Ghaffer and Wahba (2006) revealed that wheat crop yield was higher by 15 per cent with subirrigation treatment compared to surface irrigation treatment. Gubir Singh *et al.* (2021) reported that grain yield variability generally decreased from a dry to a normal year. Long-term yield data indicated that narrower drain tile spacings with subirrigation reduce grain yield variability in dry and wet environments; however, the cost-effectiveness of these systems needs to be determined.

Water Use efficiency under subirrigation system

The highest water use efficiency of (0.86 kg/m^3) was recorded in 7.5 m spacing + 60 cm drain depth + 75

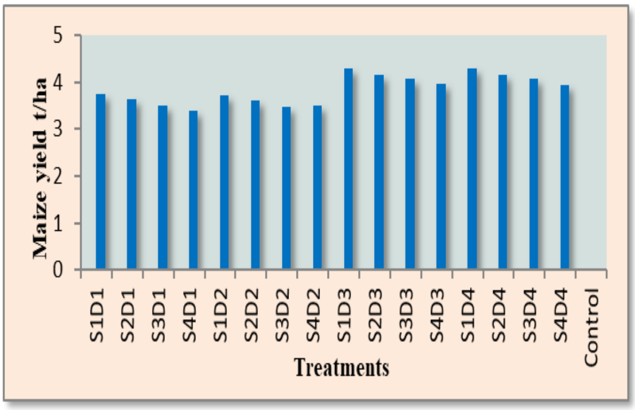

Fig. 3. *Maize yield after various treatments.*

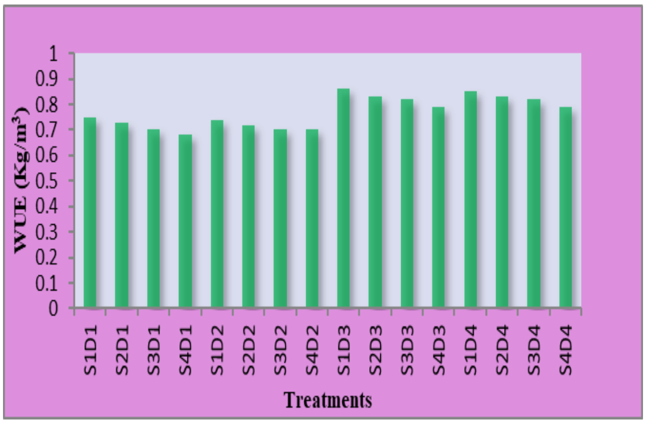

Fig. 4. *Water-use efficiency in various treatments.*

mm drain diameter (S_1D_3) whereas the lowest value (0.68 kg/m^3) in 15 m spacing + 75 cm drain depth + 63 mm drain diameter. (S_4D_1). The water use efficiency for all the treatments are presented in Fig. 4. Similarly, Martinez (2014) has reported that the subirrigation method seemed to perform better than the conventional irrigation system because the yield and the irrigation water use efficiency were higher.

Conclusion

The present study concluded that Subirrrigation system operated the traditional drainage system during wet periods. Subirrigation system spacing was arrived using Moody's equation calculated as 10 m. The highest volumetric water content was recorded in 7.5 m spacing + 45 cm soil depth + lower reach ($S_1t_3T_1$). Capillary rise on water table management system under subirrigation mode was fixed as 33.5 cm and the average deep percolation loss was obtained in 0.3 cm/d at the development stage of crop period. The highest maize yield (4.30 t/ha) was obtained in 7.5 m spacing + 60 cm drain depth + 75 mm diameter (S_1D_3). The highest water use efficiency of (0.86 kg/m^3) was recorded in 7.5 m spacing + 60 cm drain depth + 75 mm drain diameter (S_1D_3). The present subirrigation system could furnish water to plants due to upward flux, and the same system also functioned efficiently under drainage modes to remove the waterlogging during wet periods and hence will benefit the farmers.

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Conflict of interest

The authors declare that they have no conflict of interest.

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