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Geometrical model for determining soil water content under sprinkler and raingun irrigation system

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■ **ABSTRACT :** In India, conventional surface irrigation methods to pressurized irrigation systems are in use. Pressurized irrigation including micro irrigation, sprinkler irrigation system as well as raingun are among the efficient irrigation techniques which may achieve field level application efficiency in the range of 60-95 per cent. These have vast potential and suitable for almost all field crops like wheat, gram, pulses, vegetables, cotton, soya bean, tea, coffee, and other fodder crops. The information on soil water content and wetted depth of wetted zone as well as duration of water application has importance towards uniformity and performance of irrigation system. The water content in geometry of soil wetted zone has importance in irrigation management to deliver required amount of water and nutrients to the plants to realize enhanced crop yield. Estimation of water content of wetted zone soil based on simplified geometry will serve purpose for most of field conditions and also reduces complexities encountered in numerical and analytical methods. A model based on simplified geometry and water volume balance was developed to simulate soil water content, wetting depths and duration of water application through sprinkler and raingun irrigation system. The geometry of wetted soil depth resulting from uniform and non-uniform water application through sprinkler and raingun was considered. With uniform water application the soil wetted zone could take shape of cylinder. However, with non-uniform water application, depth of wetted soil volume reduces towards the periphery of the wetted soil, that may be assumed as curved shape of ellipsoid or parabolic shape. Water volume balance method was considered in wetted geometry to develop model to estimate change in soil water content.

■ **KEY WORDS :** Sprinkler, Raingun irrigation, Geometry of wetted zone soil, Model, Soil water content

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Irrigation has played an important role in process of development of Indian agricultural, which in future has to produce ever-increasing quantities of food with decreasing quantities of water available for irrigation, because of competing demand of water in other non agriculture sectors. Therefore, optimum and efficient utilization of water in agriculture for irrigation assumes great significance. In India, conventional surface irrigation methods to pressurized irrigation systems are in use. Conventional surface irrigation methods are utilized in about 90 per cent irrigated area in India. These have low field level application efficiency upto 40 per cent because of huge conveyance and distribution losses (INCID, 1994 and Rosegrant, 1997). The conventional irrigation poses numerous problems such as; soil salinity; seepage, conveyance and evaporative losses; higher energy cost; faster soil erosion; more wastage of fertilizer and other nutrients. It also results in higher weed population; increased operational difficulties and cost; uncontrolled, unmeasured and uneven water supply.

Pressurized irrigation includes micro irrigation as well as sprinkler irrigation system including raingun. Pressurized irrigation systems are among the efficient irrigation techniques which may achieve field level application efficiency in the range of 60-95 per cent, as surface runoff and deep percolation losses are minimized (Heermann *et al*., 1990 and Postel, 2000). Thus pressurized irrigation may allow more crop per unit water, and allow crop cultivation in an area where available water is insufficient to irrigate through surface irrigation methods. The coverage area under theses methods is growing fast in the country with a potential area of 27 million-hectare land in India (Narayanamoorthy, 2004 and RTFM, 2004).

Sprinkler irrigation is suited for most row, field and tree. These are suitable for almost all field crops like wheat, gram, pulses, vegetables, cotton, soya bean, tea, coffee, and other fodder crops. Rainguns are similar to impact sprinkler, except that they generally operate at very high pressures. Conventional sprinklers need 2.5 to3.5 kg/cm^2 operating pressure which discharge 1500-3000 Lph with wetted diameter of 24-35 m. However, Gun sprinkler or raingu require 4.0-6.0 kg/cm^2 and discharge 5000-45000 Lph with wetted diameter of 60-80 m (Phocides, 2001).

Rain guns are most suitable for a variety of climates like tropical, temperate and humid climates as in India. These have long wear life and low maintenance. They provide uniform distribution profile with adjustable jet breaker arrangement. Rain guns have reduced risk of structural damage of soil and delicate plants due to evenness and lightness of watering. These are available in full circle and part circle models. These can be recommended for field crops like sugarcane, pulses, oil seeds, cereals, tea, coffee, and vegetables. They can be easily used with portable irrigation system. It is useful for large turfs, lawns and playground.

The uniformity of sprinkler irrigation is a central design goal (Keller and Bliesner, 2000). Uniformity of water application is sought to minimize variability of crop yield, or plant quality. The catch can test is a commonly used measurement tool to assess the uniformity of sprinkler systems. Standards have been developed for center pivot and linear move irrigation machines (ASAE, 2001).

The performance of irrigation systems may be described by uniformity and irrigation system application efficiency (Haman *et al.*, 2003). For high value crop and any system where chemicals are applied with irrigation water, the uniformities should be high (Distribution uniformity (IA, 2005) greater than 80%, or Uniformity co-efficient greater than 87%). When coefficients fall below the acceptable values for a given system the repairs and adjustments should be performed. Even wheat crop canopy can redistribute water to achieve improved uniformity before redistribution within the root zone is considered (Li and Rao, 2000). The information on soil water content and wetted depth of wetted zone as well as duration of water application has importance towards uniformity and performance of irrigation system.

The water content in geometry of soil wetted zone has importance in irrigation management to deliver required amount of water and nutrients to the plants to realize enhanced crop yield (Singh *et al.*, 2006 (a); Singh and Rajput, 2007 and Singh *et al.*, 2010). The water content in wetted zone soil can be determined by either direct measurement in field, which is site–specific, or by using some mathematical tools *i.e.* models. The mathematical models based on Richards's equation for water flow under unsaturated conditions display high spatial variability of soil water matric potential, and so soil water content because of highly non-linearity of hydraulic conductivity (Warrick and Nielson, 1980). Detailed information on properties of soil are required for this models, which are lacking and make it complicated to define it for many field soils as well as expensive and time consuming. At the same time, these solutions require many simplifying assumptions that limit their applicability in practical field conditions, and also large differences were observed between simulated and observed values of soil water contents (Lafolie *et al.*, 1997).

However, on the other hand the information on water content of the wetted zone of soil based on simplified geometry will serve purpose for most of field conditions and also reduces complexities encountered in numerical and analytical methods (Dasberg and Or, 1999; Singh 2004; Singh *et al.*, 2006 and Singh *et al.*, 2013). Therefore, strong need is felt to develop a model based on simplified geometry and volume balance to simulate soil water content, wetting depths and duration of water application through sprinkler and raingun irrigation system.

■ METHODOLOGY

Sprinklers and raingun wetting soil surface in circular fashion when operated are common in use. The wetted soil surface has been considered as circular under ideal condition. However, the depth of wetted soil due to water applied may be variable and change from centre to the periphery of wetted soil zone. Therefore, both uniform and non-uniform application of water depth along the soil wetted radius of sprinkler and raingun was considered for model development. The study was carried out at ICAR-Central Institute of Agricultural Engineering, Bhopal, MP during 2009-2010.

Geometry of wetted soil:

The uniform water application from centre to periphery along wetted soil radius consequently, result in uniform water depth in wetted soil as depicted in Fig. A. soil wetted zone could take shape of cylinder with uniform water application. However, with non-uniform water application, the depth of wetted soil volume reduces towards the periphery of the wetted soil which may be assumed as curved shape either of ellipsoid or parabolic shape (Fig. B).

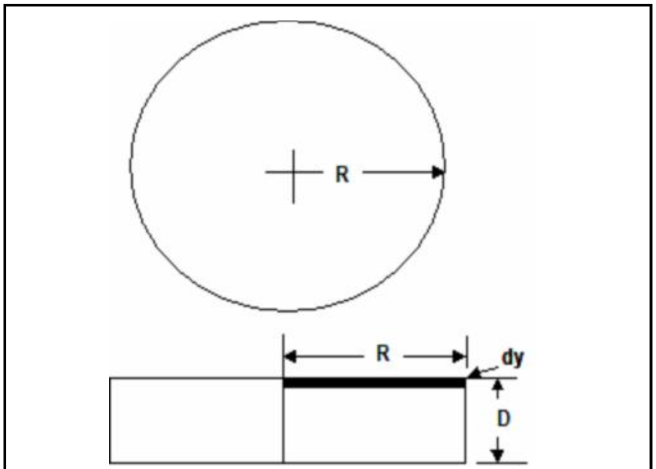

Fig. A : Uniform water application through raingun

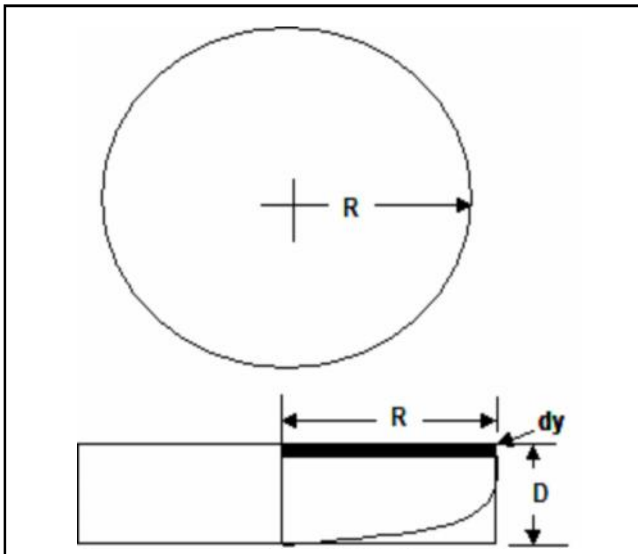

Fig. B : Non-uniform water application through raingun

Development of model:

Water volume balance approach in soil wetted zone under considered geometry was used to develop model to estimate changes in soil water content, duration of water application, wetted depth with water applied at given discharge rate and duration (Singh and Rajput, 2020). Irrigation water applied for a given duration increases the soil water content and depth of wetted zone after contributing losses towards evaporation from the surface of wetted zone of soil without water extraction. Information about Initial soil water content before and after 24 hours of irrigation event is required to calculate change in soil water content.

Assumptions:

It was assumed that water applied in soil through raingun was uniformly distributed in wetted soil volume, and moisture content of surrounding soil was uniform; and also wetted depth is advancing downward with duration.

■ RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Model for soil moisture regime with uniform water application:

The wetted volume, V (L^3) due to raingun irrigation at discharge rate, q (L^3T^{-1}) with evaporation rate, E (LT^{-1}) and without water extraction from soil surface at any time, t (T) for an elemental unit of soil in radius of cross section, R (L) of wetted soil width, *dy* (L) can be given in terms of change in soil water content of wetted profile (Fig. A).

$$V = \pi \int_{-D}^{0} R^2 . dy \qquad (1)$$

$$V = \pi R^2 . D \qquad (2)$$

Volume of water (V_w) stored in above soil volume

$$V_w = V . \Delta\theta \qquad (3)$$

where

$\Delta\theta$ = Change in soil water content (L^3/L^3) and

$$\Delta\theta = \theta_{av} - \theta_i \qquad (4)$$

θ_{av} = Average water content in wetted soil volume (L^3/L^3)

θ_i = Initial water content of the profile (L^3/L^3)

Combination of Eq. (2) and (3) yielded following relation:

$$V_w = (\pi R^2 . D . \Delta\theta) = (q - \pi R^2 . E) t \qquad (5)$$

The duration of water application for given soil water content can be given as

$$t = \frac{D . \Delta\theta}{\{(q/\pi R^2) - E\}} \qquad (6)$$

The above equation can be used to simulate wetted depth, D

$$D = \frac{t\left\{\frac{q}{\pi R^2} - E\right\}}{\Delta\theta} \qquad (7)$$

The change in soil water content in wetted soil profile can be given as

$$\Delta\theta = \frac{t\left\{\frac{q}{\pi R^2} - E\right\}}{D} \qquad (8)$$

Model for soil moisture regime with non-uniform water application:

The depth of wetted soil volume reduces towards the periphery of the wetted soil. It may be assumed as curved shape of ellipsoid or parabolic shape (Fig. B).

Ellipsoid Shape:

Considering the shape of wetted volume as half ellipsoid with equal two semi- principal axes with radii a and b, along the X and Y- axes and c is the radius along the Z-axis. In this case a=b >c it is disk shaped spheroid. The volume of wetted soil as half ellipsoid is given as below:

$$V = 2\pi R^2 . D/3 \qquad (9)$$

Volume of water (V_w) stored in above soil volume

$$V_w = V . \Delta\theta \qquad (10)$$

where

$\Delta\theta$ = Change in soil water content (L^3/L^3) and

$$\Delta\theta = \theta_{av} - \theta_i \qquad (11)$$

θ_{av} = Average water content in wetted soil volume (L^3/L^3)

θ_i = Initial water content of the profile (L^3/L^3)

Combination of Eq. (9) and (10) yielded following relation:

$$V_w = \{2\pi R^2 . D/3) \Delta\theta\} = (q - \pi R^2 . E) t \qquad (12)$$

The duration of water application for given soil water content can be given as

$$t = \frac{2 D . \Delta\theta}{3 . \{(q/\pi R^2) - E\}} \qquad (13)$$

The above equation can be used to simulate wetted depth, D

$$D = \frac{3 . t\left\{\frac{q}{\pi R^2} - E\right\}}{2 . \Delta\theta} \qquad (14)$$

The change in soil water content in wetted soil profile can be given as

$$\Delta\theta = \frac{3 . t\left\{\frac{q}{\pi R^2} - E\right\}}{2 . D} \qquad (15)$$

Parabolic shape:

Considering the shape of wetted soil volume as paraboloid with height D and radius R. Therefore, the volume of wetted soil as paraboloid

$$V = \pi R^2 . D/2 \qquad (16)$$

Volume of water (V_w) stored in above soil volume

$$V_w = V . \Delta\theta \qquad (17)$$

where

$\Delta\theta$ = Change in soil water content (L^3/L^3) and

$$\Delta\theta = \theta_{av} - \theta_i \qquad (18)$$

θ_{av} = Average water content in wetted soil volume (L^3/L^3)

θ_i = Initial water content of the profile (L^3/L^3)

Combination of Eq. (16) and (17) yielded following relation:

$$V_w = \{(\pi R^2.D/2)\ \Delta\theta\} = (q - \pi R^2.E)t \qquad (19)$$

The duration of water application for given soil water content can be given as

$$t = \frac{D.\Delta\theta}{2.\{(q/\pi R^2) - E\}} \qquad (20)$$

The above equation can be used to simulate wetted depth, D

$$D = \frac{2.t\left[\frac{q}{\pi R^2} - E\right]}{\Delta\theta} \qquad (21)$$

The change in soil water content in wetted soil profile can be given as

$$\Delta\theta = \frac{2.t\left[\frac{q}{\pi R^2} - E\right]}{D} \qquad (22)$$

Validation:

The soil moisture regime can be assessed using eq. (8) with uniform application of water. Eq. (15) and (22) could be used soil moisture regime under non uniform application of water through raingun. These could be validated with field data for wider applicability. The efficiency of models could also be estimated statistically using following relations. Developed model could be tested for its performance by comparing observed and modeled values of soil water content under given wetted geometry and t- test to ensure model validity under field conditions (Singh, 2004). Statistical parameters like mean error (ME), root mean square error (RMSE) and model efficiency (EF) as given below could be used for evaluation of performance of developed model (Willmott, 1982)

$$ME = \frac{1}{N}\sum_{i=1}^{N}\left(C_{si} - C_{oi}\right) \qquad (23)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=2}^{N}\left(C_{si} - C_{oi}\right)^2\right]^{1/2} \qquad (24)$$

$$EF = 1 - \frac{\sum_{i=1}^{N}\left(C_{si} - C_{oi}\right)^2}{\sum_{i=1}^{N}\left(C_{oi} - C_{o}\right)^2} \qquad (25)$$

where

N = total number of data

C_{si} = simulated data (L)

C_{oi} = observed data (L)

C_o = mean of observed data (L)

The performance of model could be considered better for smaller RMSE value; lower absolute value of ME; and greater value of EF (Willmott, 1982 and Jacovides and Kontoyiannis, 1995).

Conclusion:

The soil water content under irrigation play important role for achieving irrigation uniformity and resulting crop yields. The soil moisture could be assessed using models developed based on geometry of wetted soil depth considering uniform and non-uniform water application and water volume balance in wetted geometry. With uniform water application the soil wetted zone could take shape of cylinder. However, with non-uniform water application, depth of wetted soil volume reduces towards the periphery of the wetted soil that may be assumed as curved shape of ellipsoid or parabolic shape. The developed mode could be validated and performance could be estimated using field observations.

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